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HYDRODYNAMIC MODELING OF WETLAND LANDSCAPE EVOLUTION IN THE GNYLOPYAT RIVER BASIN THROUGH INTEGRATION OF SATELLITE INDICES AND HYDROCHEMICAL ANALYSIS OF BOTTOM SEDIMENTS

The evolution of wetland landscapes represents a critical component of hydrological systems, particularly under increasing anthropogenic pressure and climate variability. This study presents a comprehensive assessment of wetland landscape evolution in the Gnylopyat River Basin through the integration of multi-temporal satellite remote sensing data and detailed hydrochemical analysis of bottom sediments. The research employs a novel methodological approach combining spectral indices analysis with entropy-based stability assessment to quantify ecosystem transformation processes over a 30-year period (1995-2024).

Bottom sediments were collected during summer 2025 using standardized Van Veen grab sampler methodology [1] at predetermined locations throughout the river basin and adjacent wetland areas. Laboratory analysis encompassed comprehensive determination of macroelements, general physicochemical parameters, mesoelements, microelements, and water-soluble components using established analytical procedures. The hydrochemical characterization revealed elevated organic matter content (15.9 %) combined with exceptionally high manganese concentrations (135.74 mg/kg), indicating the development of reducing conditions in the bottom layer typical of waterlogged ecosystems with slow mineralization processes.

Satellite data analysis utilized four key normalized multispectral indices: Colored Dissolved Organic Matter Index (CDOM), Modified Normalized Difference Water Index (MNDWI), Normalized Difference Moisture Index (NDMI), and Normalized Difference Vegetation Index (NDVI). Multi-temporal analysis of Landsat imagery (Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI, and Landsat 9 OLI-2) provided temporal consistency throughout the study period. The CDOM index demonstrated a steady increase from values of 0.9000-1.0000 in 1995 to values exceeding 1.5000 in 2024, indicating intensive accumulation of dissolved organic matter and formation of eutrophic conditions in wetland landscapes. Entropy analysis of wetland system stability revealed critical instability levels with normalized entropy of 87.5 % for overall system parameters (table 1).

Table 1.

Summary table of entropy of wetland landscape subsystems of the Gnylopyat basin

Subsystem	No. Parameters	Average Entropy (bits)	Normalized Entropy (%)	System Status
General Indicators	5	0.350	87.5%	CRITICAL
Macro Elements	3	0.289	57.8%	MODERATE
Meso/Micro Elements	6	0.440	73.3%	HIGH
Water Extract	5	0.366	48.7%	STABLE
Ionic Composition	9	0.391	61.9%	MODERATE
Total Entropy	28	0.367	65.8%	CRITICAL

Among individual subsystems, the water extract demonstrated the highest stability (48.7%), while meso/microelements showed high instability (73.3 %). The integral assessment of entropy characteristics (65.8% with 28 parameters) classifies the wetland systems of the Gnylopyat Basin as critically unstable, requiring implementation of comprehensive ecological rehabilitation measures.

Correlation analysis revealed the evolution of hydroecological processes over the 30-year period. The most significant change was observed in the CDOM-MNDWI relationship, shifting from weak negative correlation (-0.15) in the early period to moderate positive correlation (0.58) in the recent period, indicating activation of dissolved organic matter accumulation processes in water bodies . Strong positive correlation CDOM-NDMI (0.73) in the current period indicates formation of hydromorphic conditions with intensive humus accumulation (table 2)

Table 2.

Multi-temporal dynamics of spectral indices in the Gnylopyat River Basin (1995-2024)

INDEX	**CDOM**	**MNDWI**	**NDMI**	**NDVI**
CDOM	1.00	0.42	0.64	-0.55
MNDWI	0.42	1.00	0.35	-0.63
NDMI	0.64	0.35	1.00	0.12
NDVI	-0.55	-0.63	0.12	1.00

The temporal dynamics of spectral indices confirmed progressive transformation of the Gnylopyat Basin landscapes toward wetland formation. The MNDWI index showed expansion of areas with high surface moisture, particularly after 2011, with formation of zones MNDWI > 0.5000. The NDMI evolution was characterized by gradual increase in vegetation and soil moisture from values 0.0000-0.2000 in the early period to NDMI > 0.5000 in 2011-2024, corresponding to formation of hygrophilic and helophytic communities.

Conclusions. The comprehensive study of the Gnylopyat River Basin reveals accelerated wetland formation processes characterized by critical ecosystem instability and progressive eutrophication over the 30-year observation period. The entropy analysis demonstrates that wetland systems have reached critically unstable conditions with 65.8% normalized entropy across 28 parameters, while satellite data confirms intensive accumulation of dissolved organic matter evidenced by CDOM index increases from 0.9-1.0 in 1995 to over 1.5 in 2024. The correlation dynamics between spectral indices, particularly the shift from negative CDOM-MNDWI correlation (-0.15) to strong positive correlation (0.58), indicates fundamental changes in hydroecological processes with formation of reducing conditions and organic matter accumulation in bottom sediments.

The integration of hydrochemical analysis and remote sensing data provides compelling evidence of ecosystem transformation toward hydromorphic conditions with dominance of helophytic vegetation communities and significant organic carbon deposition. The elevated manganese concentrations (135.74 mg/kg) combined with high organic matter content (15.9%) in bottom sediments confirms the development of anaerobic conditions typical of waterlogged ecosystems. These findings suggest that without immediate implementation of comprehensive ecological rehabilitation measures, the Gnylopyat Basin will continue its trajectory toward eutrophic floodplain bog formation, representing a significant shift in regional hydrological and ecological balance that requires urgent scientific attention and management intervention.

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