Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 453 (E-14), 2025, pp. 115–117
DOI: 10.25171/InstGeoph_PAS_Publs-2025-057
XLII International School of Hydraulics, Radocza, Poland, 20–23 May 2025

Satellite-based Analysis of River Morphology and Riparian Vegetation Changes: Insights from the Vistula River Case Study

Raveena Raj NAGARAJAN and Michael NONES

Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland

✉ raveena.nagarajan@igf.edu.pl; mnones@igf.edu.pl

Abstract

Rivers continually alter their planform due to natural processes and human activities, affecting their morphology and the enclosing ecosystems. Understanding these changes is crucial for managing water resources, floods, and conservation efforts. In this study, we use satellite-derived indices, including Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), and Automated Water Extraction Index (AWEI), to assess sediment deposition, erosion, sinuosity variations, and riparian vegetation shifts over a 40-year period (1984–2024). Using Google Earth Engine, we analyze river morphology and vegetation changes, providing insights into environmental and anthropogenic influences on the Vistula River and its sub-reaches. This watercourse was selected for its historical significance and susceptibility to urban pressures, and to test the approach proposed here. Preliminary results reveal key trends in river morphology and vegetation dynamics, emphasizing the importance of remote sensing in large-scale river monitoring. This research contributes to broader efforts to understand climate-driven changes in river planforms, with future studies aiming to improve accuracy through higher-resolution data and field validation.

Keywords: Google Earth Engine, remote sensing, riparian vegetation, river morphology, sinuosity.

1. INTRODUCTION

The Vistula River, the largest river in Poland, has long been the subject of intensive geomorphological and hydrological research across its various valley reaches. Its dynamic fluvial system exhibits distinct morpho-dynamic patterns shaped by both natural processes and historical human interventions. Unlike many other European rivers, the Vistula has experienced a unique historical trajectory due to geopolitical influences, which continue to shape present-day fluvial processes and morphological characteristics, such as braided channels and island formations.

Traditionally, satellite imagery has been employed for tracking river morphological changes, but the advent of cloud-based geospatial analysis platforms like Google Earth Engine (GEE) has revolutionized large-scale river system monitoring (Hansen et al. 2013). By enabling the efficient processing of extensive satellite datasets, GEE facilitates the detection of river meandering, sediment deposition, and erosion patterns across large spatial and temporal scales.

This study leverages GEE to examine river morphology changes and riparian vegetation dynamics along the Vistula River (Poland) while proposing a general framework for extending such analyses to global river systems. Using satellite-derived indices such as Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), and Automated Water Extraction Index (AWEI) (Tobón-Marín and Barriga 2020), the research quantifies sediment deposition, erosion patterns, and sinuosity variations over the period 1984–2024. The findings contribute to a broader understanding of river planform evolution and offer a methodological approach that can be applied to river systems worldwide.

2. MATERIALS AND METHODS

2.1 Study area and data pre-processing

The Vistula, Poland's longest river, spans around 1,047 km and drains an area of approximately 194,000 km², with more than half of its basin lying within Poland (Majewski 2013). Rising in the Carpathian Mountains at an altitude of 1,200 m a.s.l., it flows northward through major cities such as Kraków and Warsaw, ultimately emptying into the Bay of Gdańsk. This study employed Landsat (5, 7, and 8) satellite imagery from 1984 to 2024 to guarantee images for each year with extended coverage in the region. To delimit river surfaces, annual mosaics were created, combining multiple images of the same river covering the entire study period. Given that only Landsat images were used, the Simple Composite algorithm was leveraged, and the mosaics were created by taking the pixels with the lowest cloud content of all the images available in the selected period. To ensure high-quality images, a maximum cloud coverage threshold of 20% was imposed.

2.2 River delimitation and riparian vegetation

To assess river morphology and riparian vegetation dynamics, three satellite-derived indices were applied: MNDWI and AWEI for river surface delineation and NDVI for vegetation monitoring. The table below summarizes the formulas and purposes of each index.

Target	Index	Formula	Purpose	Reference
River delimitation	Modified Normalized Difference Water Index (MNDWI)	$\mathrm{MNDWI} = \frac{\mathrm{G} - (\mathrm{SWIR_1})}{\mathrm{G} + (\mathrm{SWIR_1})}$	Enhances water detection by suppressing noise from built-up areas; improves contrast between water and land.	Xu 2006
	Automated Water Extraction Index (AWEI)	$\mathrm{AWEI} = 4 \times (\mathrm{G} - (\mathrm{SWIR_1})) - (0.25 \times (\mathrm{NIR}) + 2.75 \times (\mathrm{SWIR_1}))$	Improves water classification in shadowed/dark areas where traditional indices may underperform.	Feyisa et al. 2014
Riparian vegetation	Normalized Difference Vegetation Index (NDVI)	$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{R})}{(\mathrm{NIR} + \mathrm{R})}$	Measures vegetation health and density. Applied only on dry, non-water pixels to assess greenness trends along riparian zones.	Petrakis et al. 2023

3. PRELIMINARY RESULTS AND FUTURE OUTLOOKS

Preliminary results indicate that satellite-derived indices are effective for monitoring long-term changes in large rivers like the Vistula. However, further validation using high-resolution satellite/aerial imagery and field data is needed. Key observations include:

- Sinuosity variations: changes in meandering intensity observed in some reaches, likely driven by hydrological shifts and climate change;
- Sediment dynamics: distinct erosion and deposition patterns have been detected, correlating with urban and agricultural developments and climate-related shifts in precipitation patterns;
- Riparian vegetation changes: NDVI trends suggest fluctuations in vegetation density, possibly due to land-use changes and climate variability.

Future work will enhance spatial accuracy using higher-resolution data, validate findings with field measurements, and expand the methodology to other global river systems. This will support the analysis of climate impacts on river sinuosity and sediment transport, contributing to adaptive river management strategies. Ultimately, we aim to develop a more comprehensive framework for understanding river planform dynamics under both natural and anthropogenic influences.

Acknowledgements. This study has been financed by NCN National Science Centre Poland – call SONATA BIS-13, Grant Number 2023/50/E/ST10/00261.

References

Feyisa, G.L., H. Meilby, R. Fensholt, and S.R. Proud (2014), Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery, *Remote Sens. Environ.* **140**, 23–35, DOI: 10.1016/j.rse.2013.08.029.

Hansen, M.C., P.V. Potapov, R. Moore, M. Hancher, S.A. Turubanova, A. Tyukavina, D. Thau, S.V. Stehman, S.J. Goetz, T.R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C.O. Justice, and J.R.G. Townshend (2013), High-resolution global maps of 21st-century forest cover change, *Science* **342**, 6160, 850–853, DOI: 10.1126/science.1244693.

Majewski, W. (2013), General characteristics of the Vistula and its basin, *Acta Energetica* **2**, 6–23, DOI: 10.52710/ae.333.

Petrakis, R.E., L.M. Norman, and B.R. Middleton (2023), Riparian vegetation response amid variable climate conditions across the Upper Gila River watershed: informing Tribal restoration priorities, *Front. Environ. Sci.* **11**, DOI: 10.3389/fenvs.2023.1179328.

Tobón-Marín, A., and J. Cañón Barriga (2020), Analysis of changes in rivers planforms using Google Earth Engine, *Int. J. Remote Sens.* **41**, 22, 8654–8681, DOI: 10.1080/ 1431161. 2020.1792575.

Xu, H. (2006), Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery, *Int. J. Remote Sens.* **27**, 14, 3025–3033, DOI: 10.1080/ 01431160600589179.