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GIS resources as a tool for monitoring and managing river basin conditions

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SUMMARY

Traditional methods of collecting and processing statistical environmental information require significant time expenditures. This is usually due to the dispersion of available environmental data across various subjects of the state monitoring system and the lack of a unified database of reliable environmental data. Solving this problem for small and medium river basins is further complicated by the fact that the majority of representative information is not digitized. In the context of digitalizing approaches to accumulating and processing large data sets, the potential of using remote sensing and electronic GIS mapping tools opens new prospects for conducting scientific research. This includes monitoring the state of hydrological ecosystems, conducting retrospective analyses, modeling, and predicting variable changes. The research objective is to analyze the potential capabilities of GIS maps for assessing changes in the ecological state of river basins in Southern Ukraine. Additionally, it examines the relevance of this approach compared to traditional research methods and the reliability of open-access GIS resources as an alternative means of monitoring dynamic changes within river basins.

Keywords: GIS technologies, environmental monitoring, RIVER BASIN, ecological state of the hydroecosystem

Introduction

Managing the state of a river basin is impossible without sufficient information about the processes occurring within it. This data is provided by monitoring, which is one of the most critical components of the state's ecological and socio-economic security system, environmental condition accounting, and natural resource potential control. Depending on the defined goals and tasks, state water monitoring includes three types of procedures: diagnostic, operational, and research monitoring, which are carried out on a basin principle. The state water monitoring program is implemented for surface water bodies to: identify the causes of deviation from ecological goals; determine the scale and consequences of accidental water pollution; establish the reasons for the risk of failing to achieve ecological goals identified during diagnostic monitoring before the commencement of operational monitoring.

Theory

The object of the research is a typical river basin of Southern Ukraine (the Molochna River), which has its own specificity due to natural and climatic factors. In the pre-war period, we thoroughly analyzed various aspects of the ecological state formation of the Molochna River basin and the factors that caused hydromorphological changes. The factors of ecological destruction of this hydroecosystem include: the imbalance of the landscape structure (88.1% of arable land; 4.05% forest-covered areas, a general indicator for the Zaporizhzhia region); the predominance of irrational approaches to nature management; excessive levels of anthropogenic load, among others.

From the first days of the full-scale invasion of the Russian Federation, the territory of the river basin was occupied, making it impossible to conduct field observations and obtain any data to determine changes in ecological parameters within the basin. In wartime conditions, ecosystems suffer destructive impacts caused by the uncontrolled activities of the invaders, such as: destruction of large areas of tree plantations for the construction of fortifications; conducting military exercises involving the detonation of ammunition within the aquatic complexes of the Molochna Estuary, which is included in the Ramsar List and the Emerald Network; changes in the microclimate of the area due to the depletion of the Pryazovskyi Main Canal and the destruction of the irrigation farming system; blocking the channels of small and medium rivers, among other impacts.

Examples

An important element in determining changes in ecological parameters is the analysis of the hydrological and hydrochemical regimes of the river. Information on the average water discharge of the Molochna River is available only for two hydrological posts: 0.95 m³/s (Tokmak, observation period 1950-1980) and 1.77 m³/s (Tirpynia, 1957-1980) (Azov River Basin Management Plan (2025-2030), 2023), with the last year of observations being 1980. The scientific project "Land & Water," developed and presented in 2023 by scientists from the Ukrainian Hydrometeorological Institute (UkrHMI) of the State Emergency Service of Ukraine and the National Academy of Sciences of Ukraine, in collaboration with IBM Research and Texas Agrilife Research, allows ecologists and researchers to instantly obtain a dataset of hydrological and climatic parameters (water runoff, water balance, discharge, air temperature, precipitation, snow cover, evapotranspiration, soil water) for 1980-2020 (Figure 1).

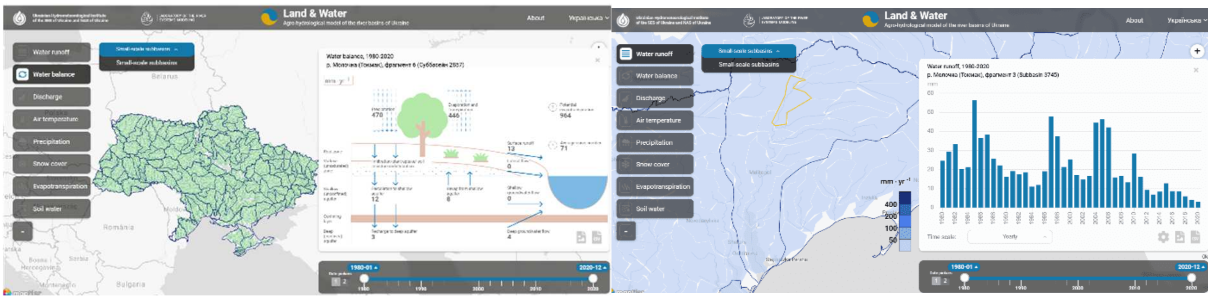

Figure 1*. Interface of the Agro-Hydrological Model for River Basins in Ukraine "Land & Water"*

The agro-hydrological model SWAT, configured to reproduce the hydrological processes of river basins in Ukraine, provides comprehensive geospatial information. This information enables the assessment of the impact of land cover, soils, and fertilizers on water parameters (land cover, soils, slopes, crops, and the amount of applied fertilizers) (Osypov et al., 2023). In the future, the developers plan to integrate the Ukrainian agro-hydrological model "Land & Water" with weather forecasts from IBM's The Weather Company and IBM Cloud resources to create an online drought forecasting platform.

To reflect the dynamics of changes in the hydrochemical regime at the end of 2017, the State Water Resources Agency of Ukraine launched a GIS map "Monitoring and Environmental Assessment of Water Resources of Ukraine". This interactive system provides information on the results of hydrochemical analysis at designated water quality monitoring points, allowing for retrospective analysis in tabular and graphical forms for a selected period. For the majority of river basins in Ukraine, data sets over a multi-year observation period are available, but for the Molochna River basin, unfortunately, they are not. Hydrochemical studies for this river basin began in 2021, and an appropriate data array was created; however, it has not been reflected in the corresponding electronic GIS map.

The use of GIS technologies in research is a modern method of environmental risk assessment, which we have already applied in our practice (Skyba et al., 2021). While the above-mentioned GIS tools enable retrospective analysis and a quick and detailed assessment of the dynamics of certain changes within a hydrological basin, the interactive development by the World Resources Institute (WRI), using the Aqueduct 4.0 geospatial data base on the ArcGIS platform, allows for the interpretation of a complex array of hydrological data into intuitively understandable indicators of water-related risks (Figure 2).

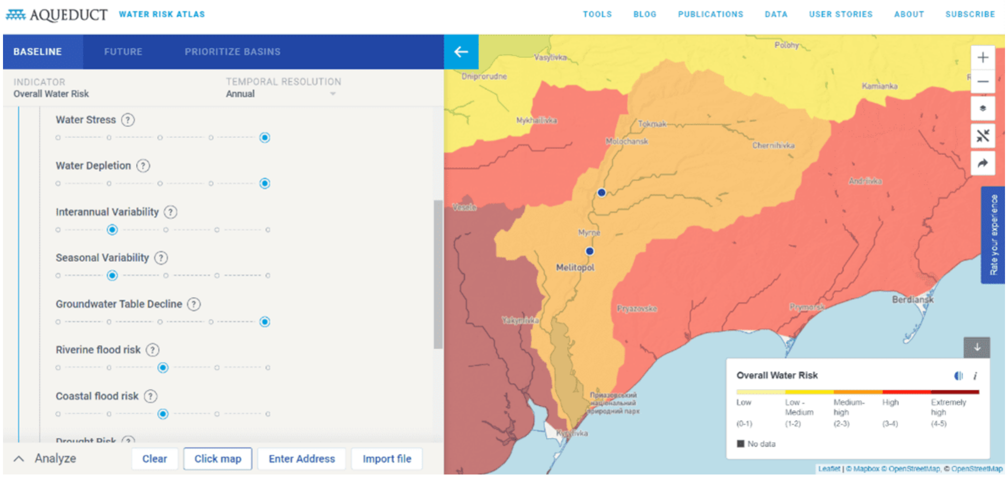

Figure 2. *Determination of the Generalized Water Stress Indicator for the Molochna River Basin*

The water risk indicators have been aggregated by category (quantity, quality, reputational, and overall) into composite risk scores using sector-specific weighting schemes. This resource enables the determination of the current ecological state of the river basin and the prediction of the likelihood of water risk occurrence for the years 2030, 2050, and 2080, under one of three scenarios: business-as-usual SSP 3 RCP 7.0, optimistic SSP 1 RCP 2.6, and pessimistic SSP 5 RCP 8.5 (Kuzma et al., 2023). The multifactorial analysis, presented through an interactive GIS map, is based on analyzing three blocks of indicators: physical risks quantity, physical risks quality, and regulatory and reputational risk, averaging the data, and providing an overall determination of water risk for the studied basins. Thus, the worst values on the conditional compliance scale criterion "Extremely high" (4-5) for the Molochna River basin were identified for the indicators: Water Stress, Water Depletion, Groundwater Table Decline; and "High" (3-4) for the criteria: Drought Risk, Untreated Connected Wastewater, Unimproved/No Drinking Water, Unimproved/No Sanitation (Aqueduct Publications).

The destruction of river basins is a significant problem for the southeastern region of Ukraine, associated with the transformation of natural and anthropogenic landscapes and the emergence of belligerent landscapes, loss of forest cover, and biodiversity. Another danger during military actions is pyrogenic terrorism, given that pine forests in the steppe zone are the most fire-prone forest category in Ukraine (Osadchyi, Oreshchenko, & Savenets, 2023). Potential losses of tree plantations can be determined using the open-source GIS application Global Forest Watch (GFW). This interactive system provides comprehensive information about the state of forests, their dynamics, and retrospection within a specific study area. It shows year-by-year tree cover loss, defined as the stand-level replacement of vegetation greater than 5 meters, within the selected area. The tree cover loss data set is a collaboration between the University of Maryland, Google, USGS, and NASA, and uses Landsat satellite images to map annual tree cover loss at a 30 × 30 meter resolution (Figure 3B).

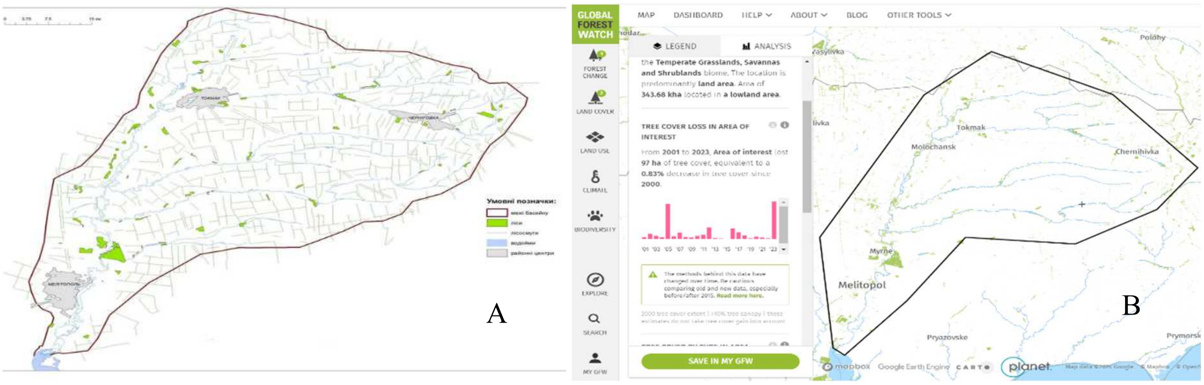

***Figure 3**. A) A forestation map of the Molochna River basin, presented in the "Program for the Ecological Rehabilitation of the Molochna River Basin, Restoration of its Hydrological Regime, Improvement, and Preservation of Biodiversity for 2014-2025" (2013); B) Schematic depiction of the river basin in Global Forest Watch (GFW), with graphical representation of forest cover losses from 2001 to 2023.*

Additionally, by demonstrating the dynamics of forest area loss, the service allows the identification of the time of logging or the occurrence of a fire. The use of remote monitoring methods is an effective and convenient tool for analyzing forest cover (Suska & Polyakh, 2023). For instance, Melnyk A. A. and Yachnyuk M. O. conducted decryption and analysis of Sentinel 2 satellite images using QGIS, which allowed them to identify 251 hectares of areas where forest vegetation was cut. For comparison, according to the online resource Global Forest Watch, the area of logging for the same period was 253 hectares. According to the authors, this indicates the effectiveness of using GIS for spatiotemporal analysis of forest areas (Melnyk & Yachnyuk, 2022). Thus, GFW allows determining the area of tree plantations within both the delineated map territory and each administrative-territorial unit.

In the Southern Steppe zone of Ukraine, the overall percentage of territory covered by tree plantations is lower than the average for the Zaporizhzhia region (1.7% according to literary sources; 1.6% according to GFW data). On the GFW interactive map, we schematically outlined the river basin, which was then analyzed by the system (Figure 3B). The largest losses of forest plantations occurred in 2005 and 2023, with the latter year seeing losses amounting to 25 hectares, corresponding to the highest number of fire outbreaks recorded in the zone of active hostilities.

Conclusions

In summary, it is worth noting that interactive GIS resources, created based on remote sensing of the Earth's surface or large arrays of publicly available environmental data, are a convenient method for monitoring river basins. They can serve as an alternative approach for determining variable changes in hydro-ecosystems under conditions of uncertainty, such as during wartime, when traditional scientific research methods cannot be applied. It is also important to note that this approach is not a full replacement for traditional scientific research methods; however, it has demonstrated reliable results and can serve as a supplement and innovative solution for monitoring surface waters in the context of digitalization and the need for alternative approaches in river basin management. This method allows for instantaneous retrospective analysis across multiple indicators and can determine the presence of destructive changes or the stability of the hydro-ecosystem within certain time periods. In our opinion, interactive GIS resources are modern alternative technologies for multifactorial analysis of the ecological state of river basins, allowing for the rapid grouping and analysis of large statistical data sets.

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