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Satellite-Based Assessment of Post-Disaster Landscape Renaturalization in the Former Kakhovka Reservoir (2023–2026)

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SUMMARY

The destruction of the Kakhovka Dam in 2023 triggered one of the largest hydrological disturbances in contemporary Europe, resulting in the rapid drainage of the 2,155 km² Kakhovka Reservoir and exposing the former floodplain landscapes of the historic Velykyi Luh. Initial assessments predicted prolonged land degradation, extensive aeolian erosion, and regional desertification. This study evaluates the subsequent trajectory of landscape transformation using multi-temporal Sentinel-2 imagery acquired between 2023 and 2026. Surface reflectance Level-2A products were processed to derive the Normalized Difference Vegetation Index (NDVI) and the Gao Normalized Difference Water Index (NDWI). The complementary application of these spectral indices enabled simultaneous assessment of vegetation development and substrate moisture dynamics throughout the post-disaster succession. The NDWI time series documents the abrupt collapse of the reservoir's hydrological regime immediately after dam failure, followed by the stabilization of moisture conditions along relic river channels and newly developing floodplain corridors. Concurrently, NDVI reveals exceptionally rapid vegetation establishment, progressing from nearly barren exposed sediments in June 2023 to dense vegetation cover by June 2026. The results demonstrate that the former reservoir has followed a rapid natural renaturalization pathway rather than the previously anticipated desertification scenario. The combined use of NDVI and NDWI derived from freely available Sentinel-2 imagery provides an efficient, reproducible framework for monitoring post-disaster landscape dynamics, particularly within conflict-affected regions where conventional field investigations remain severely constrained. The findings provide an important scientific basis for future ecological restoration planning, protected area expansion, and long-term environmental monitoring of the recovering Velykyi Luh landscape.

Keywords: Remote sensing; NDVI; NDWI; Sentinel-2; Kakhovka Reservoir; Landscape renaturalization; Velykyi Luh; Post-disaster ecology.

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Introduction

The destruction of the Kakhovka Dam on 6 June 2023 by Russian occupation forces triggered one of the most extensive anthropogenic hydrological disturbances in Europe in recent decades. Within several days, the 2,155 km² Kakhovka Reservoir was rapidly drained, exposing the former floodplain of the historic Velykyi Luh and initiating rapid geomorphological adjustment and ecological succession. Initial assessments predicted extensive aeolian deflation of exposed limnic sediments and prolonged regional desertification (Vyshnevskyi, Shevchuk, Komorin, Oleynik, & Gleick, 2023). Subsequent satellite observations, however, revealed a fundamentally different trajectory of landscape transformation. Spectral indices derived from multispectral satellite imagery provide spatially explicit quantitative evidence for monitoring these processes while avoiding many of the logistical and security constraints that substantially limit field investigations within frontline areas and territories currently outside Ukrainian governmental control (Sorokina, & Tsyhanok, 2024).

The Normalized Difference Vegetation Index (NDVI) and the Gao Normalized Difference Water Index (NDWI), derived from freely available Sentinel-2 imagery, provide complementary and non-redundant information on post-disturbance ecosystem dynamics. NDWI characterizes vegetation and substrate moisture conditions and facilitates the identification of persistently wet landscape elements, whereas NDVI quantifies vegetation development and biomass accumulation. Their combined application enables an integrated assessment of the successive hydrological and ecological phases of landscape transformation throughout the 2023–2026 monitoring period. Such long-term environmental monitoring is particularly important given the conservation status of the Velykyi Luh as a protected area within Ukraine's nature conservation network (History of the Great Meadow, 2026). The resulting evidence provides an objective scientific basis for resolving potential conservation conflicts and supports future landscape-functional zoning and ecosystem restoration planning for the recovering floodplain geosystems (Havrylenko, Shyshchenko, & Tsyhanok, 2020).

Method and Theory

Multispectral Sentinel-2 imagery (ESA/Copernicus Level-2A Bottom-of-Atmosphere surface reflectance products) was accessed through the Copernicus Browser (Copernicus Data Space Ecosystem, 2026). Image scenes with cloud cover below 20% were preferentially selected to minimize cloud contamination and maximize temporal comparability. Because Level-2A products provide atmospherically corrected surface reflectance, no additional atmospheric correction was required. To ensure methodological consistency between spectral indices, the same near-infrared band (Band 8A, 865 nm) was used throughout the analysis. The Normalized Difference Water Index (NDWI) was calculated following Gao (1996):

$$\boldsymbol{NDWI = (B8A - B11) / (B8A + B11)} \tag{1}$$

where Band 8A (near infrared, 865 nm) and Band 11 (short-wave infrared, 1610 nm) were used to characterize surface and vegetation moisture conditions. It should be noted that two conceptually distinct indices share the acronym NDWI in the remote sensing literature. The Gao (1996) formulation, based on the NIR and SWIR spectral regions and adopted in this study, is primarily sensitive to vegetation and substrate moisture, whereas the McFeeters (1996) index, based on the Green and NIR bands, was specifically developed for open-water delineation. The Normalized Difference Vegetation Index (NDVI) was calculated according to the classical formulation proposed by Tucker (1979):

$$\boldsymbol{NDVI = (B8A - B4) / (B8A + B4)} \tag{2}$$

where Band 4 (red, 665 nm) and Band 8A (near infrared, 865 nm) were used to derive a standardized proxy for photosynthetically active green vegetation, particularly suitable for detecting early successional vegetation. All spectral indices were computed directly within the Copernicus Browser environment.

Results

The NDVI time series provides robust evidence of accelerated ecological succession within the former Kakhovka Reservoir. On 30 June 2023 (Figure 1), the exposed reservoir bed exhibited NDVI values close to zero, indicating largely unvegetated sediments with minimal photosynthetically active vegetation. This spectral pattern was consistent with the early projections of prolonged ecological degradation. By 29 June 2026, the same area displayed uniformly high NDVI values that locally exceeded those observed over adjacent agricultural land, indicating the establishment of dense floodplain vegetation. Independent field surveys confirmed the development of native willow-poplar communities (Salix alba L. and Populus nigra L.) as the dominant woody vegetation layer, documenting 65 vascular plant species across newly formed habitats exceeding 150,000 ha (Vasyliuk & Kolodezhna, 2025). The rapid establishment of these plant communities is consistent with shallow groundwater conditions, capillary moisture supply through fine-grained limnic sediments, and progressive soil enrichment during early pedogenesis, corresponding to successional trajectories reported from comparable floodplain ecosystems (Lisovets et al., 2025). No evidence of large-scale aeolian erosion has been reported, suggesting rapid surface stabilization by pioneer herbaceous vegetation and subsequently developing woody communities.

The NDWI maps complement the vegetation analysis by documenting the evolution of surface moisture conditions throughout the study period. On 5 June 2023, consistently high NDWI values reflected the fully inundated state of the Kakhovka Reservoir prior to dam failure. By 20 June 2023, more than 80% of the former reservoir exhibited an abrupt transition to low or negative NDWI values, indicating rapid drainage and exposure of limnic sediments. Positive NDWI values persisted primarily along the relic channels of the historic Dnipro River and isolated oxbow lakes, suggesting continued hydraulic connectivity with shallow groundwater within the deepest portions of the former floodplain. During the subsequent years, NDWI stabilized into a spatially heterogeneous pattern characterized by moderate to high moisture values concentrated along newly developing riparian corridors. This distribution is consistent with sustained groundwater influence and capillary moisture transport through fine-grained sediments, which likely reduced the susceptibility of exposed surfaces to extensive aeolian deflation.


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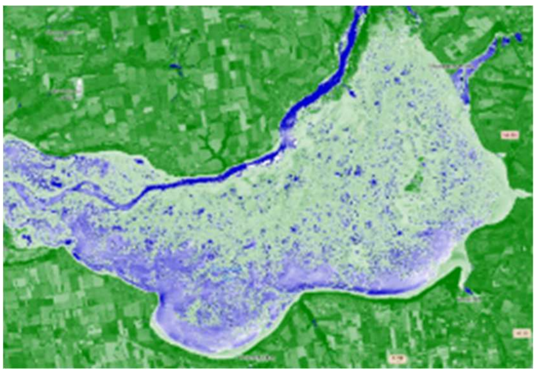
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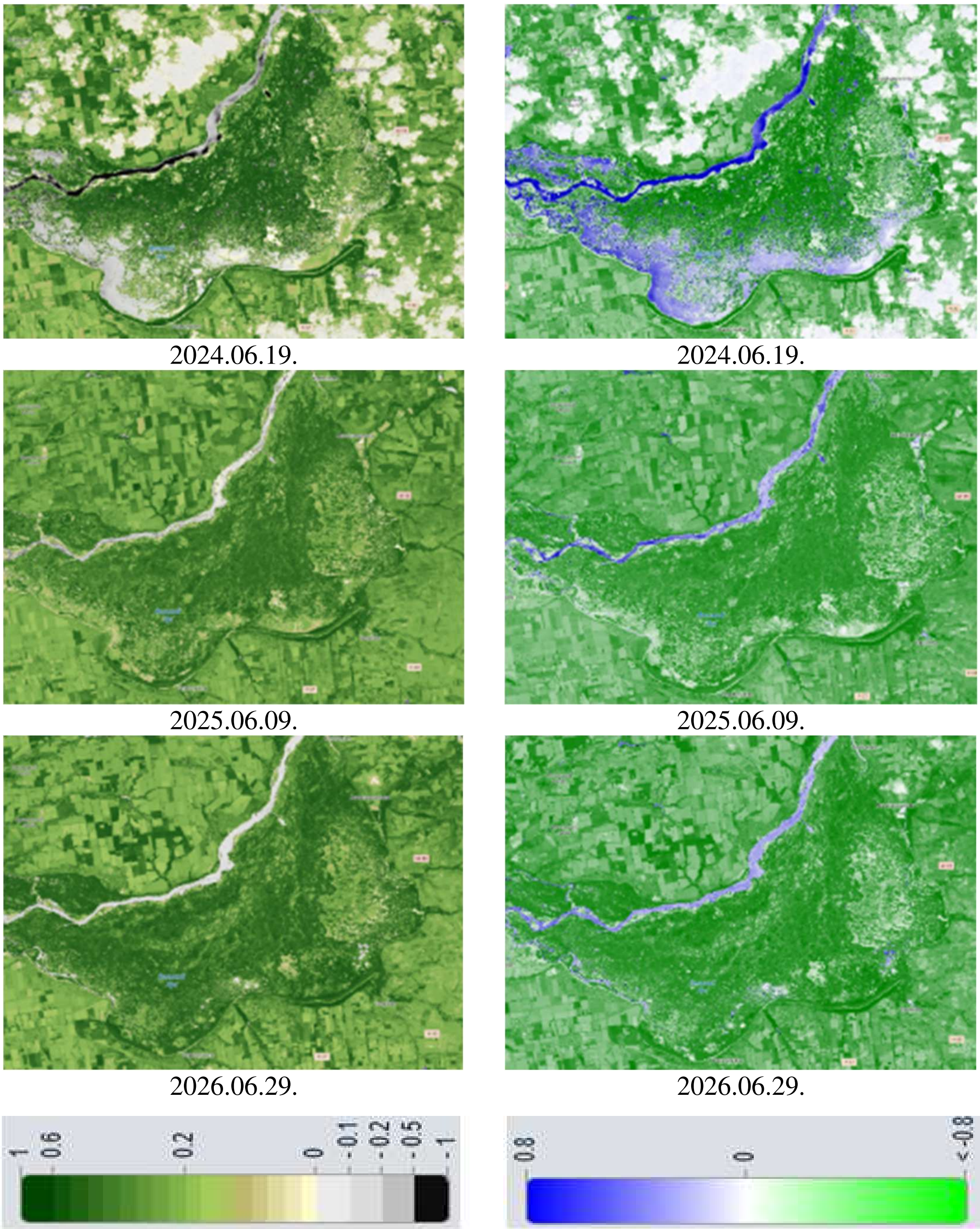

Figure 1. *Multi-temporal evolution of NDVI (left column) and NDWI (right column), illustrating hydrological transformation and vegetation succession in the Velykyi Luh landscape*

Conclusions

The integrated multi-temporal analysis of NDVI and NDWI demonstrates that the former Kakhovka Reservoir has undergone rapid natural renaturalization during the three years following the hydrological disaster. The observed ecological trajectory is consistent with sustained moisture availability within fine-grained limnic sediments and continued groundwater influence, as reflected by the NDWI time series, while the NDVI record documents progressive vegetation development comparable to natural successional processes reported for similar European floodplain ecosystems. The recovering landscape has the potential to function as one of the largest continuous ecological corridors within the Emerald Network of Central Europe and may provide substantial long-term carbon sequestration capacity. These findings are directly relevant to future conservation planning and ecosystem restoration strategies, including the implementation of the EU Nature Restoration

Regulation (EU 2024/1991). The combined application of complementary Sentinel-2-derived spectral indices provides an effective and reproducible framework for periodic remote monitoring of post-disaster landscape dynamics, particularly within conflict-affected regions where conventional field surveys remain severely constrained by security and logistical limitations. Building upon established landscape principles for protected area planning (Havrylenko & Tsyhanok, 2018), the recovering National Nature Park Velykyi Luh ecosystem warrants comprehensive landscape assessment to support the scientifically justified expansion of its boundaries.

References

Copernicus Data Space Ecosystem. (2026). Copernicus Browser [Software]. ESA. https://browser.dataspace.copernicus.eu/

Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment, 58(3), 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3

Havrylenko, O., Shyshchenko, P., & Tsyhanok, Ye. (2020). Landscape functional zoning of urban protected areas. Journal of Environmental Research, Engineering and Management, 76(3), 121–136. http://dx.doi.org/10.5755/j01.erem.76.3.24258

Havrylenko O., & Tsyhanok Ye. (2018). Landscape analysis for the optimization of nature protection management in the urbanized environment. Ukrainian Geographical Journal 1(101), 24–29. https://doi.org/10.15407/ugz2018.01.024 [In Ukrainian].

History of the Great Meadow. National Nature Park "Great Meadow". (2026). http://grandmeadow.org.ua/index.php/publisher/articleview/frmArticleID/47

Lisovets, O., Podorozhniy, S., Tutova, H., Molozhon, K., Kunakh, O., & Zhukov, O. (2025). Hemeroby reveals the dynamics of vegetation cover following the destruction of the Kakhovka Reservoir. PeerJ, 13, e19607. https://doi.org/10.7717/peerj.19607

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7), 1425–1432. https://www.tandfonline.com/doi/abs/10.1080/01431169608948714

Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869. (2024). Official Journal of the European Union, L series. http://data.europa.eu/eli/reg/2024/1991/oj

Sorokina, L., & Tsyhanok, Ye. (2024). Analysis of the land cover structure dynamics of landscapes in the Chernobyl Nuclear Power Plant exclusion zone (methodical aspect). Proceedings of the International Conference of Young Professionals “GeoTerrace-2024”, 1–5. https://doi.org/10.3997/2214-4609.2024510084

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8(2), 127–150. https://doi.org/10.1016/0034-4257(79)90013-0

Vasyliuk, O. V., & Kolodezhna, V. V. (Eds.). (2025). Destruction of the Kakhovka Reservoir: environmental impact. Druk Art. https://uncg.org.ua/wp-content/uploads/2025/02/znyshhennya-kahovskogo-vodoshovyshha-naslidky-dlya-dovkillya-2025.pdf [In Ukrainian].

Vyshnevskyi, V., Shevchuk, S., Komorin, V., Oleynik, Y., & Gleick, P. (2023). The destruction of the Kakhovka dam and its consequences. Water International, 48(5), 631–647. https://doi.org/10.1080/02508060.2023.2247679