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Satellite monitoring for the optimization of landscape-territorial structure of river basins

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SUMMARY

The formation of optimal basin landscape-territorial structure (LTS) is an important component of the River Basin Management Plan (RBMP). During its development, it is necessary to consider a number of aspects inherent to contemporary challenges. Thus, against the backdrop of global climate change, there arises a need to refine the optimal values of LTS indicators for river basins and the condition of forest plantations in different natural-climatic zones of Ukraine. Of particular importance is the documentation of changes in basin LTS in the context that landscapes become theaters of military operations, consequently undergoing transformations and contamination, particularly as a result of aviation strikes. The restoration of such territories is possible only with the availability of up-to-date information regarding their condition and the scale of damage. Traditionally, in the process of studying basin LTS, cartographic data, environmental status reports, and materials from the certification of Ukrainian rivers have been used. Taking into account contemporary challenges, there arises a need to utilize modern alternative information sources and technologies that are based, in particular, on the use of GIS and remote sensing. In connection with this, the objective of our research became the study of possibilities for using modern approaches to LTS analysis, based on information obtained through the application of a geomatics approach (namely, satellite imagery).

Introduction

The Water Strategy of Ukraine for the period up to 2050 provides for the implementation of an integrated water resources management (IWRM) system based on the basin principle for major river basins and effective economic instruments that stimulate the economical use of water resources. One of the criteria for achieving the effectiveness of the management, development, protection, and use of water resources system is the implementation of River Basin Management Plans (RBMPs). The adoption of RBMPs is a European integration commitment in accordance with the Association Agreement with the EU and one of the key indicators in the "Water Quality" sector during the negotiation process for Ukraine's accession to the EU. Accordingly, as of the beginning of 2025, the Government of Ukraine has officially approved nine RBMPs for 2025-2030: for the Danube, Dnieper, Southern Buh, Dniester, Don, Vistula, the rivers of the Black Sea region, the Azov Sea region, and Crimea (Resolution, 2022).

In the RBMPs, the LTS is considered a fundamental basis for analyzing the state of water resources, modeling hydrological processes, and developing specific environmental protection measures. When substantiating landscape-ecological measures in the process of developing RBMPs, it is effective to study the LTS, which reflects the interrelation between the ecological state of water bodies and the properties of the surrounding landscapes. Therefore, the optimization of the LTS will contribute to solving a number of environmental problems in the river basin at the stage of implementing the measures provided for in the RBMPs. For most rivers in Ukraine, a disruption of the natural ecological balance is characteristic, which is caused by anthropogenic pressure on their basins. The main causes of negative phenomena on the rivers include excessive development of the basins and disruption of the natural mechanism of liquid and solid surface runoff.

Method and Theory

In our work, we utilized the concept of Integrated Water Resources Management (IWRM), which is based on the principle that the natural ecosystems of a river basin, adjacent wetlands, and groundwater are sources of fresh water. This approach is becoming increasingly relevant in the context of global climate change and the ever-growing scarcity of water resources. Disruption of the optimal ratio of areas occupied by forests, perennial grasses, and annual agricultural crops, along with insufficient implementation of anti-erosion measures in the watershed, leads to rapid surface runoff, activation of erosion processes, and ultimately, the siltation of rivers (Grodzinsky, 2005).

Optimization of the landscape structure in river basins can be achieved by creating a system of forest plantations (anti-erosion, water protection, soil protection, gully-side, etc.) throughout the entire basin, particularly on lands not used for agricultural production. This will not only increase the area of ecologically stable territories but also reduce the activity of erosion processes. The expediency of applying GIS technologies, using the NDVI vegetation index, and remote sensing for assessing the condition of forest plantations, as well as for developing measures to optimize the condition of these territories, is confirmed by the results of scientific research (Zatserkovnyi, Oberemok & Kun, 2018; Melnyk & Yachniuk, 2022). It should be emphasized that this approach is not a complete replacement for traditional research methods; however, it has demonstrated excellent, reliable results and can serve as a supplement and an innovative solution for monitoring surface waters and studying the LTS of river basins in the context of digitalization and the need to find alternative approaches to river basin management (Skyba, Vozniuk & Vozniuk, 2024). In doing so, it is necessary to take maximum account of the terrain features, adhering to the principles of contour-reclamative land organization, which also involves the use of GIS technologies and remote sensing. For example, by using software such as ArcGIS, QGIS, Global Mapper, etc., which allows for the rapid and accurate creation of a digital elevation model.

For long-term monitoring of LTS changes in river basins, satellite images with a low temporal resolution (e.g., Landsat satellites) are typically used. The analysis can be carried out using satellite images of:

- Medium resolution (Sentinel-2, Landsat satellites), which allows for tracking changes in the LTS (changes in the area of agricultural lands and forests, the appearance of large infrastructure objects). These images are usually free of charge, which significantly expands their accessibility and application in research projects;
- High resolution (Maxar WorldView, Planet Skysat satellites), which are generally not optimal for analyzing the LTS of entire basins. However, these images are indispensable for conducting detailed analysis of specific, small areas within the basin, for example, monitoring erosion-deformed areas; detecting unauthorized objects within the coastal protective strip; and assessing damage and losses caused by military actions in areas with limited physical access (occupied territories, active combat zones).

Results

The object of research is the basins of medium-sized rivers located in different natural-climatic zones and belonging to different hydrological basins. Previous research by the authors was focused on the analysis and assessment of the LTS of the river basins of these watercourses.

1) The basin of the Turiia River, which flows through the territory of the Volyn Region and belongs to the Prypiat basin, being its first-order right tributary. The length of the Turiia is 188 km, and its catchment area is 2900 km². The results of previous studies have established that the overall ecological state of the Turiia River largely depends on the level of anthropogenic pressure on the basins of small rivers that are its 1st and 2nd order tributaries.
2) The basin of the Molochna River, which flows through the territory of the Zaporizhzhia Region and empties into the Molochnyi Estuary of the Sea of Azov basin. Its length is 197 km, and the river's catchment area is 3450 km². The overall state of the Molochna River ecosystem, according to the induction coefficient of anthropogenic load index (IKAN), is characterized as approaching a "very poor" condition.

We investigated the use of floodplain lands in the basins of the Turiia and Molochna rivers. The landscape structure of the floodplains of small rivers in the Turiia basin is determined by natural factors, and the specifics of its functioning were defined by spatio-temporal aspects. The modern development of floodplain landscapes is predominantly driven by anthropogenic factors associated with various types of economic activity.

1) In the Turiia River basin, a high level of agricultural pressure on the floodplains of small rivers is observed, ranging from 37.27% (unnamed river No. 3) to 91.25% (Srebnytsia River). Between 1.25% (unnamed river No. 5) and 24.3% (Rudka River) of the floodplain territory is plowed, which is impermissible according to the requirements of the Water Code of Ukraine. A high level of land reclamation in the floodplains should be noted, which fluctuates between 16.6% (Srebnytsia River) and 54.1% (Rudka River). At our disposal are cartographic data from Google, showing a section of the Turiia River in the area of the pedestrian bridge (Komarove), Volyn Region, as of June 2015 (Fig. 1). Using data from this resource, we obtained a current map of the studied section of the Turiia River as of August 2025 (Fig. 2).

2) For the Molochna River basin, destructive anthropogenic factors are typical: arable land comprises 72.8% (accordingly, improper plowing is observed within the river floodplain boundaries – approximately 4%). Almost the entire river floodplain is overgrown with reeds, not forested, meadowed, and waterlogged over an area of 12.5%. Over time, the Molochna River floodplain has undergone significant changes due to silting and shallowing of steppe watercourses, which resulted from mass plowing of steppe landscapes in the mid-20th century. At the same time, the envisaged environmental protection measures aimed at preserving, protecting, and restoring small and medium watercourses are typically implemented inadequately due to lack of funding and proper oversight.

Figure 1 *Section of the Turiia River in the area of the pedestrian bridge (Komarove), Volyn Region (cartographic data from Google, 2015)*

Figure 2 *Section of the Turiia River in the area of the pedestrian bridge (Komarove), Volyn Region (cartographic data from Google, 2025)*

a) 2010 *b) 2019* *c) 2023* *d) 2025*

Figure 3 *Section of the Molochna River within the boundaries of Melitopol, Zaporizhzhia Region (cartographic data from Google Earth)*

A particular example of increased anthropogenic pressure on the studied river basin is the construction of a solar power plant with a capacity of 33.1 MW, which occupies an area of 50 hectares and is equipped with over 91,000 solar panels. Analysis of the level of thermal pollution of the landscape made it possible to determine that the location of this solar power station is a hotspot with the highest temperature, even compared to the industrially-loaded areas of Melitopol city, within which large industrial enterprises are located (metallurgical and food industries) (Fig. 3).

Results

The analysis of cartographic materials based on satellite imagery made it possible to conclude that the situation regarding the use of floodplain lands in the studied section of the Turia River channel remained practically unchanged during the period 2015–2025. Intensive agricultural use of floodplain lands within the water protection zone, which includes the river's floodplain, is observed. It can also be stated that there are no water-protective or anti-erosion plantings along the river in this section. By contrast, the examined floodplain section of the Molochna River has undergone significant anthropogenic transformations during the specified period. It should be noted that the use of remote sensing methods enables not only the acquisition of objective information about the state of basin landscapes, but also the detection of changes essential for management decision-making. Under present conditions, the issue of identifying surface damage caused by military actions through satellite data is also of great relevance (Mikava & Drozd, 2023).

Conclusions

The creation of an effective mechanism for optimizing the landscape–territorial systems (LTS) of river basins requires up-to-date information on the condition of the studied territories and, given current realities, on the extent of their damage caused by military actions. The analysis of satellite imagery using modern GIS technologies has today become a powerful source of spatial information, particularly regarding the structural features of landscapes and the condition of forest plantations of various functions. The current accessibility of GIS ensures efficient, rapid, and reliable opportunities for monitoring changes in basin LTS in any region of Ukraine. Thus, the study confirms the appropriateness of applying GIS technologies and remote sensing for the development of measures aimed at optimizing basin LTS. Accordingly, geomatic approaches constitute an integral part of modern integrated water resources management, providing a scientifically grounded basis for decision-making and contributing to the sustainable development of river basins.

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