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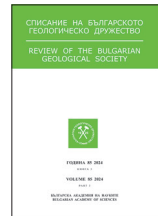
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Roughness analysis of the riverbed in the study of torrential events using terrestrial photogrammetry data

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Анализ на грапавостта на речното легло при изследване на поройни явления с използване на данни от наземна фотограмметрия

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Abstract. This study examines the riverbed in the lower course of the Damdere River in the Eastern Rhodope Mountains (southern Bulgaria), a region prone to torrential flow events. Two field campaigns were carried out – in October 2023 and October 2024, employing terrestrial photogrammetry to generate high-resolution 3D point clouds for the computation of geometric features of the riverbed. Using CloudCompare open source software, roughness values were calculated from the photogrammetric data and compared with manually measured sediment “b” axis values. Results show that maximum roughness values were higher in 2024, but more significant spatial variability of the roughness across the test site is observed at the 3D point cloud of 2023, likely reflecting sediment transport due to torrential flows. These findings suggest that in the absence of rain gauges, sediment size, and roughness data serve as viable indicators of torrential activity, with local rainfall patterns supporting erosion and sediment displacement.

Keywords: roughness, riverbed, grain size, photogrammetry.

Introduction

Torrential events, such as torrential floods and debris floods, are hazardous hydro-geomorphic phenomena characterized by sudden onset and specific hydrologic and sediment regimes. Typically occurring in mountainous areas, they are triggered by heavy rainfall or rapid snowmelt and are influenced by the region’s geological and geomorphological features, vegetation, and land use. Understanding debris floods is essential for effectively planning and implementing prevention and mitigation measures. The roughness analysis of a riverbed is an important part of hydrological and hydraulic studies

and gives information about the distribution of the sediments (Vázquez-Tarrío et al., 2017; Flatley et al., 2022). The grain size distribution indicates the dynamic of the sediment transport, the type of the flow, and the deposition conditions (Steer et al., 2022). This analysis requires extensive and time-consuming field measurements. For large clasts, a big volume of deposits should be analyzed on the field and taken for laboratory work. This directs the research to the application of geospatial technologies in data acquisition and analysis of torrential flows. In this relation, the current study aims to evaluate the roughness of the riverbed as an indicator of sediment transport and deposition based on

3D point cloud data derived from terrestrial photogrammetry. The applied methodology enables high-accuracy analysis of riverbed changes and sediment transport, accessing thousands of grains across large areas in a manageable time.

Data and methods

The study area focuses on the lower course of the Damdere River in the Eastern Rhodopes Mountains, southern Bulgaria (Fig. 1), which frequently experiences torrential events. Covering approximately 39 km², nearly 48% of the catchment has slope gradients greater than 15° (Nikolova et al., 2021), facilitating rapid runoff into the riverbeds. The watershed's diverse petrographic composition includes mainly biotite gneisses in the upper and middle sections and metagranites, limestones, and volcanic-sedimentary complexes in the lower section (Sarov et al., 2007a, 2007b). The region is characterized by alternating wet (winter) and dry (summer) periods, further contributing to the occurrence of torrential events.

The present study includes two field campaigns for terrain data acquisition – in October 2023 and October 2024. The selected part of the riverbed was captured using the photogrammetric method with a Sony Alpha A7R IV digital camera featuring a full-frame sensor. It is equipped with an updated 61MP Exmor R BSI CMOS sensor and an improved BIONZ X image processor. Targets with fixed spacing were used to accurately determine the model's metric scale. The capture was done from all sides and various positions, with the camera tilted between 80° and 60°, at distances from the object ranging from 1.2 m to 3.5 m. The capabilities of close-range photogrammetry were used to generate point clouds with a relative accuracy of 0.5×10^{-3} m, aligned in position based on GNSS measurements for the two data acquisition time moments. Peripheral areas of the point clouds with the highest error values were removed, and points with low reliability in determination were filtered out.

For the analysis of the riverbed, both 3D point clouds were processed in CloudCompare open source software, v. 2.14.alpha to compute the roughness of the selected test sites. This parameter represents the distance between each point and the best-fit plane of its neighboring points. The local neighborhood radius was set to 0.2 based on the gravel size in the riverbed. The computation was done in all directions, without assigning up direction vector, considering the features of the riverbed. Both point clouds are very similar in area, with the number of points being 3 438 720 for the 2023 cloud and 3 187 668 for the 2024 cloud. To compare the results from the photogrammetric data, the inter-

mediate axis “b” of the clasts was measured for randomly selected gravels every 40 cm, with one piece on each side of two 10-meter lines in the test area.

Results and discussion

The computed roughness values are presented in Figure 1 and Table 1. The results indicate a slightly higher maximum roughness in the 2024 data than in the 2023 data. These values are distributed differently across the test site for each data acquisition period. The uneven roughness distribution suggests sediment transport through intermittent or torrential water flow, with a notably more irregular distribution observed in the 2023 data. Overall, areas with a roughness index of up to 0.01 m predominate, accounting for 52.01% of cases in the 2023 data and 70.66% in 2024. The higher prevalence of low-roughness areas in 2024 suggests either a reduction in sediment transport intensity or a shift in flow patterns that favor smoother sediment deposition in the observed areas.

The roughness results derived from terrestrial photogrammetry data align with the manually measured “b” axis of sediment clasts. Although this axis does not directly reflect surface elevation, previous research demonstrates a strong correlation between the “a” and “b” axes and roughness values derived from 3D point clouds (Heritage, Milan, 2009). A slightly higher coefficient of variation in the size of the intermediate axis of clasts was observed in the 2023 data (Table 1). This increased grain size variation, along with higher roughness values, points to a temporary and turbulent flow regime. The extremely high values of the roughness are single cases and can be ignored.

In the absence of rain gauge stations in the Damdere River catchment, changes in sediment size and riverbed roughness can be used as indicators of tor-

Table 1. Roughness values and statistical parameters of manually measured grains

Parameter	2023	2024
Roughness (m) – 3D point cloud		
0.00 – 0.01	52.01	70.66
0.01 – 0.02	31.39	22.33
0.02 – 0.03	11.2	5
0.03 – 0.04	3.41	1.42
0.04 – 0.05	4.65	0.39
0.05 – 0.09	0.75	0.2
> 0.09	0.009	0.005
Manually measured grains axis “b” (mm)		
Average	42.2	54.50
Stand. dev.	28.11	30.61
Coeff. of variation	66.6	56.16

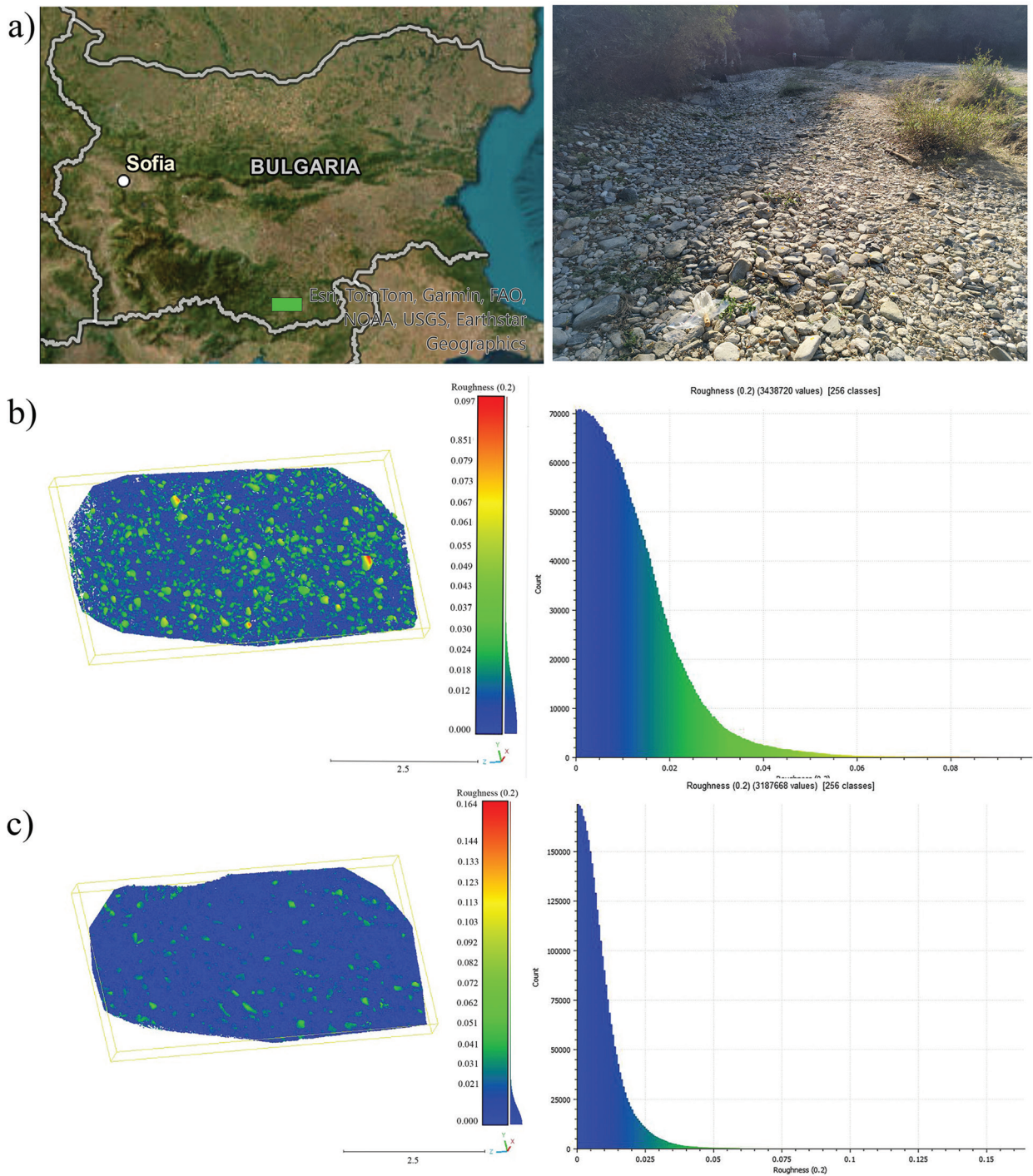


Fig. 1. Study area and riverbed roughness derived from terrestrial photogrammetry point cloud: *a)* geographical location and view of the test site (October 2024); *b)* roughness values based on the data of October 2023; *c)* roughness values based on the data of October 2024

rential events. Data from nearby meteorological stations (Kardzhali and Dzhebel), within a radius of approximately 30 km, show high rainfall erosivity (Nikolova et al., 2021, 2024). This high erosivity is a crucial factor that influences sediment transport dynamics, as it can lead to the mobilization of various grain sizes. As sediment is transported during

intense rainfall events, the grain size may vary significantly, leading to a shift in riverbed roughness.

Conclusion

The analysis reveals a slightly higher maximum roughness in the 2024 data compared to 2023, with

distinct distribution patterns across the test site for each period. Although the differences in the roughness are not high, the uneven roughness distribution indicates sediment transport driven by intermittent or torrential flow, with the 2023 data exhibiting a notably more irregular pattern. The advent of terrestrial photogrammetry offers an efficient and accurate tool for acquiring high-resolution data for analysis of torrential flows based on the features of the riverbed and grain size of the deposits.

The results of the present study give insights into the relation between the sediment size and the roughness of the riverbed and contribute to a better understanding of the sediment dynamics in ungauged watersheds.

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