GeoTerrace-2026-002

Geospatial modeling of sand extraction potential based on integrated topographic and bathymetric surveys: a case study for the Dnipro river near Vyshhorod in the Polissia region of Ukraine

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SUMMARY

Sustainable management of river sand resources requires accurate spatial information to support environmental monitoring and rational natural resource using. This study addresses the problem of assessing sand extraction potential within river channels through the integration of topographic-geodetic and bathymetric survey data. The research was conducted at the "Vyshhorodska" sand deposit located in the Dnipro River channel near Vyshhorod, within the Polissia region of Ukraine. The methodology was based on integrated geospatial surveying using a Hi-Target V100 GNSS receiver operating in RTK mode and a Lowrance Hook4 echo sounder for bathymetric measurements. Spatial coordinates and depth data were processed using Topcon Tools, SonarViewer, and GeoniCS 13 for AutoCAD. A total of 32 control points and 8,493 survey points were collected across an area of 270.7 ha. The acquired datasets were integrated to develop high-resolution digital terrain and riverbed models and to create a large-scale topographic plan of the study area. The results revealed significant spatial variability of riverbed morphology and enabled the identification of areas suitable for sand extraction. The most promising deposits were found in the central part of the channel, where stable bottom forms, moderate depths, and low flow velocities favor sustainable extraction activities. The developed geospatial models also facilitated the delineation of environmentally sensitive zones where extraction should be restricted. The study confirms that integrated topographic and bathymetric surveys provide reliable geospatial information for environmental monitoring, resource assessment, and decision support. The resulting digital models can be effectively applied for planning extraction operations, monitoring riverbed dynamics, and promoting sustainable management of river sand resources.

Keywords: geospatial modeling; natural resources; assessment; bathymetric surveying; digital model; GNSS measurements; environmental monitoring; GIS.

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Introduction

The increasing demand of the construction sector for mineral resources highlights the importance of sustainable management of river sand deposits and environmentally responsible natural resource use. River sand extraction remains an important source of raw materials for infrastructure development. However, intensive mining activities may cause significant changes in river channel morphology, accelerate bank erosion, alter sediment transport processes, and negatively affect aquatic ecosystems. Sciences studies by Kondolf, G. M. (Kondolf, 1997), Hackney C. R., Vasilopoulos G., Heng S., Darbari V., Walker S., Parsons D. R. (Hackney et al., 2021), demonstrated that continuous monitoring of riverbed dynamics is essential for balancing resource utilization and environmental protection. In the context of environmental monitoring, geospatial technologies play a crucial role in collecting, processing, and analyzing spatial information related to riverine environments. The integration of GNSS surveying, bathymetric measurements, GIS applications, and digital terrain modeling provides high-quality spatial data that can support natural resource assessment, environmental analysis and for sustainable environmental (Caballero et al., 2020; Falcao et al., 2016; Klemas, 2011; Moskalenko, 2024; Rokochinskiy et al., 2021).

Therefore, this study aims to develop a geospatial model of the Dnipro River channel based on integrated topographic-geodetic and bathymetric surveys and to evaluate the potential of sand extraction using GIS-based spatial analysis. The resulting geospatial database and digital models can serve as an effective tool for environmental monitoring, resource management, and decision support in sustainable riverbed utilization (Moskalenko, 2024).

The study area covers the “Vyshhorodska” sand deposit located approximately 1.5 km southeast of Vyshhorod city within the Dnipro River channel surrounding Velykyi Island, in Vyshhorod District of Kyiv Region, within the Polissia region of Ukraine. This territory represents a valuable river sand resource and requires detailed spatial assessment to ensure environmentally sustainable extraction practices (Fig. 1).

Figure 1. *Spatial position of study area and extent of the Vyshhorod sand deposit in the Dnipro river (Google Maps 50°34'11.05" N, 30°33'50.54" E)*

Method and Theory

The assessment of sand extraction potential was based on the integration of topographic-geodetic and bathymetric surveys within the “Vyshhorodska” sand deposit located in the Dnipro River channel near Vyshhorod, Kyiv Region, Ukraine. The methodology involved the acquisition of spatial data describing both the water surface and underwater relief, followed by the development of a unified geospatial model of the study area. Such an approach enables comprehensive characterization of riverbed morphology and provides a reliable basis for evaluating the distribution and extraction potential of sand deposits.

Topographic-geodetic surveys were carried out using a Hi-Target V100 GNSS receiver operating in real-time kinematic (RTK) mode. The study was conducted within the "Vyshhorodska" sand deposit, which covers an area of 270.7 ha in the Dnipro River channel near Vyshhorod, Kyiv Region, Ukraine. GNSS observations were performed to determine the spatial coordinates of characteristic points distributed throughout the study area. A total of 32 survey points were established and measured, providing a sufficient spatial framework for the subsequent integration of topographic and bathymetric data. All measurements were referenced to the Ukrainian Spatial Reference System USK-2000, ensuring compatibility with national geospatial datasets and engineering surveying standards. The acquired coordinates were used to define the boundaries of the investigated area, characterize shoreline geometry, and support the development of a detailed topographic base. The obtained GNSS measurements provided a reliable planimetric and elevation framework for the creation of a large-scale topographic plan and ensured accurate spatial referencing of bathymetric observations within a unified coordinate system. The high positional accuracy achieved through RTK technology contributed to the generation of consistent geospatial datasets required for digital terrain modeling, riverbed analysis, and the assessment of sand extraction potential (Fig. 2).

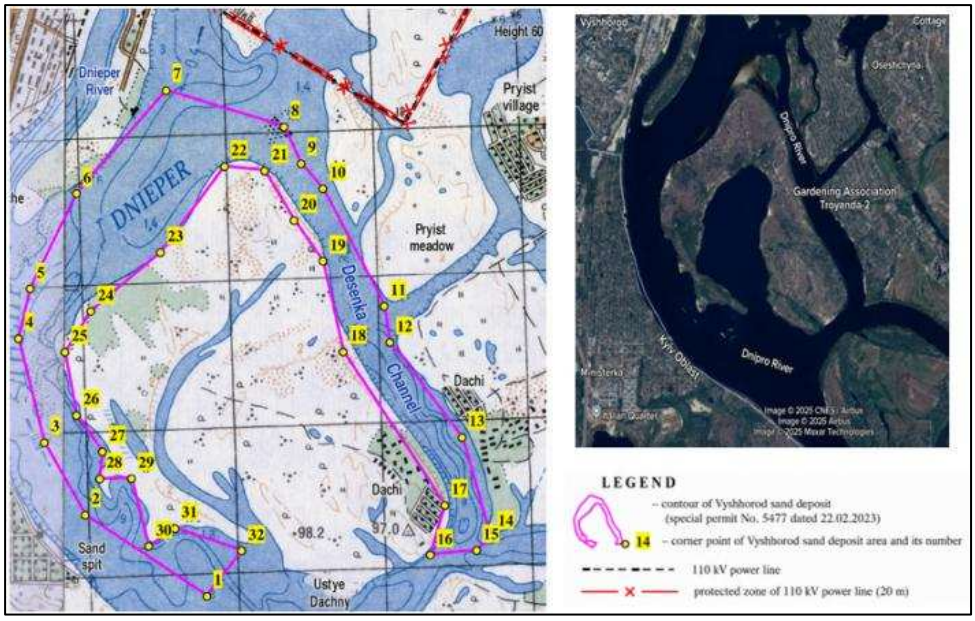

Figure 2. *Control points of the Vyshhorod sand deposit in the Dnipro river (Google Maps 50°34'11.05" N, 30°33'50.54" E)*

Bathymetric surveying of the river channel was performed using a Lowrance Hook4 echo sounder installed on a survey boat. Depth measurements were collected along a system of longitudinal and transverse survey profiles covering the investigated water area. The acquired bathymetric data were used to characterize the underwater topography and identify local variations in riverbed morphology associated with sediment accumulation and redistribution processes. The GNSS observations were processed using Topcon Tools software, while bathymetric data were processed and visualized in SonarViewer (Fig. 3).

Analysis of bathymetric profile data obtained in the SonarViewer software based on echo sounding results showed significant variability of the bottom relief in the studied section of the Dnipro River. The profile clearly shows the lowering and raising of the bottom, which indicates the presence of channel relief forms characteristic of areas of accumulation and redistribution of sand deposits. The recorded depths vary within the range of about 7 to 10 m, which indicates the uneven morphological structure of the channel.

The integration of topographic and bathymetric datasets was performed in GeoniCS 13 for AutoCAD, which enabled the generation of a digital terrain model (DTM) and a digital riverbed model of the study area. Based on the resulting three-dimensional geospatial model, contour lines, elevation surfaces, and

bathymetric maps were generated. The developed geospatial database and digital models served as the basis for spatial analysis of the riverbed morphology and assessment of sand extraction potential. The integrated use of GNSS and bathymetric surveying (by the Lowrance Hook4 echo sounder) technologies ensured a high level of spatial detail and data consistency, providing reliable information for environmental monitoring, resource management, and planning of sustainable extraction activities within the Dnipro River channel.

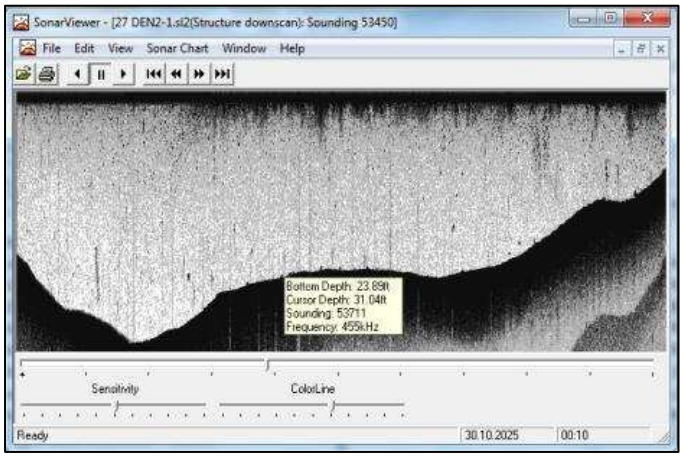

Figure 3. *Control points of the Vyshhorod sand deposit in the Dnipro river*

Results

Generated topographic plan of the "Vyshhorodska" study area, based on the results of integrated topographic-geodetic and bathymetric surveys (Fig. 2). The plan reflects the spatial distribution of bathymetric contours of a riverbed, allowing detailed visualization of the riverbed morphology and identification of areas characterized by sediment accumulation and channel relief variability. The high density of contour lines indicates significant changes in bottom topography and confirms the complexity of the geomorphological structure of the investigated river section (Fig. 4).

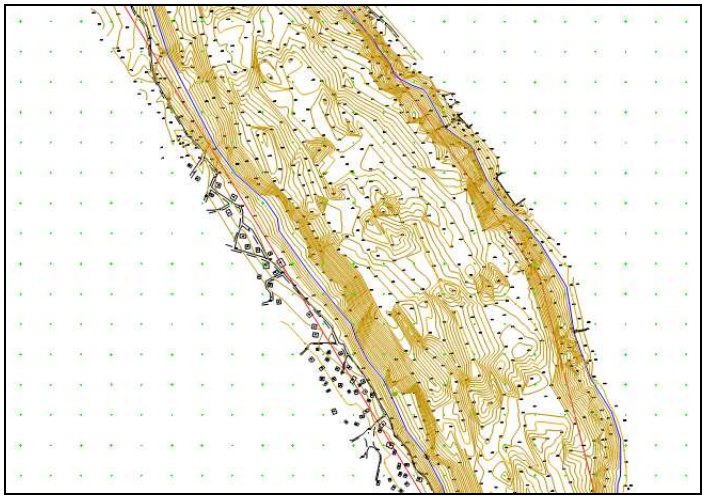

Figure 4. *Fragment of the topographic plan of the "Vyshhorodska" sand deposit created from integrated GNSS and bathymetric survey data*

A total of 8493 picket points were collected within the study area of 270.7 ha, ensuring a high density of spatial observations and reliable representation of both the terrestrial and underwater terrain. The obtained dataset provided a robust basis for generating a digital terrain model and performing subsequent geospatial analyses. Such a detailed spatial framework significantly improves the accuracy of riverbed interpolation, supports the assessment of sand extraction potential, and serves as a valuable source of information for environmental monitoring and sustainable management of river resources.

Conclusions

The conducted topographic-geodetic and bathymetric surveys demonstrated the effectiveness of integrated geospatial technologies for assessing the sand extraction potential of riverbed deposits. Based on GNSS measurements and echo-sounding data, a high-resolution digital terrain and riverbed model was developed for the "Vyshhorodska" sand deposit located within the Dnipro River near Vyshhorod. A total of 8,493 survey points were collected across an area of 270.7 ha, providing a dense spatial dataset for accurate interpolation of riverbed morphology and detailed geospatial analysis. The resulting models enabled the identification of areas characterized by favorable geomorphological conditions for sand extraction and provided a reliable basis for evaluating the spatial distribution of riverbed sediments. The study confirmed that integrated topographic and bathymetric surveying represents an efficient approach for environmental monitoring, natural resource assessment, and GIS-based decision support in riverine environments.

The analysis of the digital riverbed model revealed that the most promising sand deposits are concentrated within the central part of the channel, where water depths range from 4 to 6 m and flow velocities remain relatively low (0.2–0.3 m/s). These areas are characterized by stable bottom morphology and a low risk of shoreline erosion, making them suitable for sustainable extraction activities. At the same time, several zones were identified where extraction activities should be restricted or prohibited, including the nearshore zone, areas affected by hydraulic disturbances downstream of the Kyiv Hydropower Plant, and sections hydraulically connected with groundwater systems near Osechyna village. The developed geospatial database provides a practical framework for planning extraction operations, positioning dredging equipment, and implementing environmental monitoring programs. Regular topographic and hydrographic surveys, integration of spatial data into GIS environments, and continuous monitoring of riverbed dynamics and water quality are recommended to ensure environmentally responsible and sustainable utilization of sand resources within the Dnipro River channel.

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