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Satellite Imagery in Hydraulic Research

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Abstract

This study, conducted in the framework of the Future Lab Water project funded by the Federal State of Lower Saxony, Germany, explores the potential of satellite imagery in hydraulic research, focusing on floodplain vegetation roughness. A Machine Learning (ML) framework will be developed to derive accurate estimates of vegetation parameters, such as Leaf Area Index (LAI) and vegetation height, from Moderate-resolution Imaging Spectroradiometer (MODIS) and ICESat-2 via high resolution Sentinel data. These parameters will be used to calculate vegetation roughness maps through formulas developed for flexible, foliated vegetation, enhancing the accuracy of flood modeling with openly accessible satellite data.

The presently ongoing Future Lab Water project is a collaborative project involving multiple research facilities in the federal state of Lower Saxony in Germany. It addresses various water-related challenges that can be enhanced using digitalization and artificial intelligence such as detection of water- and energy usage in agriculture, retrieving river morphology and vegetation characteristics by publicly provided data and black box models to estimate flood extend in real time. The present paper introduces details of a sub-project focusing on the determination of vegetation characteristics on floodplains making use of advances in remote sensing technologies that have enabled the collection of geospatial data with unprecedented accuracy.

Alongside drone imagery and aerial surveys, satellite-based imagery has become a powerful tool for scientific research and environmental monitoring. Due to the high spatial and temporal resolution, satellite data provide valuable solutions for assessing critical parameters in fluvial environments. For example, the European Earth Observation Copernicus Programme captures radar and multispectral images at resolutions of up to 10 meters per pixel with a revisit cycle of less than a week (Liang et al. 2024, Radočaj et al. 2020). Multispectral sensors like Sentinel-2 and Landsat 9 record certain spectral band widths. By analysing the spectral reflectance or the combination of multiple spectral bands with indices such as the Normalized Difference Water Index (NDWI) and the Normalized Difference Vegetation Index (NDVI), valuable information

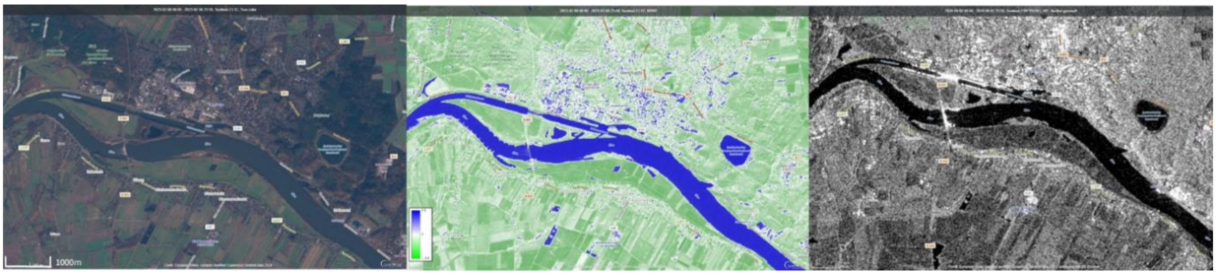

Fig. 1. Comparison of a true-color image (left), a NDWI image (middle) derived from Sentinel-2, and a SAR image (right) from Sentinel-1, showing the Elbe River at Geesthacht, Germany. Copernicus Sentinel-2 imagery was acquired on August 2, 2023, and Copernicus Sentinel-1 imagery on September 2, 2024 downloaded on September 6, 2024. Map data © OpenStreetMap contributors, licensed under the Open Database License (ODbL). Analysis and visualization were conducted in QGIS.

regarding the land cover can be derived. Active sensors, such as the Sentinel-1 Synthetic Aperture Radar (SAR) satellite, have the advantage that their signal can penetrate cloud cover and deliver valuable information also during night-time with high temporal and spatial resolution (see Fig. 1). By analysing the reflectance value, information concerning the surface roughness and the moisture of soil and vegetation can be estimated (Radočaj et al. 2020).

In the field of environmental hydraulics multiple studies have been conducted using satellite imagery data in combination with digital elevation models and artificial intelligence to, for example, estimate sediment transport rates (Kryniecka et al. 2022), extract small water bodies (Sun and Li 2024), and determine vegetation borders (Muir et al. 2024) as well as vegetation characteristics (Fortes et al. 2024), to name just a few recent applications. Especially the latter aspect is of interest for the inclusion of novel approaches for the determination of the flow resistance of flexible foliated vegetation in hydrodynamic models. In this context, Folke (2023) developed a hybrid equation for submerged flexible vegetation by combining the formulas of Järvelä (2004) and Baptist et al. (2007) and showed that it delivered the most accurate results with close proximity to the original formula of Järvelä (2004) compared to other approaches. The equation was also tested in a nature-scale hydraulic simulation with vegetation parameters derived by Airborne Laser Scanning (ALS) during the low vegetation period to create DEMs. Folke (2023) suggested to use image-based solutions to acquire data at high temporal and spatial scales in different vegetation periods to effectively model flooding scenarios and acquire validation data for the hydraulic models based on new vegetation roughness formulas to improve the accuracy in vegetation roughness and flood prediction.

So far, the application of such novel approaches in combination with remote sensing data has been limited in practice and the objective of the present FLW-sub project is therefore to determine the roughness of flexible, foliated riparian vegetation with high spatial and temporal resolution using satellite data. In order to derive required vegetation parameters, it is planned to downscale data from Moderate-resolution Imaging Spectroradiometer (MODIS) for accurate estimates of the Leaf Area Index (LAI) (e.g. Fortes et al. 2024) and ICESat-2 data for accurate vegetation heights (e.g. Xi et al. 2022) via Sentinel-2 data as well as Sentinel-1 data for the latter. This will enable the derivation of vegetation roughness maps with high temporal and spatial resolution that can be used to validate hydraulic simulations on past scenarios and to carry out simulations with, more or less, real time data. This will improve the flood prediction accuracy with benefits in the protection of infrastructure and human lives.

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