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APPLICATION OF MODERN PLATFORMS FOR THE ACQUISITION OF SPATIAL DATA IN LANDFILL MONITORING

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Abstract

Environmental contamination due to poor solid waste management represents a global ecological issue. The real need for quality spatial data in the processes of solid waste management plays a key role in improving work performance and facilitating work processes. Through the implementation of modern platforms for the acquisition of spatial data, an efficient and quality method for conducting measurements without direct contact with the terrain is achieved. This paper presents the monitoring of waste quantities generated at the non-standardized "Mavrovica" landfill in Sveti Nikole using the results obtained from LiDAR scanning of the territory of the Republic of North Macedonia as well as the conducted UAV-based imaging.

The presented results represent the progress and refinement of modern platforms for the acquisition of spatial data, thereby serving as a reference point for analyzing the value states of waste generated from a certain temporal distance.

Key words: *environment, non-standardized landfill, spatial data, LiDAR technology, drone*.

INTRODUCTION

In recent years, as a result of rapid socio-economic development, an uncontrolled increase in non-standardized landfills with significant amounts of waste has appeared on the surface of the Earth. This phenomenon globally characterizes waste as a global ecological, social, and economic challenge [1]. If we take as a starting point the fact that it is reported that there are more than 1,000 wild and non-standardized landfills across the entire territory of the Republic of North Macedonia, and only one landfill in accordance with the national legislation for safe waste management, we will notice that the global waste problem fully reflects its existence within our country [2,3].

Considering that environmental protection implies a set of procedures and activities taken to prevent its endangerment in order to ensure its sustainability, it is necessary in the entire process of waste management to conduct a relevant analysis of the quantity of waste generated at non-standardized landfills based on the spatial data obtained from observing the space. The rapid development of science leads to the application of new modern technologies in every scientific and applied field, which initiate an increasing demand for a larger quantity of quality and detailed data, especially for space, which has a direct impact on preserving, protecting, and improving the quality of the environmental life.

The paper will present modern platforms for the acquisition of spatial data with a special emphasis on the analysis of the results obtained from their use in the processes of determining the quantity of waste generated at the non-standardized "Mavrovica" landfill in Sveti Nikole. In addition to the application of the results from LiDAR scanning of the territory of the Republic of North Macedonia, UAV-based imaging was also conducted with an unmanned aerial vehicle (drone).

MATERIAL AND METHODS

Methods for Spatial Data Acquisition

Fundamentally, there are several possibilities for the acquisition of spatial data, but it is necessary to mention that the acquisition of spatial data can be approached from two aspects:

- Methods for acquisition; and
- Techniques for acquisition.

Regarding the methods for acquisition, it should be noted that there are three methods for acquisition:

- Cartographic;
- Field survey; and
- Photogrammetric;

Considering that each of these methods finds serious application in the acquisition of spatial data but guided by the need to improve the work processes themselves through the development of technology, this paper applies the photogrammetric method.

Photogrammetric Method

Photogrammetric methods are most rational when it comes to the mass acquisition of spatial data. With them, it is possible to achieve appropriate accuracy of measured data, and the measured set can sufficiently describe the physical characteristics of the terrain. The desired accuracy of the measured data is achieved in the flight planning phase through the selection of suitable elements needed for the UAV-based imaging itself, such as the flight height, the camera's field of view width, longitudinal and lateral overlap, and other elements that are necessary to ensure quality spatial data. Given their complexity and exceptional diversity, primarily from a geometric perspective, an extremely large amount of measured spatial data is required to obtain a quality description. It would not be possible to collect such a quantity of spatial data by bringing the measuring device into direct physical contact with the spatial entity of interest [4]. Therefore, photogrammetry is used as an efficient and quality method for the acquisition of spatial data without establishing direct contact with the spatial entity.

The advantages of photogrammetric technology over traditional methods for the acquisition of spatial data consist in faster, more efficient, and economical collection of spatial data over larger territories, as well as the possibility of working on inaccessible terrains. As a result of the photogrammetric methods, there is a possibility to create digital terrain models (DTM) with high accuracy and a quality basis for the creation of GIS (Geographic Information System).

While as anomalies of the photogrammetric technology, the following disadvantages are highlighted:

- The system does not work well in poor weather conditions;
- Strong wind reduces the quality of the data; and
- The system has no ability to identify data for boundaries, underground infrastructure, and water network.

The constant progress of science and technology leads to setting higher goals in every scientific and applied field through the development and application of advanced technologies, where undoubtedly unmanned aerial vehicles (UAVs) and LiDAR technology belong.

LiDAR Technology

LiDAR technology primarily represents one of the key elements of remote sensing. Given that the application of this technology is interdisciplinary, it should be noted that with the emergence of LiDAR technology, many areas enter a new era. Namely, it is a relatively new approach for the acquisition of spatial data, enabling quick, precise, and detailed data about the Earth's surface. Due to the high frequency of measurements over a short period, it enables the measurement of the terrain's surface shape and objects on it. We can say that the technology of spatial laser scanning is affirmed as a fully automated and exceptionally efficient method for the acquisition of spatial data, which also represents an ideal tool that allows the creation of digital terrain models.

The technology of laser scanning, known as LiDAR, functions based on the well-known method of registering the distance and angle from the scanner to a certain point in the recording area. This technology is based on collecting three different sets of data where the position of the sensor is determined using GPS by using phase measurements in relative kinematics mode. While using the inertial measurement unit (IMU), the orientation is determined. The last component is a laser scanner that emits infrared radiation to the ground where it is reflected back to the sensor and thereby results in the calculation of three-dimensional coordinates. The time spent from the transmission to the reception of the signal, with knowledge of the position and orientation of the sensor, allows for an accurate calculation of the three-dimensional coordinates of the Earth [4].

Regarding the methods of recording, fixed and mobile systems are distinguished. In fixed systems, the recording is done with scanners that are installed on stationary geodetic tripods. When it comes to recording the terrain over larger areas, mobile systems installed on vehicles for land transport, watercraft, or an aerial platform via airplane or unmanned aerial vehicles find wider applications.

Due to the best accessibility of larger terrain surfaces for scanning and the possibility of great mobility of the scanner itself, LiDAR scanning is most often performed using an airplane as a platform carrying the scanner.

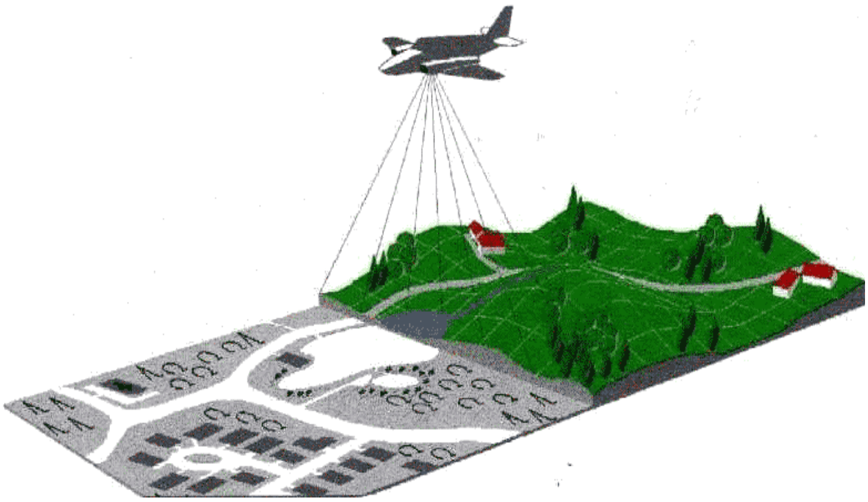

Figure 1. Aerial LiDAR Scanning

LiDAR scanning is one of the fastest-growing technologies in the process of acquiring spatial data, allowing for the recording of a large number of points with considerable speed and accuracy. It involves capturing densely arranged three-dimensional coordinate points at a rate of up to 500,000 points per second with a density of 2.5 or 10 points per square meter. This results in an exceptionally high quality of terrain scanning, where the accuracy of the laser points ranges within +/- 10 cm, both positionally and in height. It should be noted that the most commonly used products derived from the LiDAR point cloud are the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) [4].

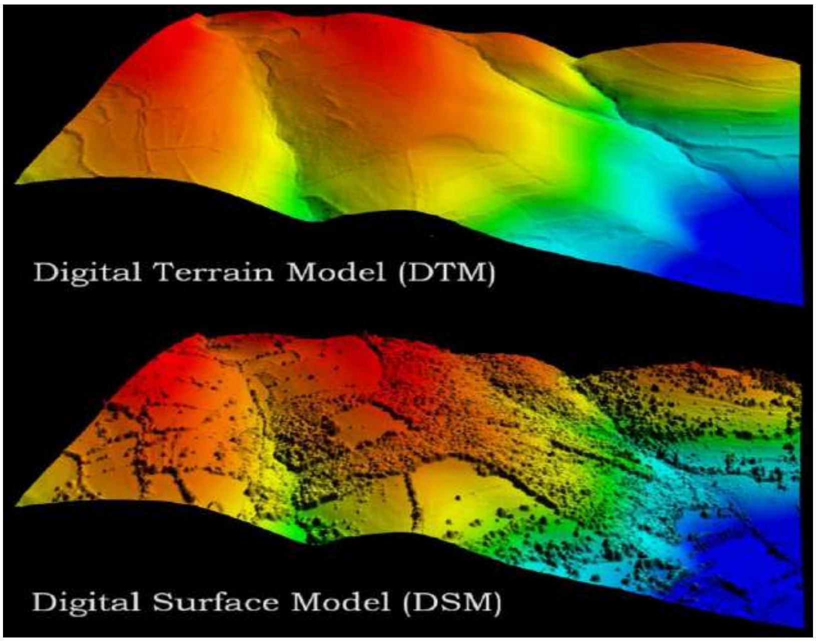

Figure 2. Essential Difference between DTM and DSM

Unmanned Aerial Vehicles (UAVs)

Unmanned Aerial Vehicles (UAVs), embodying advanced technology, form an integral part of the Unmanned Aircraft System (UAS), which includes the ground controller, the UAV itself, the communication system with the UAV, and all other components of the flight system. UAVs differ and are classified according to their own size, the weight they carry, the sensors and cameras installed, the source of power, the maneuverability during flight, the maximum height they can reach during flight, resistance, and stability against wind and other adverse natural phenomena. UAVs are controlled by a ground controller operated by a person located on the ground at a certain distance from the UAV itself. These systems have the capability for autonomous flight with predetermined coordinates for the flight and semi-autonomous flight where the operator inputs the coordinates of the movement path and the flight altitude during the flight itself. UAVs with a small weight and lesser carrying capacity are used for short-term missions for surface scanning, while for longer-term missions, UAVs made of sturdier construction that provides greater stability and resistance during flight and UAVs equipped with advanced sensor models capable of reaching higher altitudes are used [5].

For the purposes of the research within this paper, a DJI Mavic 3 Enterprise drone was used for the acquisition of spatial data, equipped with an RTK GPS system for positioning with centimeter accuracy. This type of drone, without additional attachments, has a weight of 915g and can operate at temperatures from -10° to 40° C. The DJI Mavic 3 Enterprise is designed to fly at a maximum speed of 12m/s in windy conditions, while in normal conditions, it can reach a flight speed of 15m/s. It can provide a flight duration of 45 minutes in ideal conditions, while the total hovering time in ideal conditions amounts to 38 minutes. The maximum distance that can be covered by this drone is 32 km, with the capability to operate at altitudes up to 6000 meters.

The drone has an available GNSS device capable of receiving GPS + GALILEO + BeiDou + GLONASS signals, which enables RTK accuracy in vertical positioning of ±0.1 m and in horizontal positioning of ±0.1 m. [6].

Figure 3. DJI Mavic 3 Enterprise

Depending on the type of UAV, they can be equipped with various photogrammetric systems, ranging from LiDAR cameras, multispectral cameras, to various types of sensors such as RGB (Red-Green-Blue) sensors, obstacle avoidance sensors, and anomaly indicating sensors that may point to safety hazards.

The use of UAVs for scanning a certain spatial entity represents a photogrammetric method for the acquisition of spatial data, which includes the following phases:

- Setting objectives;
- Flight planning;
- Acquisition of spatial data;
- Processing of the captured data; and
- Generation of photogrammetric models;

Based on the data obtained with UAVs and their further processing, 3D models, digital and elevation models of the terrain are generated, which have fundamental importance in conducting various analyses and calculations.

RESULTS AND DISCUSSION

Monitoring the phenomena and processes that directly influence the environment and human lives through the photogrammetric method for the acquisition of spatial data is an imperative for the creation of this paper. This paper made a special review of monitoring the value states of waste generated at the non-standardized landfill in Sveti Nikole based on the results obtained from LiDAR technology and drones at different time periods.

For the needs of this paper, an area near the village of Mechkuevci, Municipality of Sveti Nikole, was selected, where the non-standardized landfill “Mavrovica” is located. The entire area is defined by five boundary points, whose positional coordinates from the state coordinate system are presented in Table 1.

Table 1. Positional coordinates of boundary points defining the scope

Point Number	Y	X
1	7582390	4639590
2	7582710	4639415
3	7582820	4639520
4	7582640	4639700
5	7582430	4639720

In order to determine the quantity of waste at different time periods at the non-standardized landfill “Mavrovica” in Sveti Nikole, the data obtained from the LiDAR scanning of the territory of the Republic of North Macedonia and the conducted acquisition of spatial data for the area of interest with the drone DJI Mavic 3 Enterprise were used.

Following the global trends for the acquisition of spatial data, the Agency for Real Estate Cadastre began with the implementation of LiDAR scanning of the territory of the Republic of North

Macedonia, where the final products of the project were the corresponding point cloud and a precise DTM and DSM.

Within the LiDAR project, scanning of the entire country was conducted in two phases. The first phase of scanning was done in 2019, covering an area of 11072 km² and divided into 14 blocks from Block 1 to Block 14. The second phase of scanning was conducted in 2021, covering an area of 13900 km² and divided into 20 blocks from Block 15 to Block 34.

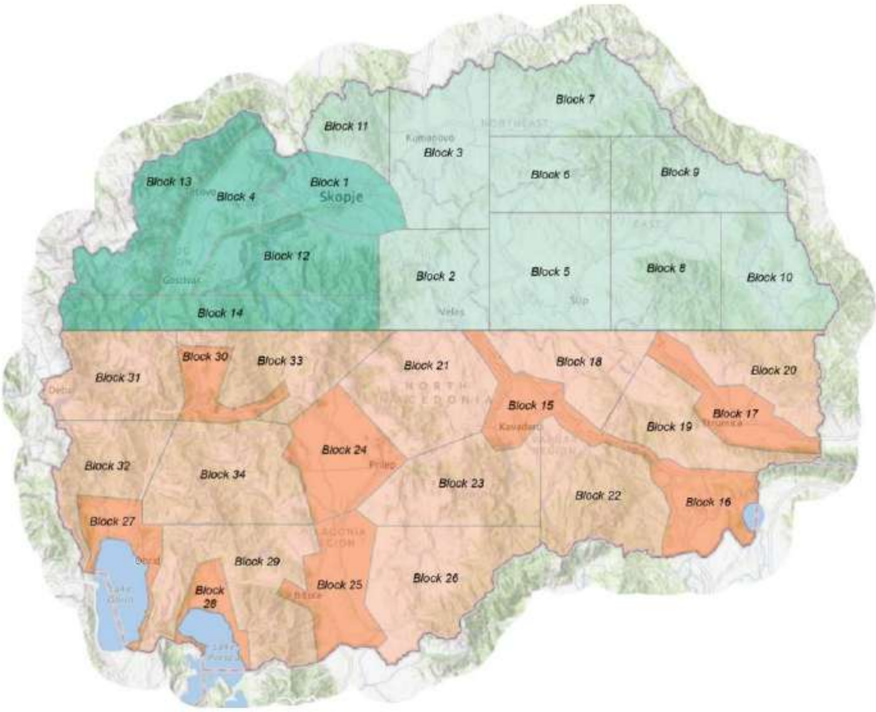

Figure 4. Display of the 34 Blocks on Which LiDAR Scanning Was Performed

The aerial LiDAR scanning of the territory of the Republic of North Macedonia was performed with a density of 2 or 5 points per m², depending on the territory of interest for which a plan for the acquisition of spatial data had been previously made based on the required point density and ground control points. The area selected for the needs of this paper falls within Block 5. The LiDAR scanning of Block 5 was carried out with a point density of 2 points per m² in the first phase of LiDAR scanning of the territory of the Republic of North Macedonia.

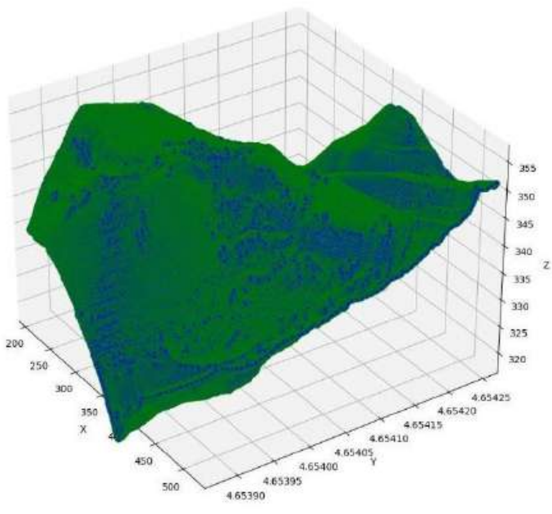

Figure 5. 3D Model in Point Cloud Format of the Non-standardized Landfill "Mavrovica"

During the field activities in 2023 for UAV-based imaging the non-standardized landfill "Mavrovica" in Sveti Nikole with the drone DJI Mavic 3 Enterprise, a point cloud was obtained from which a 3D model of the terrain was generated, as shown in Figure 6.

Figure 6. 3D Model of the Non-standardized Landfill “Mavrovica”

A flight plan for the drone is prepared before the field activity for terrain UAV-based imaging begins. The flight plan is optimized to meet the necessary requirements during the area overflight.

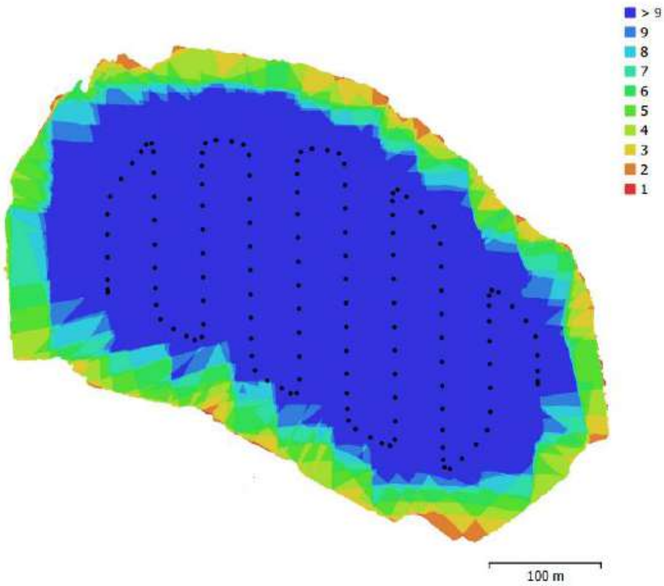

Figure 7. Flight Path Trajectory of the Drone Over the Terrain

The entire area of interest in this paper, with an area of 160000m², was recorded during a single flight along the drone's flight path trajectory with 135 photographs.

To prevent and avoid negative environmental impacts from the influences of wild landfills, the appropriate use and interpretation of the obtained data create the possibility to estimate future occurrences and opens a real opportunity to take appropriate preventive measures.

As a result of the spatial data obtained from the conducted acquisitions, a precise 3D model for the area subject to analysis in this paper was generated in the drafting program Auto CAD Civil 3D. Here, the zero state with green color shows the contours generated from the spatial data obtained through LiDAR scanning of the territory of the Republic of North Macedonia in 2019, and with red color, the contours generated from the spatial data obtained with the drone in 2023 are shown.

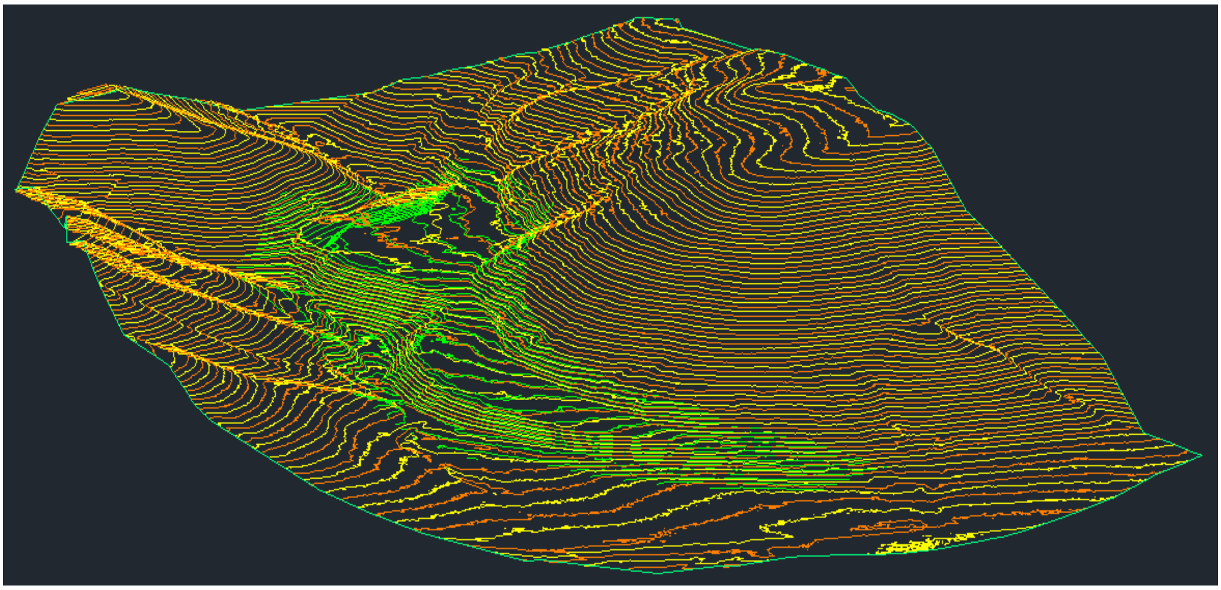

Figure 8. Visual Representation of the Generated 3D Model in AutoCAD Civil 3D

Within the model itself, where spatial data from both recordings are overlapped, 52 longitudinal profiles at intervals of 10 meters along the non-standardized landfill in Sveti Nikole were created.

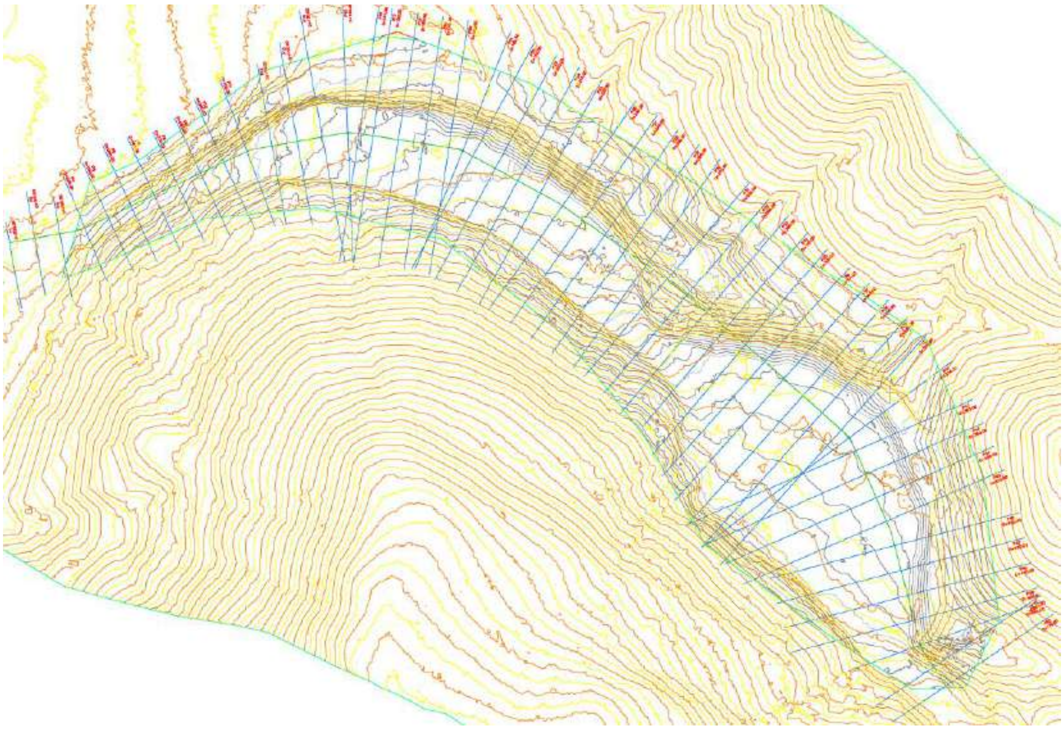

Figure 9. Visual Representation of the Generated Profiles along the Landfill Terrain

Thus, in the period between the two recordings of the area subject to analysis in this paper, a change in the terrain occurred, which can best be observed through the created cross-sections along the landfill itself. Several characteristic cross-sections profiles will be shown, where the fill is represented in orange color, and the excavation of the terrain in blue color.

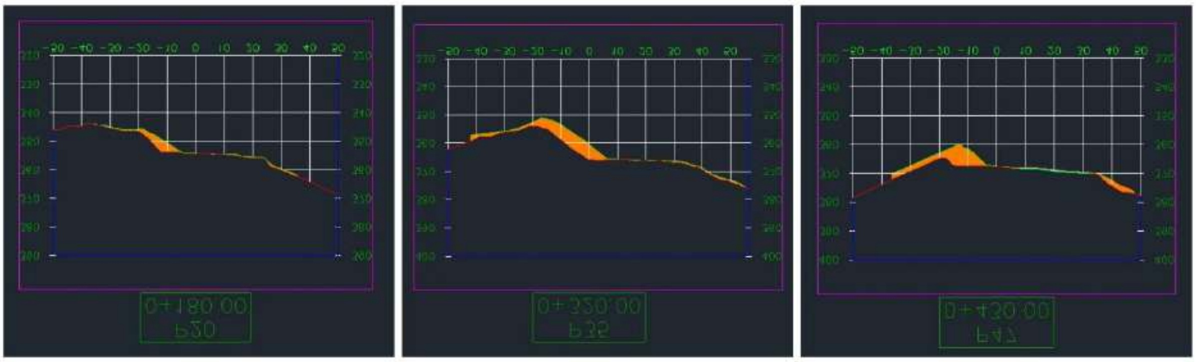

Figure 10. Characteristic Cross-section Profiles

Given that changes in the terrain, namely changes in the volume of waste, have occurred between the two recordings, through the details presented by the cross-section profiles, we can observe these changes, whose values are shown in Table 2.

Table 2. Value States of the Generated Waste

Excavation	Fill	Total Waste Volume
1512.12 m^3	31064.57 m^3	29552.45 m^3

Analyzing the results from the value states of waste generated at the non-standardized landfill in Sveti Nikole shown in Table 2, it is observed that the amount of waste for a period of four years has increased by 29,552.45 m^3.

CONCLUSION

Extensive research conducted around the world indicates that the unstoppable progress in the development of new technologies is a key moment for the modernization, progress and improvement of many areas that encompass human activity. Through the implementation of modern development trends and achievements in work processes, a greater demand is initiated for an increasing amount of quality and detailed spatial data, especially for the space that has a direct impact on the protection, preservation and improvement of the environment.

Modern spatial data acquisition platforms provide a moment of superiority over classical methods in terms of duration and efficiency. The applied combination of modern technologies within the framework of this paper significantly raises the level of spatial data acquisition, opening up the possibility of analyzing a huge amount of data, and identifying certain anomalies with potential danger to the environment.

At the end of the performed analysis, the conclusion can be drawn that the presented methodology and standards for the preparation of this paper, above all the entire process of preparation, acquisition and processing of the spatial data have been carried out with a level of satisfactory accuracy, which the achieved results speak for.

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