Byte and rates: multiple combinations of different remote sensing data for biogeomorphic interaction of river system

Octets et taux : combinaisons multiples de différentes données de télédétection pour l'interaction biogéomorphologique d'un système fluvial

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RÉSUMÉ

Les cours d'eau jouent un rôle crucial dans l'entretien des paysages en transférant de l'énergie, de la matière et des nutriments. Aujourd'hui, la géomorphologie fluviale moderne met l'accent sur l'intégration et la compréhension complexe des relations mutuelles entre les processus fluviaux et l'écologie des plaines d'inondation, en mettant l'accent sur la végétation riveraine. Pour cette étude, le système fluvial tressé et sinueux de la rivière Belá a été choisi pour l'évaluation. Ce système fluvial est un écosystème de zone humide rare et précieux, affecté par la dégradation morphologique et l'incision. Une combinaison d'anciennes images aériennes historiques (1949-2018) d'une précision de 50 centimètres et de données satellitaires modernes à faible résolution (10 mètres) (depuis 2016) a été utilisée pour l'évaluation et le suivi de l'interaction biogéomorphologique. Pour l'extraction des variables environnementales (hauteur au-dessus du canal, morphométrie, couverture végétale), l'étude a utilisé des modèles d'élévation de la surface et du terrain dérivés de données lidar. L'étendue spatiale de la végétation a été classée automatiquement à partir d'images aériennes historiques en noir et blanc (1949-1992), d'orthophotos RGB (2002-2006) et d'orthophotos RGB+NIR (2009-2018). La surveillance et la réponse à l'ajustement géomorphologique ont été analysées sur la base des indices de végétation et d'humidité calculés à partir des données du satellite Sentinel-2. La distribution spatiale des indices de végétation et d'humidité s'est avérée indépendante de la distance par rapport au canal, avec des différences notables observées entre les différentes plates-formes du canal. Les variations saisonnières des indices de végétation et d'humidité ont suivi les conditions hydrologiques locales et la courbe phénologique annuelle.

ABSTRACT

River channels play a crucial role in maintaining landscapes by transferring energy, matter, and nutrients. Nowadays, modern fluvial geomorphology emphasizes the integration and complex understanding of the mutual relationship between river processes and floodplain ecology with an emphasis on riparian vegetation. For this study, the braided-wandering river system of the Belá River was selected for assessment. This river system is a rare and valuable wetland ecosystem affected by morphological degradation and incision. A combination of old historical aerial images (1949-2018) with 50 centimetres accuracy and modern low-resolution (10 meters) satellite data (from 2016) was used for the evaluation and monitoring of biogeomorphological interaction. For extraction of environmental variables (height above the channel, morphometry, vegetation cover), the study used surface and terrain elevation models derived from lidar data. The spatial extent of vegetation was automatically classified from historical black-and-white aerial imagery (1949-1992), RGB orthophotos (2002-2006) and RGB+NIR orthophotos (2009-2018). Monitoring and response to geomorphic adjustment were analysed based on vegetation and moisture indices were calculated from Sentinel-2 satellite data. The spatial distribution of vegetation and moisture indices was found to be independent of the distance from the channel, with notable differences observed across different channel platforms. Seasonal variations in vegetation and moisture indices followed the local hydrological conditions and the annual phenology curve.

KEYWORDS

aerial images, lidar, biogeomorphology, satellite data, monitoring

images aériennes, lidar, biogéomorphologie, données satellitaires, surveillance

1 INTRODUCTION

River channels are key elements for maintaining the landscape by transfer of energy, matter and nutrients, and it is necessary to preserve this unique, diverse ecosystem and the functionality of its services. In the last decades, there has been attention to good conditions of rivers due to the application of the Water Framework Directive (2000/60/EU) for the improvement of surface water status. Several studies pointed out significant increases in global and regional temperatures with negative impacts on natural ecosystems. Further impact of climate change provides complex chains of cause-effect related to altered environmental conditions and stressors in riverine landscapes associated with precipitation and temperature fluxes. Droughts and drying river channels are one of the most significant stressors in the ecosystem. For the identification of adaptation possibilities in vulnerable riverine landscape biotopes, it is essential to recognise complex processes (Geerling et al. 2006) that connect parts of the system (water – morphology- vegetation).

Monitoring and assessment of the riparian vegetation diversity in channel riparian zones during long-time period is challenging (Dufour et al. 2019). There are a number of plant communities in the hydroseries gradient, from aquatic habitats, through grass-herb and shrub to floodplain forests responsive to changes in channel water level and reworked by channel processes (erosion and sediment deposition) and floods. The methodological framework can answer an extensive range of questions and develop planning strategies for restoring rivers and floodplains in constraining legislative frameworks at the national scale. Progress in remote sensing and digital terrain processing allows for a more sophisticated analysis of river channel processes. High-resolution imagery and digital elevation models (DEMs) constructed from LiDAR (light detection and ranging) data provide several clear advantages over previous traditional field methods. Firstly, the area that can be assessed is more extensive. Secondly, the three-dimensional morphology of the bank, floodplain and valley can be mapped at a resolution that can also infer the process. Finally, the volume and rates of different erosion and failure processes over time can be assessed where multi-temporal datasets are available.

A combination of historical aerial datasets and free available Sentinel-2 satellite data provide detailed information for long-term monitoring and identification of habitat types, which are the most supportive for ecosystem functions under alternating conditions in a highly dynamic river landscape system. Remote sensing data will be tested and verified by field survey and classification results. Furthermore, habitat quality status will be compared with field monitoring and complemented by Sentinel 2 data.

2 STUDY AREA

For biogeomorphological interaction, the last multichannel braided-wandering Belá River in northern Slovakia was selected (Fig. 1). The overall length of the river (23.6 km) was used for spatial analyses. The river originated from the Western and High Tatra Mountains and in the Liptovská kotlina Basin confluence with the Váh River. During the 20th century, Belá River underwent significant changes and planform transformation (Kidová et al., 2016; Rusnák et al., 2024). Additionally, is still lateral active with intensive modulation of channel morphology with bank erosion and gravel bars deposition. This led to the transformation of vegetation cover in close proximity to the channel and the succession and rejuvenation of the riparian belt.

Furthermore, forests there are managed by local land communities and State enterprise Forests of the Slovak Republic and with economic use of forests. With its riparian zone, the river system creates a supra-regional importance biocorridor and is included in the NATURA 2000 network. The mean annual discharge for 1964-2006 at the Liptovský Hrádok gauging station is 6.8 $m^3.s^{-1}$.

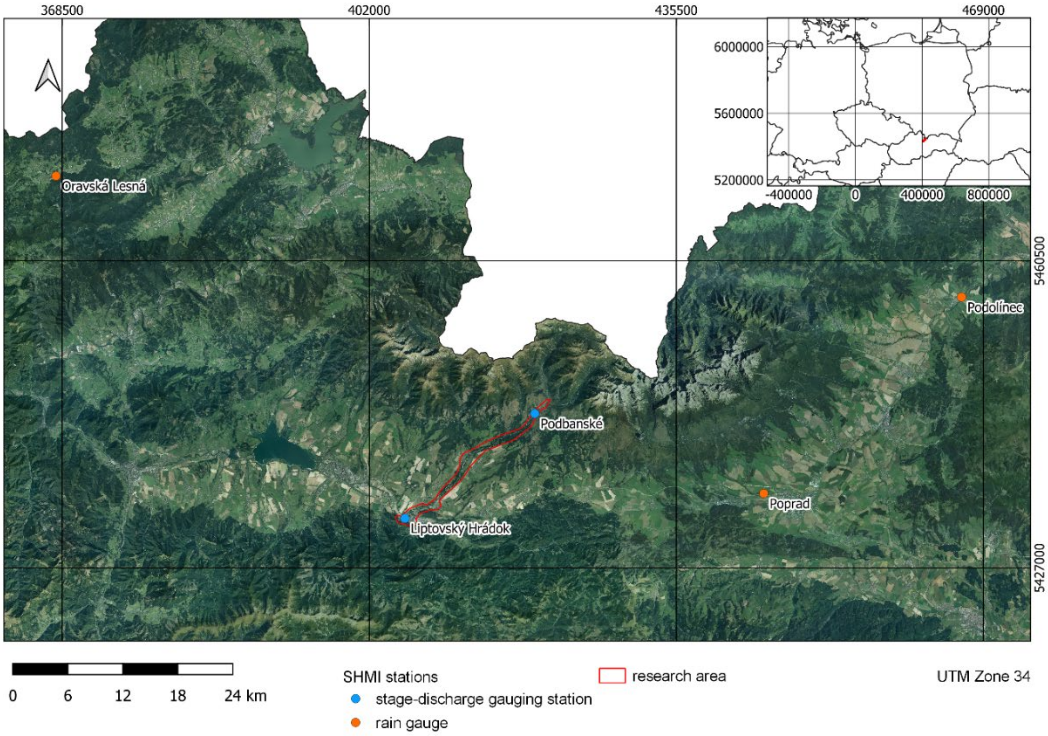

Fig. 1. The Belá River study area localisation

3 METHODS

Three main vegetation classes expressed successional stages in the study area were identified using multiresolution hierarchical classification: gravel bar, young willow and mature riparian forest. Also, 4 main channel planform types were detected: channelised section, avulsion section, single channel and wandering (Fig. 2). The accuracy assessment was performed using the validation matrix generated from 100 m fishnet and containing 942 points. Further, the homogenous riparian zone was detected based on the combination of four spatial units: 1) planform type, 2) distance from the channel, 3) in-channel processes, and 4) vegetation type. Several vegetation indices were calculated for each Sentinel-2 image: NDVI, GRVI, GCI, SIPI, MNDWI, NDWI, and MSI. Zonal statistics for each vegetation index and each satellite scene were performed using the PyQGIS library. For each homogeneous sample, the median value was calculated. If the area of each patch in each satellite image included more than 20% no-data or null-data pixels, that sample was excluded from the dataset for the relevant date.

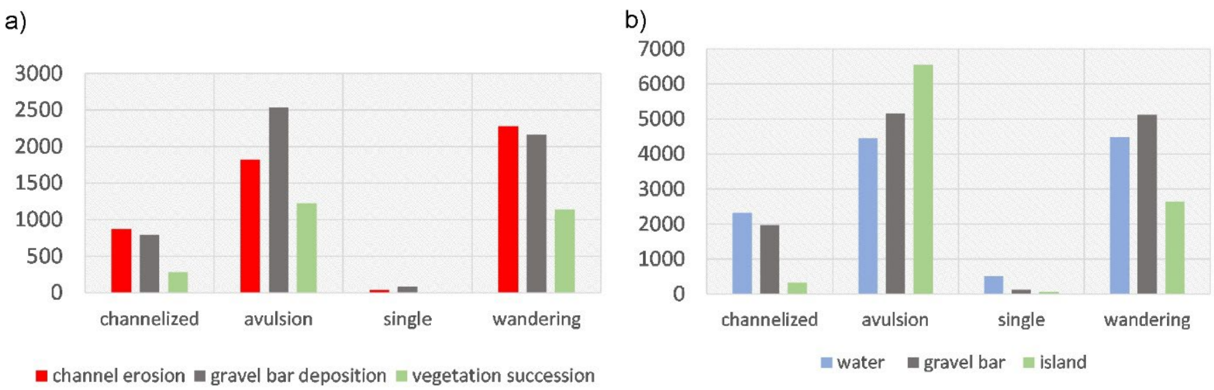

Fig. 2. Differences (in m^2) of in-channel processes (a) and geomorphologic structure (b) in different channel pattern types of the Belá River

4 RESULT AND DISCUSSION

To analyze vegetation change and dynamics, we extract the vegetation types for all studied horizons

During the study period, a gradual increase in vegetation cover was from 310 hectares in 1949 to more than 600 hectares in 2018. The highest increase and development of continuous riparian belts was noted between 1961 and 1986 and decreased after a vegetation windstorm in 2002. Over this time span, the prevailing process of afforestation over deforestation and stable forests that were preserved from previous years continuously increased. In the longitudinal direction, vegetation cover develops differently. In the downstream section, from 0 to 5.5 km, the river is flown throughout an urbanized area with a small expansion of the forest. In the upstream section between 17 and 21.5 km is vegetation development more intensive but limited by valley settings. A significant increase in vegetation is detected between 6 and 17 km (Fig. 3).

Spatial distribution of vegetation and moisture indices are not affected by distance from the channel, and the studied buffer zones reached almost identical values for buffers 50 m, 100 m, 150 m and > 150 m (Fig. 5., 6., 7., 8.). Differences are visible in different channel pattern comparisons. Spatial distribution of VI/MI values reached for wandering and avulsion channel patterns equally. This pattern represents a similar ecosystem with the dynamic river channel, lateral channel movement, and gravel-bar deposition and slightly differs from the other channel types: single and channelised. The seasonal variance of VI and MI follows the phonology curve during the year and local hydrologic conditions.

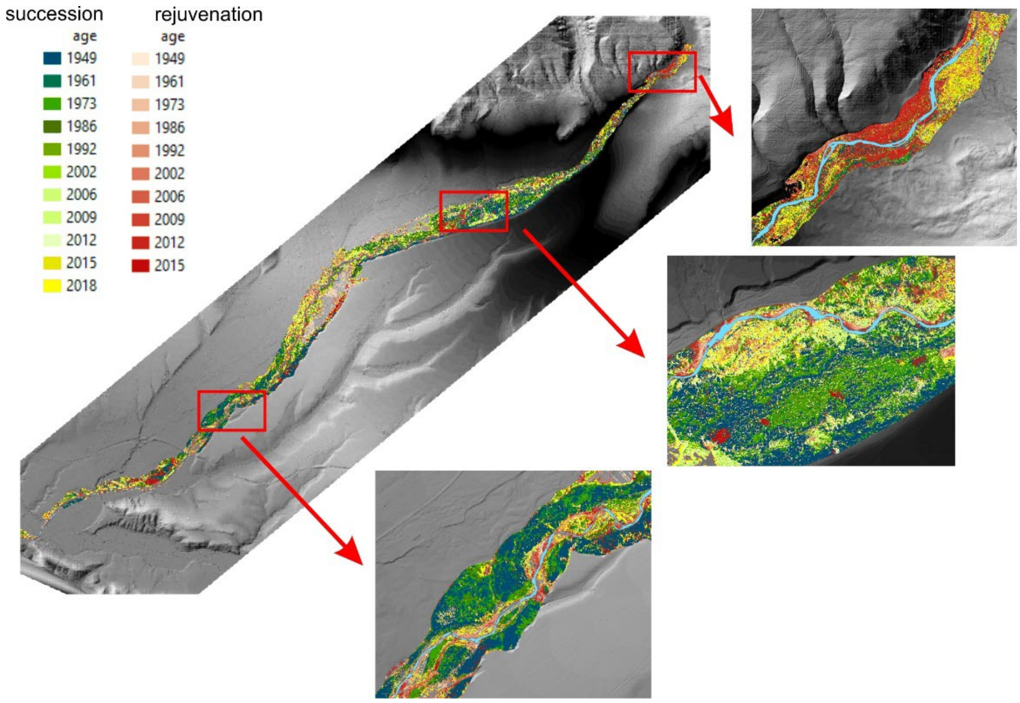

Fig. 3 Spatial distribution of succession and rejuvenation process in Riparian corridor

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