

Development of erosion prediction tool for sustainable soil management

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Deliverable D1.2

Aerial and terrestrial surveying

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1 Introduction

This report provides a detailed description of sub-activity 1.2 (WP1 (Study of selected catchment, field campaigns, and sample analyses), titled "Aerial and terrestrial surveying". This sub-activity plays a critical role in the overall development of the Predict-Er tool by contributing high-resolution geospatial datasets and terrain models essential for accurate environmental modeling, hydrological analysis, and erosion risk assessment.

One of WP1's objective is to generate high-resolution datasets from the study catchment, which are used either directly or modeled to enhance the tool's analytical capabilities. The approach integrate aerial remote sensing using Unmanned Aerial Vehicles (UAVs) equipped with LiDAR sensors and multispectral cameras, alongside terrestrial-based data collection techniques, including and 360° photogrammetry and Terrestrial Laser Scanning (TLS).

Sub-activity 1.2 focuses on the comprehensive aerial surveying of the entire catchment area. UAV-based LiDAR surveys enable the generation of high-resolution 3D terrain models with centimeter-level accuracy, critical for slope analysis, surface flow modeling, and identification of micro-topographic features. Multispectral imaging facilitates land cover classification and vegetation health assessment, contributing to the computation of parameters such as the C-factor in erosion modeling. Additionally, specific transect, gully sampling sites and test areas are examined for millimeter-resolution terrain modeling, complemented by terrestrial photogrammetry techniques based on 360° camera images.

This report outlines the implementation techniques and significant outcomes derived from employing aerial and terrestrial surveying methods, which have collectively enabled a comprehensive scan and detailed analysis of the entire catchment area. Through this innovative approach, the project not only meets its detailed mapping requirements but also significantly enhances the quality and reliability of environmental data collection and modeling.

2 Field work preparation

Field work preparation is a critical for successful surveying and data collection. Effective planning guarantees that all equipment is in working order, calibrated, and adapted to the terrain and study objectives. It also involves well-defined data capture protocols, choosing ideal ground control point (GCP) positions, and logistic preparations to enhance field productivity and safety. Planning and preparation minimizes errors, reduces the risk of data loss, and guarantees quality and consistency in the geospatial datasets collected during the campaign.

2.1 Ground control point (GCP) acquiring

Effective surveying involves detailed pre-field preparation, part of which is the tactical placement of ground control points (GCPs). GCPs are marked physical locations in the field with known geographic coordinates that are used as references in aerial and ground surveying projects. Their primary purpose is to ensure the geospatial accuracy of data captured from the air or from the ground by serving as calibration and validation points. GCPs enable the transformation of image-based data into georeferenced outputs such as orthomosaics, digital elevation models (DEMs), and point clouds that precisely reflect the surveyed environment. This alignment is critical when integrating data from multiple sources (e.g., UAV LiDAR,

multispectral imagery, 360° photogrammetry). For this study, the implementation of GCPs was carefully planned to meet both technical and practical fieldwork criteria. Each GCP location was selected based on:

- Visibility in aerial imagery – Ensuring that markers are easily distinguishable in UAV-captured images;
- Ground accessibility – Sites had to be physically reachable by the field team for precise coordinate measurement and maintenance throughout the campaign.

To ensure that these points are easily identifiable from aerial images captured by UAVs, large crosses were drawn at each GCP location using environmentally friendly fluorescent spray paint. The choice of bright, fluorescent paint is key as it stands out against natural backgrounds, significantly enhancing visibility from the air, especially when images are captured from high-flying UAV.

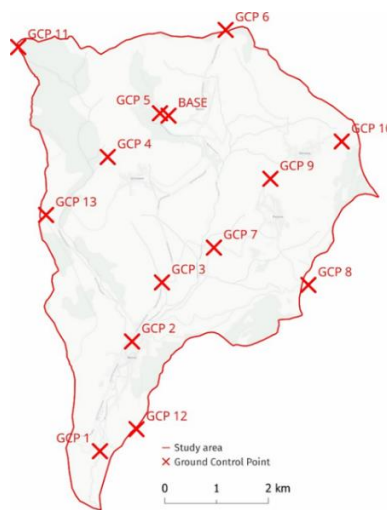


Figure 1. Spatial distribution of ground control points within the Malcanska river catchment

2.2 GNSS-based coordinate collection with RTK

The coordinates of each GCP were measured using the Emlid Reach RS3 GNSS receiver, a professional survey grade instrument capable of Real-Time Kinematic (RTK) positioning. RTK positioning involves the real-time correction of GPS signals by using a fixed base stations data as a reference to achieve centimeter-level accuracy.



Figure 2. Example of placed and measured ground control points

The method for collecting GCP involved conducting 15 separate observations at each point, leveraging the RTK functionality to enhance the positional accuracy. These observations were enabled by a continuous real-time connection to an RTK network, delivering correction data through the NTRIP protocol. After collecting the data, all observations at each GCP were averaged. This technique is based on the statistical principle that averaging multiple readings can reduce random error. By averaging 15 observations, the project significantly minimized potential deviations or inaccuracies that might occur in single measurements due to atmospheric disturbances or minor GPS signal disruptions.

3 Aerial survey

The aerial surveying phase forms a critical component of data acquisition for the Predict-Er project. It was conducted using the DJI Matrice 300 RTK, a highly versatile and reliable UAV platform capable of carrying multiple payloads. For this mission, the drone was equipped with two remote sensing instruments: the Hesai RESEPI XT32M2X UAV LiDAR system and the Agrowing Multispectral camera based on the Sony A7R IV platform. However, the LiDAR system and multispectral camera were not operated simultaneously; instead, separate flight missions were performed for each sensor to optimize data quality and meet specific acquisition requirements. This setup enabled the collection of high-resolution LiDAR data and multispectral imagery, ensuring datasets ideal for comprehensive environmental modeling, land surface analysis, and vegetation monitoring.

3.1 Flight planning and regulatory compliance

All aerial operations were preceded by extensive planning to define optimal flight paths, altitudes, and sensor configurations. The flight missions were carefully designed to achieve sufficient image and point cloud overlap (typically 70-80%) and to ensure full spatial coverage of the catchment area. Terrain characteristics such as slope, elevation changes, power lines, vegetation density were taken into account in the flight parameters.

In parallel, the team secured all mandatory permits from the relevant national airspace authorities. The approval process included the submission of flight plans detailing expected geographic coverage, flight altitudes, technical specifications of the UAV and sensors. This proactive compliance with airspace regulations ensured that the UAV operations avoided restricted zones, maintained safe distances from populated or sensitive areas, and operated within the legal boundaries defined for unmanned aircraft systems. In addition to legal conformance, these measures were crucial in the safety of both the surveying team and the general public, and to ensure the validity and acceptance of the collected data for official analyses and decision-making processes.

The rigorous planning workflow also facilitated smooth coordination among team members, minimized operational risks, and enabled efficient adaptation to changing weather or field conditions. Altogether, this comprehensive approach ensured that every UAV campaign was executed effectively, responsibly, and in accordance with best professional practices.

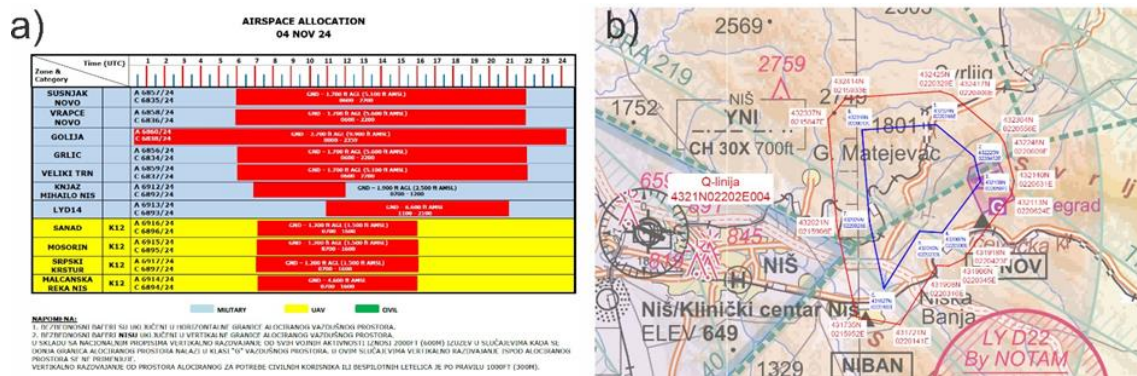


Figure 3. Example of an issued airspace allocation permit (a), and approved flight area by national airspace authorities (b)

Table 1. List of operator stand-by locations for flights at horizontal distances up to 500m

1	Babin zub	43°19'38.22"N, 22°1'9.68"E
2	Bajtarica	43°23'15.33"N, 22°1'54.71"E
3	Barci	43°21'36.52"N, 22°0'38.06"E
4	Bilo	43°22'22.11"N, 22°2'14.36"E
5	Borujevo 1	43°20'44.39"N, 22°2'54.49"E
6	Borujevo 2	43°20'17.66"N, 22°3'3.08"E
7	Buniš	43°21'40.56"N, 22°4'36.84"E
8	Vanin trap	43°22'36.68"N, 22°1'6.72"E
9	Vrelo 1	43°22'21.11"N, 22°2'53.31"E
10	Vrelo 2	43°22'34.52"N, 22°2'35.90"E
11	Vrh	43°19'46.08"N, 22°2'6.08"E
12	Galićeva glava	43°21'28.83"N, 22°1'21.57"E
13	Gornja Malča 1	43°20'22.65"N, 22°1'55.67"E
14	Gornja Malča 2	43°20'13.26"N, 22°2'21.90"E
15	Gramada 1	43°22'44.81"N, 22°3'23.16"E
16	Gramada 2	43°23'4.29"N, 22°3'35.12"E
17	Gramada 3	43°23'13.56"N, 22°2'59.77"E
18	Debeli del 1	43°22'32.24"N, 22°0'24.98"E
19	Debeli del 2	43°22'57.62"N, 22°1'54.47"E
20	Debeli del 3	43°23'2.75"N, 22°1'27.93"E
21	Delovska česma	43°20'47.75"N, 22°0'39.75"E
22	Deljena voda	43°21'43.61"N, 22°3'54.58"E
23	Detljak	43°20'25.88"N, 22°1'23.14"E
24	Donja Malča	43°19'31.61"N, 22°1'40.40"E
25	Dunjište	43°21'49.56"N, 22°1'11.72"E
26	Ječava 1	43°20'15.85"N, 22°3'34.46"E
27	Ječava 2	43°20'29.70"N, 22°3'53.49"E
28	Ječava 3	43°20'36.39"N, 22°3'30.84"E
29	Jokšina čuka	43°21'11.98"N, 22°1'13.01"E
30	Kajica	43°22'41.40"N, 22°1'40.03"E
31	Kamenita koruba	43°23'5.77"N, 22°0'45.06"E
32	Lipa 1	43°20'43.32"N, 22°1'50.26"E

33	Lipa 2	43°20'45.07"N, 22°1'14.61"E
34	Mali Gabar	43°22'48.00"N, 22°2'19.09"E
35	Mali Parkač	43°21'47.29"N, 22°2'35.72"E
36	Malčanska reka 1	43°20'22.83"N, 22°2'24.50"E
37	Malčanska reka 2	43°20'49.03"N, 22°2'28.50"E
38	Mečkin trap	43°20'4.56"N, 22°0'59.32"E
39	Nišava 1	43°18'35.29"N, 22°1'4.01"E
40	Nišava 2	43°18'56.99"N, 22°1'3.25"E
41	Nišava 3	43°19'14.19"N, 22°1'5.04"E
42	Ogranja	43°21'4.67"N, 22°3'19.56"E
43	Oštri kamen	43°21'59.39"N, 22°0'41.77"E
44	Pažar	43°23'8.88"N, 22°2'21.21"E
45	Parkač 1	43°22'1.46"N, 22°2'33.28"E
46	Parkač 2	43°21'56.36"N, 22°2'10.08"E
47	Parkač 3	43°22'9.70"N, 22°2'59.77"E
48	Pasjača 1	43°20'5.95"N, 22°1'28.31"E
49	Pasjača 2	43°21'22.09"N, 22°3'37.46"E
50	Pasjača 3	43°21'43.16"N, 22°3'17.51"E
51	Pasjača 4	43°21'57.81"N, 22°1'44.88"E
52	Pasjača 5	43°22'50.48"N, 22°2'47.53"E
53	Pasjača 6	43°21'59.16"N, 22°4'18.36"E
54	Pasjača 7	43°21'36.97"N, 22°1'41.53"E
55	Planinica 1	43°22'17.57"N, 22°0'23.86"E
56	Podripanj 1	43°22'9.83"N, 22°4'45.23"E
57	Podripanj 2	43°22'25.84"N, 22°4'32.60"E
58	Popovac	43°21'14.62"N, 22°4'15.23"E
59	Preseka	43°20'58.75"N, 22°3'56.31"E
60	Rail 1	43°22'49.35"N, 22°4'4.96"E
61	Rail 2	43°22'32.63"N, 22°3'58.14"E
62	Railova strana 1	43°22'16.50"N, 22°3'53.77"E
63	Railova strana 2	43°22'27.92"N, 22°3'29.53"E
64	Rudina	43°21'29.20"N, 22°3'10.77"E
65	Sedalište 1	43°23'1.93"N, 22°0'9.60"E
66	Sedalište 2	43°23'18.23"N, 22°0'17.71"E
67	Selište	43°22'5.66"N, 22°3'39.32"E
68	Straža	43°22'21.27"N, 22°1'44.41"E
69	Tečki del	43°22'14.55"N, 22°1'15.17"E
70	Tipšenica 1	43°21'31.06"N, 22°4'25.15"E
71	Trlica	43°21'34.09"N, 22°2'6.38"E
72	Trolište 1	43°21'10.86"N, 22°2'12.31"E
73	Trolište 2	43°21'5.60"N, 22°1'46.49"E
74	Trolište 3	43°21'5.94"N, 22°2'46.55"E
75	Trolište 4	43°21'25.12"N, 22°2'44.20"E
76	Crveni potok	43°21'14.25"N, 22°0'42.00"E
77	Čalija	43°19'11.59"N, 22°1'36.20"E
78	Šančevi	43°20'23.41"N, 22°0'39.63"E

3.2 LiDAR data collection

The first phase of aerial data acquisition involved the use of the Hesai RESEPI XT32M2X LiDAR sensor, integrated into the Matrice 300 RTK via the SkyPort interface. This sensor combines a 32-channel laser scanner with an inertial measurement unit (IMU) and GNSS receiver to produce high quality point clouds. The LiDAR system was configured to collect data with cm-level resolution and high vertical precision, ideal for generating Digital Elevation Models (DEMs), Digital Surface Models (DSMs), and for detecting fine-scale topographic features such as gullies, and erosion rills.

To enhance spatial accuracy, Post-Processed Kinematic (PPK) positioning was applied using the Emlid Reach RS3 GNSS receiver, which acted as a base station. During each flight, raw GNSS data were recorded simultaneously by both, the onboard GNSS module and the base station. Post-flight, this data was processed to correct positioning errors. The result is highly accurate georeferenced point cloud, aligning it with real-world coordinates and enabling its integration with other spatial layers collected in the project.

LiDAR data were later processed using specialized software to extract ground points, classify point clouds into surface categories (e.g., ground, vegetation, structures), and generate terrain derivatives such as slope, curvature, and hydrological flow paths. These outputs serve as inputs to the Predict-Er tool, particularly for topography based erosion and runoff simulations.

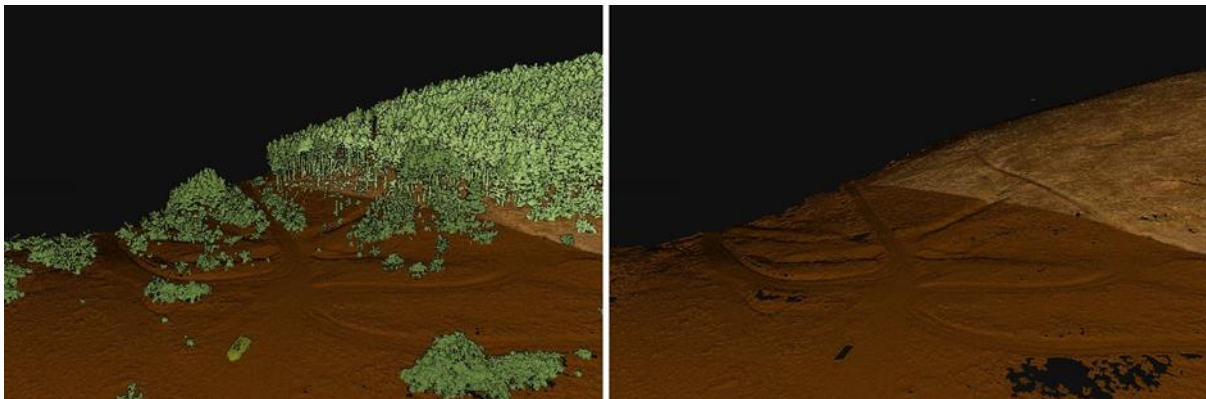


Figure 4. Example of LiDAR point cloud and classified ground points

3.3 Multispectral imaging

The aerial survey campaign employed the Agrowing multispectral camera system, built on the Sony A7R IV platform, to capture high-resolution multispectral imagery critical for environmental and agricultural analysis. This advanced system enables the simultaneous acquisition of 14 narrowband spectral channels. Multispectral flight missions were carefully planned to ensure data consistency and reliability. Data collection was conducted under midday sun and during clear or minimally cloudy conditions. Captured multispectral data were further refined through GCP alignment. The processed outputs - high-resolution vegetation and land cover maps were used to compute a variety of vegetation indices, such as NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index), OSAVI (Optimized Soil Adjusted Vegetation Index), MSAVI (Modified Soil Adjusted Vegetation Index) etc.

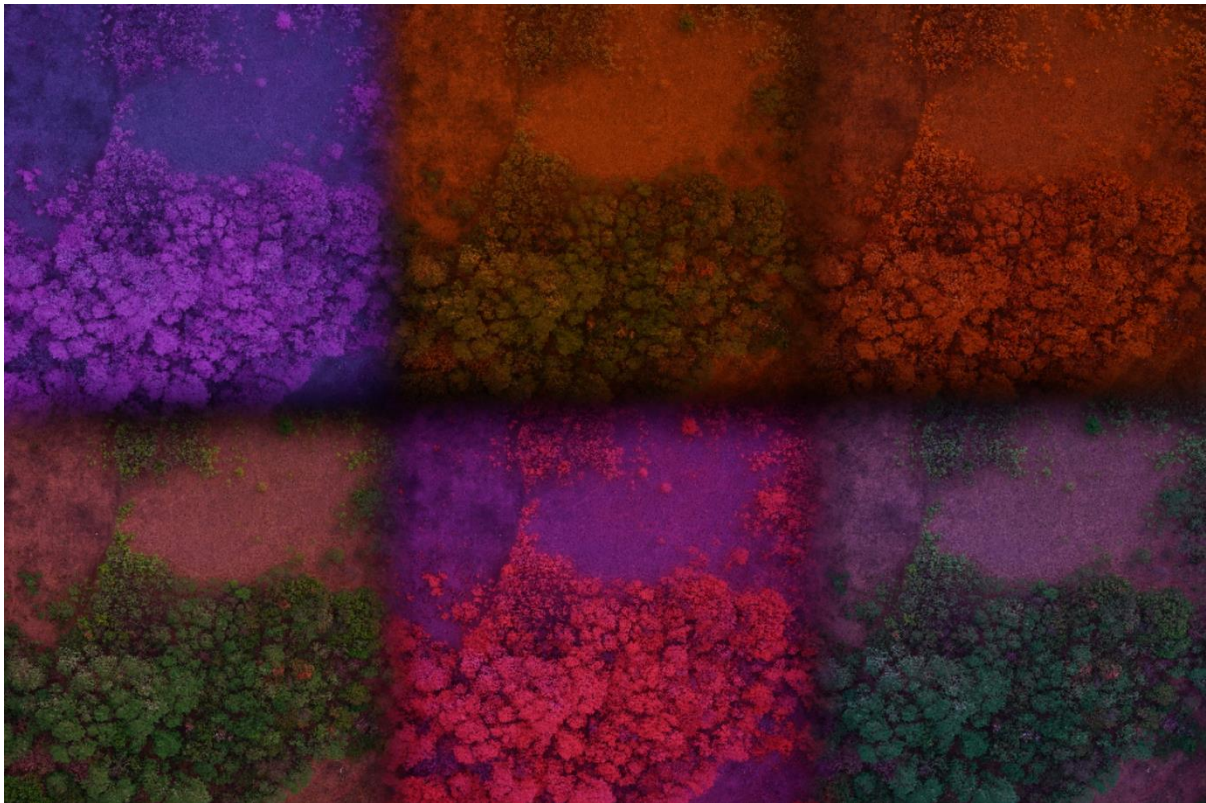


Figure 5. Example of Sony A7R IV Agrowing multispectral photo

4 Terrestrial survey

As an integral component of Sub-Activity 1.2 terrestrial surveying complements aerial data by delivering high-resolution, terrestrial based spatial information. This approach is particularly valuable in areas where UAV access is limited due to terrain complexity, vegetation density, or regulatory constraints. The objective of the terrestrial survey is to capture detailed ground level imagery and generate high accuracy 3D models, which are critical for refining terrain analyses, and enhancing landform characterization within the Predict-Er framework.

The terrestrial survey was conducted using 360° imaging systems: Ricoh Theta X and Insta360 X4. These compact, portable cameras are capable of capturing full-spherical panoramic images (equirectangular format) with high resolution and wide dynamic range. The lightweight design and rapid deployment capabilities of these systems make them ideal for fieldwork in rugged or vegetated terrain, such as steep gullies, forested slopes, and transects.

The survey team deployed the 360° cameras across a series of predefined ground locations. At each location, 360° images were captured for photogrammetric processing. The image acquisition protocol ensured a consistent camera height and orientation, and included metadata such as GNSS-tagged coordinates and timestamping, facilitating integration with aerial and GNSS datasets. The use of spherical imagery in this process provides several benefits, including omnidirectional coverage, and a larger number of matched keypoints across images, which significantly improves model stability and resolution - especially in complex terrain or under forest canopy.



Figure 6. Dual 360° camera setup

In addition to the panoramic image capture, selected locations were also surveyed using the Stonex X300 terrestrial LiDAR scanner. The Stonex X300 terrestrial laser scanner was used at selected locations to validate the 3D models generated from 360° photogrammetry. As a high-precision and well established LiDAR system, the X300 provides millimeter-level accuracy and point cloud data, making it an ideal reference for assessing the geometric accuracy of image-based reconstructions. Its use ensured the reliability of the 360° photogrammetric models, particularly in areas with complex terrain where validation through an independent, highly accurate method was essential.