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GIS-based Multi-Temporal Assessment of Wetland Regime Transformation in the Hnylopyat River Basin from Satellite Water Indices

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SUMMARY

Wetland ecosystems of the Ukrainian forest-steppe regulate regional runoff and store organic carbon, yet under a changing climate they are undergoing rapid transformation that is difficult to capture with sparse ground networks alone. This study develops a geographic information system (GIS) workflow for reconstructing the multi-decadal evolution of the wetland regime of the Hnylopyat River basin, a representative waterlogged catchment of the Ukrainian forest-steppe zone, without relying on bottom-sediment analysis or numerical soil-water modelling. A thirty-year Landsat and Sentinel-2 image archive (1995–2024) was processed in Google Earth Engine and analysed in QGIS. Two spectral water indices were mapped for each year, the Modified Normalized Difference Water Index (MNDWI) as a marker of surface wetness and the Colored Dissolved Organic Matter (CDOM) index as a proxy for dissolved organic load. Zonal statistics were used to derive the annual distribution of basin area among index classes, and per-class area trends were tested for significance. Index dynamics were then cross-related with in-situ hydrometeorological series (runoff, precipitation, evaporation) and with a concise hydrochemical characterisation of basin surface water. The GIS analysis reveals a progressive spatial differentiation of the wetland: the share of drier terrain rose while localised waterlogging cores intensified, with the high-CDOM class expanding by about ninety percent over the study period. Index area shares correlate significantly with ground runoff and evaporation, confirming that the geospatial indicators track real hydrological change. The workflow provides a transferable GIS tool for monitoring peatland transformation in other Ukrainian basins.

Keywords: GIS; Remote sensing; MNDWI; CDOM; Wetland monitoring; Google Earth Engine; Hnylopyat basin.

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Introduction

Wetland ecosystems of the Ukrainian forest-steppe zone play a critical role in regulating the hydrological regime and in storing organic carbon, yet under contemporary climate change they are undergoing intensive transformation. Between thirty and ninety percent of wetlands in different regions of the world have already been degraded, which makes systematic monitoring of their evolution an urgent task. Wetland ecosystems of the Ukrainian forest-steppe play a critical role in regulating the hydrological regime and in storing organic carbon, yet under contemporary climate change they are undergoing intensive transformation (Tsyhanenko-Dziubenko et al., 2024). Between thirty and ninety percent of wetlands in different regions of the world have already been degraded, which makes systematic monitoring of their evolution an urgent task. The Hnylopyat River basin, extending across the northern part of the Vinnytsia Oblast and the southern part of the Zhytomyr Oblast, is a typical waterlogged catchment of the forest-steppe zone and offers a suitable setting for tracking such change. Ground observation posts, however, are sparse and cannot resolve the spatial pattern of wetland transformation across the catchment.

Geographic information systems (GIS) and satellite remote sensing overcome this limitation by reconstructing the spatial and temporal behaviour of wetlands over large areas. Spectral water indices have become the standard tool for this purpose. The Modified Normalized Difference Water Index enhances open-water and wet-surface features while suppressing built-up noise (McFeeters, 1996), and the Colored Dissolved Organic Matter index serves as a proxy for dissolved organic load in optically complex waters (Kutser et al., 2016). Cloud platforms such as Google Earth Engine now make multi-decadal index time series tractable (Gorelick et al., 2017), and comprehensive reviews confirm the value of combining optical indices with GIS zonal analysis for wetland classification (Mahdavi et al., 2018; Tiner et al., 2015), while complementary modelling has been used to forecast the spatio-temporal dynamics of river hydroecological parameters in Ukraine (Tsyhanenko-Dziubenko et al., 2025). Existing work on the region's rivers has emphasised bottom-sediment geochemistry of nearby catchments (Tsyhanenko-Dziubenko & Kireitseva, 2025) and, for the Hnylopiat basin, numerical soil-water modelling; the present study deliberately takes a different, GIS-centred route, treating multi-temporal index mapping and zonal statistics as the primary method and using ground data only for validation.

The purpose of the work is to reconstruct the multi-decadal transformation of the wetland regime of the Hnylopyat River basin through a GIS workflow built on satellite water indices, and to verify the geospatial indicators against in-situ hydrological and hydrochemical observations.

Method and Theory

The study area is fragment 4 of subbasin 950 of the Hnylopyat River, the study area is fragment 4 of subbasin 950 of the Hnylopyat River, located within the forest-steppe zone of Ukraine, in the northern part of the Vinnytsia Oblast and the southern part of the Zhytomyr Oblast.

The catchment displays landscape conditions typical of the forest-steppe, with a predominance of waterlogged areas, peat-bog soils and mixed forests. A thirty-year archive of Landsat 5, 7 and 8 and Sentinel-2 imagery (1995–2024) was assembled and pre-processed in Google Earth Engine, including atmospheric correction, cloud masking and radiometric calibration (Gorelick et al., 2017; Zhu & Woodcock, 2014). All subsequent geospatial analysis, class thresholding, cartography and zonal statistics were performed in QGIS (Figure 1).

For each year two indices were computed following Xu (2006). MNDWI was derived as the normalised ratio of the green and short-wave infrared (SWIR) bands:

$$\boldsymbol{MNDWI} = \frac{(\boldsymbol{Green} - \boldsymbol{SWIR})}{(\boldsymbol{Green} + \boldsymbol{SWIR})} \qquad (1)$$

The CDOM index was derived from the blue-to-green band ratio as a proxy for dissolved organic matter (Kutser et al., 2016). Each index raster was reclassified into ordered value classes, and zonal statistics were applied to obtain the annual share of basin area occupied by every class. Per-class area time series were then tested for trend, giving a quantitative, spatially explicit record of change rather than a single static map.

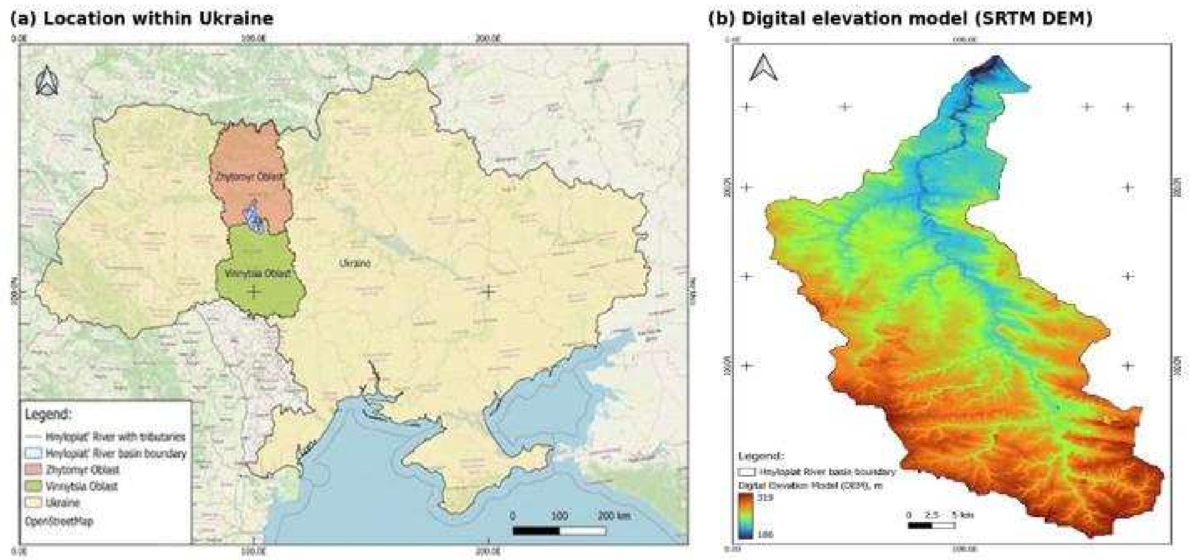

Figure 1. *Study area: (a) location of the Hnylopiat River basin within Ukraine, across the northern Vinnytsia and southern Zhytomyr Oblasts, and (b) SRTM digital elevation model of the basin*

The geospatial record was validated against in-situ hydrometeorological series for 1991–2024 (runoff, precipitation, actual and potential evaporation) drawn from a high-resolution dataset for Ukrainian river basins (Osypov et al., 2025).

Pearson correlation was computed between index-class area shares and ground parameters at a significance level of $p < 0.05$. A concise hydrochemical characterisation of basin surface water was added as interpretive context for the CDOM signal: the water is near-neutral (pH about 7.3), weakly mineralised (electrical conductivity about 0.38 mS cm^{-1}), of a sulphate-calcium type with low chloride content, consistent with a humid, precipitation-dominated regime and an elevated dissolved organic fraction.

Results

The GIS workflow resolved a clear multi-decadal reorganisation of the wetland surface that a single scene cannot show. For MNDWI, the moderately negative class (−0.3 to −0.2), characteristic of moist ground without standing water, contracted from about forty-two percent of the basin in 1995 to about thirty percent in 2024, while the more negative, drier class (−0.4 to −0.3) expanded from roughly fifteen to twenty-four percent (Figure 2a). The near-zero and positive classes, which mark persistent open-water and permanently flooded wetland cores, remained broadly stable. The pattern is therefore not uniform drying but increasing spatial differentiation, with peripheral drying alongside the persistence and local intensification of saturated cores.

The CDOM record reinforces this reading (Figure 2b). The dominant 0.8–0.9 class fell from about eighty-six percent to sixty-six percent, whereas the highest 0.9–1.0 class expanded from roughly ten to twenty-two percent, an increase of about ninety percent. Rising high-CDOM area indicates accumulation of dissolved organic matter under intensifying anaerobic conditions in the waterlogged cores, and is consistent with the sulphate-calcium, organic-rich character of the surface water.

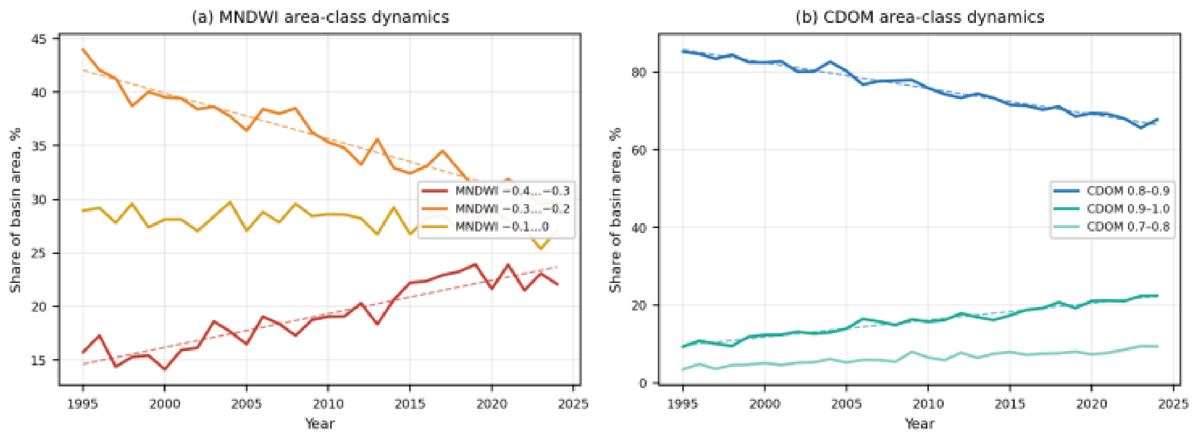

Figure 2. *GIS-derived multi-temporal distribution of basin area among (a) MNDWI and (b) CDOM index classes, Hnylopiat River basin, 1995–2024. Dashed lines are linear trends of the leading classes*

Cross-correlation with ground data confirms that the geospatial indicators track genuine hydrological change (Table 1). Mean MNDWI correlates strongly with runoff ($r = 0.72$) and precipitation ($r = 0.68$), so the index reliably reflects catchment wetness, while the drier MNDWI class shows the expected inverse relationships. Mean CDOM correlates most strongly with actual evaporation ($r = 0.58$, rising to 0.62 for the highest class), linking organic enrichment to warm-season decomposition. All reported coefficients are significant at $p < 0.05$.

Table 1. *Pearson correlation between GIS-derived index indicators and in-situ hydrological parameters ($p < 0.05$)*

Geospatial indicator	***Runoff***	***Precip.***	***Act. evap.***	***Pot. evap.***
MNDWI (mean)	0.72	0.68	0.45	–0.28
MNDWI class –0.4…–0.3, %	–0.69	–0.64	–0.41	0.33
CDOM (mean)	0.41	0.38	0.58	0.12
CDOM class 0.9–1.0, %	0.38	0.35	0.62	0.19

Taken together, the GIS indicators point to a progressive transformation of the wetland regime toward a spatially fragmented state, with expanding drier margins and intensifying organic-rich waterlogged cores. Extrapolating the observed class-area trends suggests continued expansion of the high-CDOM area toward roughly a quarter of the basin over the coming decade, which would reduce the ecosystem's self-purifying capacity.

Conclusions

A GIS workflow combining Google Earth Engine pre-processing, QGIS class mapping and zonal statistics reconstructed thirty years of wetland change in the Hnylopyat River basin from two satellite water indices, without recourse to bottom-sediment analysis or numerical soil-water modelling. The geospatial record shows growing spatial differentiation of the wetland, with the drier MNDWI class expanding by about forty-five percent and the high-CDOM class by about ninety percent between 1995 and 2024.

The indicators correlate significantly with independent ground observations of runoff and evaporation, and are consistent with the near-neutral, weakly mineralised, sulphate-calcium character of basin surface water. The approach is transferable to other Ukrainian peatland catchments and provides a low-cost geospatial basis for wetland monitoring and water-management planning under climate change. Future work will integrate radar imagery to reduce cloud gaps and extend the index-classification scheme to seasonal, rather than annual, time steps.

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