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RIVER CORRIDOR CHANGE DETECTION USING SATELLITE IMAGERY AND LIDAR DATA: A CASE STUDY OF THE SIRET RIVER NEAR CORBU VECHI VILLAGE

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Abstract

The evaluation of river course variations, such as bank erosion, sediment deposition, and the influence of nearby human-made structures, is facilitated by the use of remote sensing data and topographic analysis. These changes result from natural events, such as floods, as well as human activities, including the removal of fertile soil, sand extraction, and deforestation. This study highlights the impacts of these changes on river corridor ecosystems, as well as on the infrastructure and properties located along the watercourse. Continuous changes to the Earth`s surface are driven by both natural and artificial factors, which contribute to the erosion, transport, and accumulation of sediments. Among geomorphological agents, flowing water exhibits a particularly high erosive capacity. A primary objective of this study is to identify these changes, with a secondary focus on providing an overview of the current state of river corridors and bank erosion. To achieve this, the research utilizes remote sensing (RS) techniques and geographic information systems (GIS), along topographic data, to effectively monitor and analyze these transformations.

Key words: *remote sensing, change detection, river, GIS.*

INTRODUCTION

The Earth's surface is constantly changing due to a variety of anthropological, morphological, and atmospheric factors. The ground's surface degradation processes, such as weathering and erosion, are responsible for changes in landform (Aher et al., 2012).

Flooding and erosion naturally alter land use and land cover, leading to land loss, which significantly impacts livelihoods (Hazarika et al., 2015). Flood risk is expected to rise due to climate change, increasing flood frequency and magnitude, along with growing populations and assets in vulnerable areas. This intensifies riverbank erosion and river shifts, threatening nearby communities, causing land loss, displacement, and instability (Kundzewicz et al., 2014; Bodoque et al., 2023).

When the forces holding soil particles together are exceeded by the power of wind and water on the soil surface, it results in the natural process of soil erosion (Spalevic et al., 2020). Soil erosion is an environmental problem affecting the entire globe. Changes in land use across all river basins influence sediment dynamics, soil vulnerability to erosion, and hydrological responses (Sestras et al., 2023).

Rainfall activates the erosion process, impacting soil erosion through both the intensity and volume of precipitation, which subsequently affects the physical and chemical properties of the soil. Furthermore, topography significantly influences surface runoff, with steeper slopes and longer distances enhancing the erosion potential of precipitation, thereby increasing the risk of soil erosion (Costea et al., 2022).

To ensure the effectiveness of management and mitigation strategies, it is important to understand and examine the hydrological events (Bammou et al., 2024).

In Romania, water erosion affects approximately 3.5 million hectares of land, with certain regions in the Subcarpathian Curvature area (Vrancea and Buzău counties) experiencing erosion rates of 30-45 tons per hectare per year. This is in clear contrast to the soil's regenerative capacity, which is only about 3-6 tons per hectare per year (Mircea et al., 2010).

The shape and size of a river are primarily influenced by factors such as the steepness of the slope, water volume, water velocity, and nature of the river (Aher et al., 2012).

River channel changes, including bank erosion, down cutting, and bank accretion, are inherent processes in alluvial rivers. Bank erosion occurs when water erodes the riverbanks, while down cutting involves water activity on riverbed deepening due to erosion. Bank accretion refers to the accumulation of sediments on the banks, leading to the creation of new landforms. These processes are driven by factors such as water flow, sediment transport and deposition, and climate changes (Langat et al., 2019; Dabojani et al., 2014; Yao et al., 2013).

The bank shift of river path is a natural process in fluvial systems, caused by both human activities and climatic factors (Langat et al., 2019).

MATERIALS AND METHODS

Study Area

The primary aim of this study is to identify changes in the river corridor. The area of interest is located near Corbu Vechi village, in Brăila County, as shown in Figure 1, where the Siret River has been monitored from 2016 to 2025 using satellite images from Sentinel 2 RS (Remote Sensing) data. These changes are validated through topographical data collected in February 2025 with a LiDAR (Light Detection and Ranging) sensor mounted on an UAS (Unmanned Aerial System). This approach provides valuable insights into the evolution of river ecosystems over the specified period, offering a detailed assessment of the river's dynamics.

The Siret River, originating in the Northern Carpathians in Ukraine, flows through Romania for a distance of 559 km before merging with the Danube. Its upper course begins in Ukraine, while the middle course passes through the Suceava Plateau and the border between the Moldavian Sub-Carpathians and the Bârlad Plateau. The river's drainage network includes 1,013 water courses, covering 15,157 km, which represents 19.2% of Romania's total river network. With a drainage basin of 44,871 km², the Siret has the largest basin in Romania, covering 18.1% of the country's total area. From its source to its mouth, the river experiences an elevation difference of 1,236 meters (Romanescu et al., 2013).

Figure 1. Siret River near Corbu Vechi village

The area of interest lies in the lower Siret Valley, with elevations between 3 and 60 meters. During the 70's, extensive engineering projects were undertaken to manage frequent flooding and bank erosion, particularly in the floodplain. These efforts included regularizing the river's course and reinforcing its banks (Olariu et al., 2015).

However, over time, the efficiency of these interventions has diminished due to natural processes such as sediment buildup and erosion, along with changes in land use. As a result, the Siret River continues to present challenges, requiring new rehabilitation, development, and reinforcement works, as well as the adaptation of flood control measures to account for climate change and growing human influence.

MATERIALS AND METHODS

Remote sensing is a technique that allows data collection without physical contact with the target, using sensors to capture or analyze different forms of energy, including

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electromagnetic radiation and acoustic signals, as they are emitted, reflected, or dispersed by the object being studied (Yang et al., 2022; Aher et al., 2012; Campbell et al., 2011).

Change detection is the process of finding and evaluating changes in multispectral images that present spatial or spectral variations. It is commonly described as the analysis of two co-registered images of the same geographic region taken at different time periods to detect and evaluate changes over time (Cheng et al., 2024; Goswami et al., 2022).

The area of interest is analyzed using Sentinel-2 satellite data, which provides multispectral imagery with a resolution suitable for identifying changes in the river corridor. For watercourse extraction, the NDWI (Normalized Difference Water Index) is computed, a remote sensing index specialized in detecting and analyzing water bodies. It is calculated based on reflectance in specific wavelengths of the electromagnetic spectrum, specifically the green and NIR (Near-Infrared) bands, according to Gao (1996), or the NIR and SWIR (Short Wave Infrared) bands, according to K. McFeeters (1996), allowing accurate classification of water areas and their differentiation from other surface types, such as vegetation or dry soil.

By integrating satellite-based remote sensing data, the analysis of the Normalized Difference Water Index (NDWI) provides valuable insights into water trends, which can significantly inform decision-making processes. This method helps identify changes in water bodies over time, enabling more effective management strategies (Ghalehteimouri et al., 2024).

The calculation of NDWI and the extraction of information from the obtained results were carried out using GIS (Geographic Information Systems) software, which allowed the analysis and interpretation of spatial data.

GIS and RS are indispensable tools for monitoring and detecting changes in the physical environment, including river dynamics and bank erosion. By utilizing advanced remote sensing technologies and satellite data, these tools enable the tracking of Earth's surface changes, significantly enhancing environmental assessments. Their combined application has revolutionized the way we detect, analyze, and assess environmental transformations, making them essential for sustainable management and decision-making (Ghalehteimouri et al., 2024; Sestras et al., 2023; Bilasco et al., 2021; Aher et al., 2012; Dabojani et al., 2014). Subsequently, remote sensing results from Sentinel-2 were validated in situ through precise topographic information collected with LiDAR technology.

While remote sensing products are commonly used to assess planform changes (2D), they often neglect vertical changes (3D). However, evaluating both planform and vertical changes is essential for understanding morphological transformations. By incorporating spatio- temporal aerial imagery along with topographic data, remote sensing becomes a valuable tool for assessing changes in rivers morphology, providing a more comprehensive picture of the river system's dynamics (Andualem et al., 2024).

LiDAR sensors represent the next generation of efficient and precise land surveys. Aerial and satellite mapping, such as photogrammetry and airborne LiDAR, have greatly improved land surface elevation sampling. Traditionally, topographic data was gathered through ground surveys using total stations, GPS (Global Positioning System), or other GNSS (Global Navigation Satellite System) tools. However, this method can be time-consuming, particularly in complex topographic areas (Sestras et al., 2025; Ouédraogo et al., 2014).

Data processing and spatial analysis were performed using Romania's national projection system Stereographic 1970. The utilized workflow is presented in Figure 2 and includes several essential applications for data downloading, processing, and analysis.

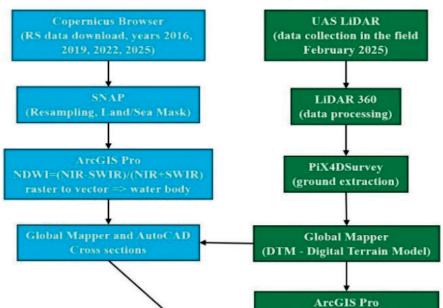

Figure 2. The workflow for satellite imagery and LiDAR data

For downloading satellite RS data, the open-source platform Copernicus Browser was used. Later, for processing the remote sensing data, the applications SNAP and ArcGIS Pro were utilized. After calculating the remote sensing indices, the analysis of the resulting vector data was performed using the applications GlobalMapper and AutoCAD for generating cross-sections. The second part involved collecting 3D data using a system composed of the DJI Matrice M200 PPK drone, equipped with the Topodrone LiDAR 200+ Hesai sensor. Flight processing and the generation of point cloud data were carried out using Topodrone PostProcessing and LiDAR 360. Subsequently, the data was filtered to obtain the necessary ground data for creating the DTM (Digital Terrain Model) using GlobalMapper. Finally, the DTM was used for spatial analysis in ArcGIS Pro.

RESULTS AND DISCUSSIONS

The Siret sector from Movileni to its confluence with the Danube, where the area of interest is situated, faces exceedances of flood protection works, as it is entirely embanked. Rising water levels are sometimes aggravated by a backflow effect from the Danube, which can contribute to an additional rise in water levels in certain sections of the Siret River. In this context, confluence areas, such as those where the Siret meets major tributaries, are exposed to flooding from both the Siret and its tributaries. At the same time, in this sector, the Siret is also affected by phenomena such as bank erosion, as can be observed in Figure 3.

Figure 3. Bank erosion Siret River near Corbu Vechi village - February 2025

To analyze the changes that occurred, Sentinel 2 images for the dates of 4 December 2016, 4 December 2019, 28 December 2022, and 13 february 2025, were downloaded. These images were processed by applying the resampling command in the SNAP software to bring the spatial resolution of all spectral bands to 10 meters. The images were then cropped to focus on the study area, and the NDWI was calculated using ArcGIS Pro. This generated raster images of the index, with values ranging from -1 to 0 indicating areas with bare soil or covered with vegetation without water, while values between 0 and 1 identified water-covered regions.

In Figure 4 and Figure 5, the NDWI index for the years 2016 and 2025 is shown, covering the same area over a span of 9 years. By comparing the two images, changes in the distribution of water and vegetation can be observed.

By comparing the two images, the phenomenon of bank erosion and the process of sediment deposition or accumulation along the river course can be observed, indicating a dynamic evolution of the river during the analyzed period.

The next step involved extracting the water body from each image using the NDWI index calculated for each year. These water bodies were then overlaid to allow the comparison and analysis of changes in the distribution of water over the studied period.

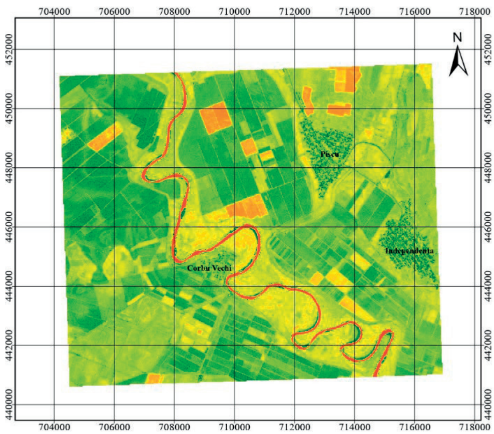

Figure 4. The Normalized Difference Water Index for the year 2016 (red - water bodies, orange and yellow - vegetation and surfaces with moisture content, light and dark green - bare soils and built-up areas)

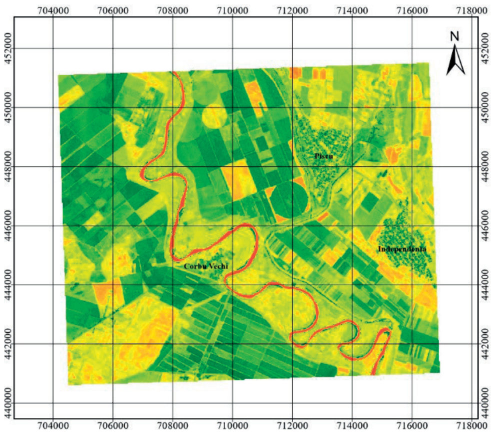

Figure 5. The Normalized Difference Water Index for the year 2025 (red - water bodies, orange and yellow - vegetation and surfaces with moisture content, light and dark green - bare soils and built-up areas)

A closer look reveals the dynamics of the changes that have occurred along the river course, an aspect highlighted in Figure 6. These changes occurring in the water bodies are caused by bank erosion and sediment deposition, which have led to shifts in the river's path.

Figure 6. Spatio-temporal changes in water bodies between 2016-2025 based on NDWI Index

In Figure 7, the evolution of the Siret River between 2016 and 2025 is illustrated using different colors to represent the river's path each year. The river exhibits significant lateral migration over this period, with visible zones of bank erosion and sediment deposition occurring along various segments of its meandering course. These geomorphological processes are primarily governed by the highly sinuous morphology of the Siret River in this sector, where the channel forms pronounced meanders. The observed pattern of bank erosion on the outer curves and sediment deposition on the inner curves is consistent with classical fluvial dynamics described in meandering river systems. In such systems, higher flow velocities on the outer bends lead to increased erosive forces, while lower velocities on the inner bends favor sediment accumulation. This natural mechanism of lateral channel migration contributes to the continuous reshaping of the river corridor over time.

Figure 7. Water bodies dynamics between 2016-2025 based on NDWI Index (orange - 2016, green - 2019, red - 2022 and blue - 2025)

The raster data of water bodies were converted into vector data in polygon format, enabling more accurate analysis and representation. Using Global Mapper and AutoCAD software, 12 cross-sectional profiles were generated along the 27.5 km length of the river course under investigation, as shown in Figure 8.
These cross-sections facilitated the extraction of river width at each specific location. The resulting data, which highlight the variations in the river's morphology along the analyzed stretch, are presented in Table 1.
Based on Table 1 it can be concluded that the studied area exhibits changes in certain profiles. For example, cross-section 2 maintains a relatively consistent width throughout the studied period, with only minor variations. This data can be correlated with Figure 9, where the changes observed in the river’s course are influenced by the linear flow of the Siret River and the presence of forest belts along the banks.

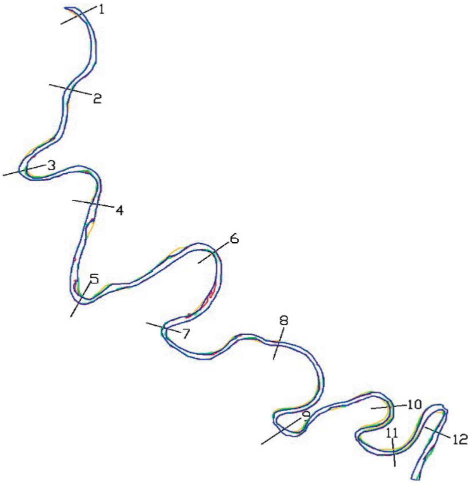

Figure 8. Cross-section of water bodies created in AutoCAD

Table 1. Variation in Siret River width from 2016 to 2025 in the studied area obtained from water bodies cross-sections

Cross section	2016 width (m)	2019 width (m)	2022 width (m)	2025 width (m)
1	112.75	77.17	88.62	89.19
2	107.51	103.23	108.11	105.68
3	151.06	112.44	136.66	144.19
4	116.26	116.32	106.89	106.34
5	150.25	154.56	146.8	138.84
6	95.59	48.88	76.27	78.3
7	91.74	85.75	77.36	69.67
8	86.22	74.86	79.41	74.93
9	92.02	84.87	94.05	88.58
10	71.00	63.95	74.04	73.6
11	98.11	58.27	54.26	56.9
12	107.69	103.24	101.5	92.04

Figure 9. Cross-section 2

The linear flow of the river, characterized by its relatively straight course in this section, contributes to some degree of erosion and sediment deposition. However, its effects are less pronounced compared to areas with more pronounced meanders. The forest belts, on the other hand, provide some stabilization to the riverbanks by acting as a natural barrier against water-induced erosion. While these forest belts can reduce bank erosion to a certain extent, their impact remains limited.

In contrast, cross-section 6 shows major changes, and when correlating the data with Figure 10, it can be concluded that cross section 6 is located on a river meander, where the phenomena of transportation and deposition of alluvial materials occur.

Figure 10. Cross-section 6

Aerial LiDAR data collected was conducted in the areas corresponding to cross-sections 5 and 7. Based on the LiDAR data, the ground was filtered, serving as the basis for vectorizing the necessary elements to create the topographic plan for these areas, as can be seen below in Figure 11.

Topographic observations were requested in these zones due to the execution of bank protection works; however, both upstream and downstream of these riverbank stabilization interventions, the phenomenon of erosion continues to persist. To better understand the effectiveness and impact of the stabilization works, aerial LiDAR data collection was conducted in the areas corresponding to cross-sections 5 and 7. These data were collected by the company BDS Topografie, which subsequently developed detailed 2D and 3D digital topographic plans. The plans were based on high-resolution LiDAR information gathered on-site, complemented by bathymetric surveys conducted in the same areas.

Figure 11. Topographic plan

The purpose of these data acquisitions was to assess how water interacts with and affects the implemented bank protection measures in these specific zones along the Siret River. The LiDAR-derived point clouds enabled the generation of a high-precision DTM for both areas. This DTM served as foundational tool for analyzing topographic variation and hydrodynamic behavior within the river corridor. In addition, the LiDAR data provided confirmation and refinement of the information obtained through remote sensing analyses, ensuring a multi-source validation of geomorphological changes. All geospatial outputs, including the DTM and topographic plans, were delivered to the project beneficiary to support further assessment and monitoring of the stability and effectiveness of the bank protection works.

Based on the data collected through LiDAR technology and bathymetric surveys, DTM was generated, as shown in Figure 12.

For cross-section 5, which shows a water body width of 138.84 meters according to NWDI, the LiDAR data indicates a width of 152.80 meters. In the case of cross-section 7, where NDWI indicates a width of 69.67 meters, the LiDAR data shows a width of 83.69 meters. The values are close, the data collection periods also being similar, with only a one-week difference between the LiDAR and remote sensing data. However, it should be noted that the remote sensing data have a spatial resolution of 10 meters, which may influence the accuracy of the output.

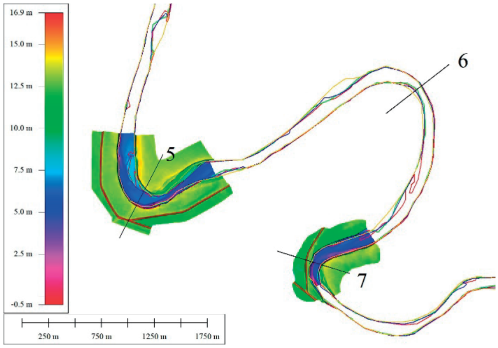

Figure 12. DTM based on LiDAR data

The Digital Terrain Model was imported into ArcGIS Pro for detailed analysis of the slope characteristics within the study area. Through this analysis, regions with higher risk were identified and marked in red as can be observed in Figure 13.

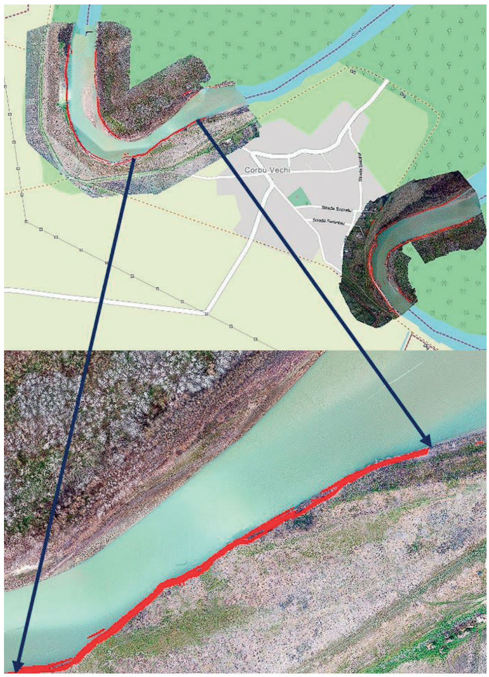

Figure 13. Slopes with an inclination between 30 and 70 degrees - with color red

These areas, where the slope of the riverbank ranges from 30 to 70 degrees, extend over approximately 2,115 meters on the DTM near the cross-section 5 area and around 1,350 meters in the vicinity of cross-section 7, as determined through slope length calculations performed in ArcGIS Pro. These zones were flagged as particularly vulnerable, specifically, for slopes between 30 and 50 degrees, it is typically recommended to implement bank stabilization measures. These include the installation of protective mesh, as well as the planting of trees, shrubs, and other vegetation to help secure the soil and prevent further erosion. For areas where the slope exceeds 50 degrees, the erosion risk is significantly higher, and more solid engineering solutions are required. In these situations, it is necessary to construct retaining walls, gabion baskets, stone revetments, or even apply concrete to the embankment to stabilize the slope effectively. These engineering measures provide structural support to prevent soil movement and mitigate the long-term risk of erosion, ensuring the durability of the riverbank in the face of continuous environmental pressures.

The slope analysis aligns with the study's main objective outlined in the title and abstract, detecting changes within the Siret River corridor using satellite imagery and LiDAR data. By identifying steep riverbanks ranging from 30 to 70 degrees near cross-sections 5 and 7 based on the DTM, the study highlights areas with elevated erosion risk. These results also support the secondary objective stated in the abstract: providing an overview of the current condition of the river corridor and assessing riverbank stability. Steep slopes significantly influence erosion processes and increase the likelihood of landslides. The use of the Digital Terrain Model enables a detailed spatial assessment of these vulnerabilities, while satellite imagery facilitates the evaluation of changes over time in a spatio-temporal context. These analyses enhance the study's value in detecting changes and evaluating current geomorphological conditions, while also identifying high-risk areas to guide effective mitigation strategies.

CONCLUSIONS

River channels undergo morphological changes due to both human activity and natural processes. Remote sensing and remote sensing indices, particularly the NDWI index applied in this study, provide valuable tools for monitoring and understanding the dynamics of river flows. By using satellite image archives spanning several years or even decades if past satellite missions are considered, these techniques offer a quick and cost-effective means of monitoring changes in water bodies over extended periods.

In the case of the Siret River, the NDWI index was used to track variations in the river's width, which were essential for identifying events like erosion and sediment deposition. With a spatial resolution of 10 meters, the satellite data proved sufficient for this type of study. These satellite data were subsequently verified with topographic information collected using LiDAR technology.

The integration of GIS in processing and analyzing satellite data, combined with LiDAR data, represents an effective approach to extracting and integrating information on the changes occurring in the river course over time. These tools are essential for evaluating risks and identifying vulnerable sections of the riverbanks. For example, in the areas corresponding to cross-sections 5 and 7, detailed topographic observations were carried out. The LiDAR data, collected just one week prior to the satellite data, confirmed and enhanced the initial observations made through remote sensing, providing a comprehensive understanding of the river's dynamics and morphology in these areas. Sustainable management of water resources and safeguarding infrastructure from natural hazards depends on understanding the dynamics of river courses, especially hydrological events such as erosion and sediment deposition. In the case of the Siret River, the combined study of LiDAR data and RS has revealed how the riverbanks have evolved over time.

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