# GEODETIC SURVEYING OF THE DEPOT USING THE COMBINED METHOD AND MASS CALCULATION AT THE "JABLAN" QUARRY

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***Abstract:*** *Geodesy is widely used in various engineering branches of the economy. Various products of geodetic surveying are needed every day, in order to obtain a 3D model of the terrain, to determine the position of works, volumes of deposited masses, depots, etc. With the development of technology and the advent of unmanned aerial vehicles, data collection has become much easier. This paper compares the data obtained by the Global Navigation Satellite System method with the data obtained by the aerial photogrammetry method, and based on these data the volume of the depot was calculated in two ways, by the method of cross profiles and through a model formed using a network of irregular triangles. The obtained values of the calculated amounts of mass deposited at the landfill help in future activities related to the creation of the landfill and forecasting as well as making decisions about the total quantities that can be disposed of at this and future researched locations.*
***Keywords:*** *geodetic survey, GNSS, aerial photogrammetry, depot, cross profiles, triangles of irregular network*

## INTRODUCTION

Engineers of various professions often have problems on the site when determining the location of works, precise calculation of the amount of mineral raw materials, the volume of landfills, etc. To get the volume of a body, we have to define it in space and to collect appropriate data. The classic way to collect data is by terrestrial method and Global Navigation Satellite System (GNSS) method. However, with the development of technology, we have the application of unmanned aerial vehicles, where we can obtain a larger amount of data in a shorter period of time. The aerial photogrammetric method is increasingly being applied, because a realistic tree dimensional (3D) model of the actual situation can be obtained. This paper compares data obtained by GNSS and by the aerial photogrammetry method. The method of cross profiles is the most common way to obtain the volume. With the development of technology and software, the volume of body can also be obtained through a 3D model. This paper compares the volumes calculated by processing the data obtained by the terrestrial method and the aerial photogrammetric method, as well as by the methods of cross profiles and the Triangles of Irregular Network (TIN).

Jansson and Lundgren (2018) in their report compared different methods using the GNSS in GNSS in Real Time Kinematic (RTK) to establish control points that will be used to establish a free total station and pointed out that it is important in addition to the number of observations and lengths observation period to minimize risk. Pearson, Fricks, and Penna (2023) provide a comprehensive overview of geodetic surveying using the GNSS method with a special focus on survey methods, errors as well as the coordinate reference system and quality assurance and control. Raeva, Filipova, and Filipova (2016) through their paper aim to test and evaluate the accuracy of Unmanned Aerial Vehicles (UAV) data for volumetric measurements to the conventional GNSS techniques. Two sets of measurements at open pit quarry were performed. Firstly, a stockpile was measured by GNSS technologies and later other terrestrial GNSS measurements for modeling the berms of the quarry were taken. Secondly, the area of the whole quarry was mapped by a UAV flight. Extremely precise measurements could be performed by GNSS technologies, but UAV photogrammetry presents a fast, accurate method for mapping large areas and calculating stockpiles volumes. In yours study, authors Hastaoğlu et al. (2019), a new methodology for monitoring 3D areal displacements with UAV photogrammetry and software suitable for this methodology were developed, and by comparing the results of the software with GNSS results, UAV-based monitoring results were tested. Štroner et al. (2021), were demonstrated the linear dependence between the systematic elevation errors of the models based only on the on-board GNSS RTK data and the deviation in the determined internal orientation parameters. In addition, they have shown that a combination of two flights with different image acquisition axes can eliminate this systematic error even in real-world conditions and that geo-referencing without GPS is, therefore, a feasible alternative to the use of GPS.

## MATERIAL AND METHODS

In order to be able to monitor the works in the field in real time as effectively as possible, it is necessary to use all available techniques, equipment, methodologies and materials. Specifically, in the considered case, presented through this article, for the purpose of determining as precisely as possible the volumes of materials that are disposed of at the landfill (depot), the equipment that will be used for the purposes of geodetic measurement, recording and data storage as well as the methodology of volume calculation is defined. Two methods for measured and three methods of calculating volumes were used in order to determine the optimal methodology to help make decisions during further activities, which significantly affects the costs and time of designing and using the landfill.

***Geodetic Network***

A geodetic network is defined as a configuration of three or more points that are connected by terrestrial geodetic, satellite, astronomical measurements or their combination (Štroner et al., 2021). The geodetic network is represented by all permanently stabilized geodetic points, with known coordinates, on a certain part of the Earth's surface that are needed for a defined task. Depending on the shape and measured quantities, terrestrial grids can be: trigonometric, polygonal, linear and leveling. Also, geodetic networks can be vertical (1D), horizontal (2D), and spatial (3D). Geodetic networks, depending on the application, can be: general and special purposes (Department of Municipal Affairs and Transport, 2016).

***Alignment of geodetic networks***

Geodetic measurements and the parameters calculated from them are related to various mathematical models. In order to increase the accuracy of measurement and calculation results and to enable internal control of measurements from closed mathematical models, a certain number of redundant measurements are usually added to the necessary measurements. Then these excessive measurements create disagreements within the model and enable equalization (Raeva et al., 2016). If there is need to create a unique equalization method, then an additional mathematical condition must be formulated that the corrections to the measurements must satisfy. That additional mathematical structure is the least squares condition. The least squares condition requires that the sum of the squares of the corrections multiplied by the corresponding weights has a minimum value (Frankić, unpublished). In practical applications, the leveling of geodetic networks is most often used according to the method: indirect, conditional, conditional measurements with unknown parameters and indirect measurements when the parameters are in certain mathematical conditions.

***Parametric model***

The most popular equalization method in geodesy is the parametric model. It is appropriate in all cases where each measurement can be expressed as a function of some unknown and independent parameters. Each element of the n-dimensional vector l is expressed as a function of the u-dimensional vector of parameters. The number of parameters u must be less than the number of measurements n, only then is equalization possible. The parametric model should be predetermined. The parametric model is perfectly consistent when, after equalization, the vector of random corrections v is added to the measured vector l, and at the same time a vector of approximate values of independent parameters $x_0$ was corrected with a correction vector δ. Equalization with a parametric model is a relatively simple procedure. First design matrix A must be formed, and then the disagreements vector ω and the weight matrix P. Since parametric models are generally non-linear, it is common practice to perform the equalization in several iterations. After the first equalization, the vector of equalized parameters is taken as a new approximation and the disagreements are recalculated. The deterministic part of the equalization model consists of three important vectors: equalized parameters x, equalized measurements l and finally from the repair vector v. This stochastic part consists of three variance-covariance matrices for vectors of: equalized parameters, equalized measurements and corrections (Frankić, unpublished).

***Methods of mass calculation***

Engineers often have a problem on the site when determining the location of works, precise calculation of the amount of excavation or embankment of some mineral raw material, the volume of landfills, etc. The method that is mainly used to obtain the volume of a body in space is the method of cross profiles. The development of technology and access to the various software, enabled the creation of a digital model of the terrain, which greatly facilitated the calculation of the volume, where the model is taken into account as a whole, and not divided into segments as in the case of calculations through cross profiles (Raeva et al., 2016); (Kovanič et al., 2021).

***Method of cross profiles***

This method is based on the placement of a series of parallel sections along the scope, whose volume we want to obtain. It is based on calculating the area of individual sections separately, and then calculating the arithmetic mean between two adjacent sections to obtain the average value of the area. To calculate the volume, we multiply the mean value of the area by the distance between the two sections (TOPS Marketing, 2020).

***Determining volume from a network of triangles***

Triangular Irregular Networks are used as a digital means of representing surface morphology. TINs are a form of vector digital geographic data and they are constructed by triangulating a set of vertex. The vertices are connected by a series of edges in a network of triangles. There are different interpolation methods to shape these triangles (TOPS Marketing, 2020). TINs are typically used for highly accurate modeling of smaller areas. For the purposes of determining the volumes two digital models of the terrain (base and new condition) are necessary (Raeva et al., 2016); (Mijić and Janić, 2015).

***Used equipment***

For the purposes of geodetic measurement, the following equipment was used: Trimble R8 GNSS system, Phantom 3 Professional drone, and The Ruide R2 Pro total station. The latest advancements in Trimble R-Track technology consistently deliver precise positioning performance in the most challenging GNSS conditions. Compact Measurement Record (CMRx) protocol provides maximum compression of corrections to optimize communications bandwidth and fully utilize all of the satellites and signals in view. The Trimble R8 GNSS (Figure 1) supports a wide range of satellite signals, including GPS L2C and L5 and GLONASS L1/L2 signals (Trimble, 2024).


Figure 1. Trimble R8

Dron Phantom 3 Professional as shown in Figure 2, represents a new generation of quad-copters. It can record 4K videos. The built-in camera has an integrated gimbal to make the aircraft as stable as possible considering its size and weight. Even when the GPS signal is not available, the aircraft uses the Vision Positioning System to land the aircraft at the set point (DJI, 2024).

Figure 2. Dron DJI Phantom 3 Professional

The Ruide R2 Pro total station as shown in Figure 3, is a unique and innovative Electrical Discharge Machining (EDM) technology that enables precision up to 800 m without a prism in 0.3 seconds of measurement.

Figure 3. Dron DJI Phantom 3 Professional

This station is equipped with an auto sensor for temperature and pressure, and therefore corrects the measurement result in real time. The guide is the LED indicator on the EDM (GEONOVA Ltd., 2024).

***Recording methods***

In the specific case of choosing the optimal method of calculating the amount of material that is disposed of and that can be disposed of at the landfill, two data recording methods are used: photogrammetric and GNSS.

***Photogrammetry***

Photogrammetry is a measurement technique that uses photographs as the basic measurement medium. In addition to the classic methods of terrestrial photogrammetric, high-quality digital measuring cameras are used today. By applying methods of digital photogrammetry, new application possibilities appear by introducing faster, cheaper and more complex procedures, based on digital technology (Department of Municipal Affairs and Transport, 2016); (Hastaoğlu et al., 2019). The basic principle used by photogrammetry is triangulation. By taking photos from at least two different locations, so-called "lines of sight" can be developed from each camera to points on the object. These lines of sight are mathematically intersected to obtain the three-dimensional coordinates of the points of interest (Kovanič et al., 2021); (Geodetic services Ltd., 2024). A somewhat more innovative and younger method of photogrammetry is a type of aerial photogrammetry method, with the use of UAV with cameras. Apart from technical aspects, a big advantage is that information technology enables 3D visualization, virtual models, data distribution on the Internet, etc. Creating and archiving source materials is also simplified (Štroner et al., 2021); (Dream Civil, 2024).

***GNSS***

GNSS is now a widely used 3D measurement system that uses radio signals emitted from satellites to determine position. It is important to understand that the application of such technology in a certain industry significantly depends on the level of accuracy and availability that is possible and necessary to achieve. The most precise and accurate GNSS measurements are carried out for geodetic purposes. The method of determining the position that surveyors most often use is called GNSS RTK (Kovanič et al., 2021); (Jansson, and Lundgren, 2018). The mentioned method is based on the principle of differential positioning, which means that the position of one GNSS receiver is determined in relation to another, whose 3D coordinates are known. The receiver that is placed on a point with known coordinates is called a base receiver. The receiver used to determine the coordinates of new points is called a rover. It receives the corrections of the base device and calculates its precise position in relation to them and its own measurements. Correction can be transmitted between two receivers via radio or internet connection. It is very important that both devices receive signals from the same satellites. In order to obtain centimeter accuracy of 3D coordinates, it is necessary that both receivers "see" at least 5 of the same satellites (Štroner et al., 2021); (Pearson et al., 2023).

## RESULTS

Three points were determined on the ground as shown in Figure 4, which served as existing polygon networks, from which three points were observed, which served for geo-referencing the terrain model obtained by the aerial photogrammetric method. The coordinates of the points can be found in Table 1.


Figure 4. Geodetic Base of the Terrain

Table 1. List of Coordinates of the Existing Polygon Network

| ID | Y | X | Z |
|---|---|---|---|
| P1 | 6543021.056 | 4946205.144 | 259.601 |
| P2 | 6542931.633 | 4946255.932 | 250.103 |
| P3 | 6542953.927 | 4946155.833 | 249.394 |

For the purposes of aerial photography and geo-referencing the model, it was necessary to stabilize the points. Three supplementary polygon points of the network were stabilized on the ground, and tachymetry measurements were made from the known ones using a total station. The points are stabilized with a pin, but also marked with color, and crosses on the ground, so that they can be seen on the photos and can be marked on the same, and get a geo-referenced 3D model of the terrain. From each point of view (P1, P2, P3), all points of the grid are observed, where the values of directions and lengths are registered for each observed point. The measurement of horizontal directions was performed using the gyros method (a method of measuring directions in two binocular positions). The averages of all observed horizontal directions, as well as the averages of zenith angles (Table 2), and the averages of all lengths (Table 3) were calculated.

Table 2. Measured Directions Used in 2D Leveling

| Station | Sight | Orientation | Direction |
|---|---|---|---|
| P1 | P3 | P3 | 0°0’0” |
| P1 | D1 | P3 | 9°2’27” |
| P1 | D3 | P3 | 55°35’15” |
| P1 | D2 | P3 | 59°27’29” |
| P3 | P2 | P2 | 0°0’0” |
| P3 | D3 | P2 | 4°17’21” |
| P3 | D1 | P2 | 36°13’25” |
| P3 | D2 | P2 | 49°53’37” |
| P2 | P1 | P1 | 0°0’0” |
| P2 | D2 | P1 | 1°58’19” |
| P2 | D3 | P1 | 34°55’26” |
| P2 | D1 | P1 | 39°42’36” |

Then the definitive height differences are calculated, which are obtained on the basis of the height difference over the zenith angle and the measured length between the points (Table 3).

Table 3. Measured Lengths Used in 2D Leveling and Height Differences Used for 1D Leveling

| From | To | Lengths | Height difference |
|---|---|---|---|
| P1 | P3 | 83.29 | |
| P1 | D1 | 66.132 | -10.19 |
| P1 | D2 | 24.207 | -3.27 |
| P1 | D3 | 82.924 | -10.251 |
| P2 | P1 | 102.842 | |
| P2 | D1 | 86.67 | -0.691 |
| P2 | D2 | 78.831 | 6.225 |
| P2 | D3 | 25.914 | -0.755 |
| P3 | P2 | 102.557 | |
| P3 | D1 | 20.767 | 0.015 |
| P3 | D2 | 73.996 | 6.94 |
| P3 | D3 | 77.505 | -0.051 |

All these data are needed to access the network leveling. In addition to the measured data, it is also necessary to take into account the data on the measuring instruments and their declared accuracies.

***Assessment of the accuracy of points for supplementary polygons of the grid and error ellipses***

A global test for two-dimensional (2D) flattening, with probability 95%: $0.637885509150189 \leq 1 \leq 2.80007372103773$

The global test is satisfied.

Local 2D levelling test results, with probability 99% are found in Table 4.

Table 4. Local Test Results for 2D Smoothing

| **Measurement** | | **The test passes** |
|---|---|---|
| 1 | 3.523 | No |
| 2 | 2.965 | Yes |
| 3 | 1.610 | Yes |
| 4 | 3.377 | No |
| 5 | 1.244 | Yes |
| 6 | 0.849 | Yes |
| 7 | 1.846 | Yes |
| 8 | 1.834 | Yes |
| 9 | 2.622 | Yes |
| 10 | 0.495 | Yes |
| 11 | 5.186 | No |
| 12 | 1.801 | Yes |
| 13 | 0.979 | Yes |
| 14 | 0.949 | Yes |
| 15 | 0.340 | Yes |
| 16 | 0.668 | Yes |
| 17 | 0.461 | Yes |
| 18 | 0.186 | Yes |
| 19 | 1.367 | Yes |
| 20 | 1.105 | Yes |
| 21 | 0.417 | Yes |
| 22 | 0.857 | Yes |
| 23 | 0.621 | Yes |
| 24 | 0.006 | Yes |

A global test for one-dimensional (1D) smoothing, with probability 95%: $3.290489805E\text{-}10 \leq 1 \leq 3.842546033E\text{-}09$

Global test not satisfied!

Local 1D leveling test results, with probability 99% are found in Table 5.

Table 5. Local Test Results for 1D Smoothing

| Measurement | $\tau_i$ | The test passes |
|---|---|---|
| 1 | 2.186 | Yes |
| 2 | 0.036 | Yes |
| 3 | 2.452 | Yes |
| 4 | 3.486 | Yes |
| 5 | 3.449 | Yes |
| 6 | 0.320 | Yes |
| 7 | 0.416 | Yes |
| 8 | 3.376 | Yes |
| 9 | 5.009 | No |

Rating of accuracy is shown in Table 6, and elements of standard and absolute error ellipses in Table 7.

Table 6. Rating of Accuracy

| ID | $S_Y$ | $S_X$ |
|---|---|---|
| D1 | 0.00146 | 0.00085 |
| D2 | 0.00085 | 0.00144 |
| D3 | 0.00153 | 0.00094 |

Table 7. Elements of Standard and Absolute Error Ellipses

| | Elements of the standard error ellipse | | | Elements of the absolute error ellipse | | |
|---|---|---|---|---|---|---|
| ID | Semi-major axis | Semi minor-axis | Rotation angle | Semi-major axis | Semi minor-axis | Rotation angle |
| D1 | 0.0017317 | 0.0006231 | 0.4355601 | 0.0046995 | 0.0016909 | 0.4355601 |
| D2 | 0.0016775 | 0.0007245 | 1.9687456 | 0.0045524 | 0.0019662 | 1.9687456 |
| D3 | 0.0018119 | 0.0007571 | 2.7040697 | 0.0049173 | 0.0020547 | 2.7040697 |

***Detailed recording of the depot***

The area of the mentioned landfill/depot was recorded (measured) with the help of two methods: photogrammetric and GNNS. When collecting data with aerial photogrammetry, at least two shots are used, this must overlap in the range of 60% to 90%. When recording, not all points are always clearly visible, so it is desirable that the camera changes its height and position during recording. Due to the absolute orientation of the model, it is necessary to use control points on the ground. In this particular case, three control points were set. Two points were located at the base of the depot, and the third point was placed on the depot itself, in order to obtain approximately the maximum height of the depot.

Before starting recording using the GNSS method, it is necessary to perform localization. The points used for localization are the points of the National Survey which are located in the vicinity of the location that was recorded. The recording was done with a GPS device manufactured by Trimble-R8 model 3, using the RTK recording method. Recording of detailed points was necessary in order to obtain the contours of the depot and the model, so that they could calculate the volume.

## DISCUSSION

After recording and collecting all data, their processing was started. The first processed data are those obtained by the photogrammetric method, all with the aim of creating a cloud of points, then a model and finally calculating the volume. Agisoft Metashape and SURFER software were used for data processing. The application Agisoft Metashape generates 120 of photos taken based on the entered flight parameters. After importing the photos, the photos are merged based on the overlap. It should be paid attention to whether all the photos are aligned. After that, the geo-referencing of the model is approached, by marking control points on the photos. Those points are marked on the ground, and their position is determined by a GPS device using the RTK method. In this step, it is necessary to define the coordinate system (official state coordinate system of Bosnia and Herzegovina MGI Balkans zone 6, EPSG: 31276). After geo-referencing the model, the generation of a dense cloud of points is approached, where there is a possibility of determining the quality of the output product, i.e. the higher the quality, the more points the software will generate. In addition to the model created with the points obtained by the aerial photogrammetry method, a model was also created from the points obtained by the RTK method, recorded with a Trimble R8 GPS device. According to obtained data is created a relief model in the form of a wireframe presented in Figure 5, and TIN model presented in Figure 6.


Figure 5. Wireframe Model of Terrain

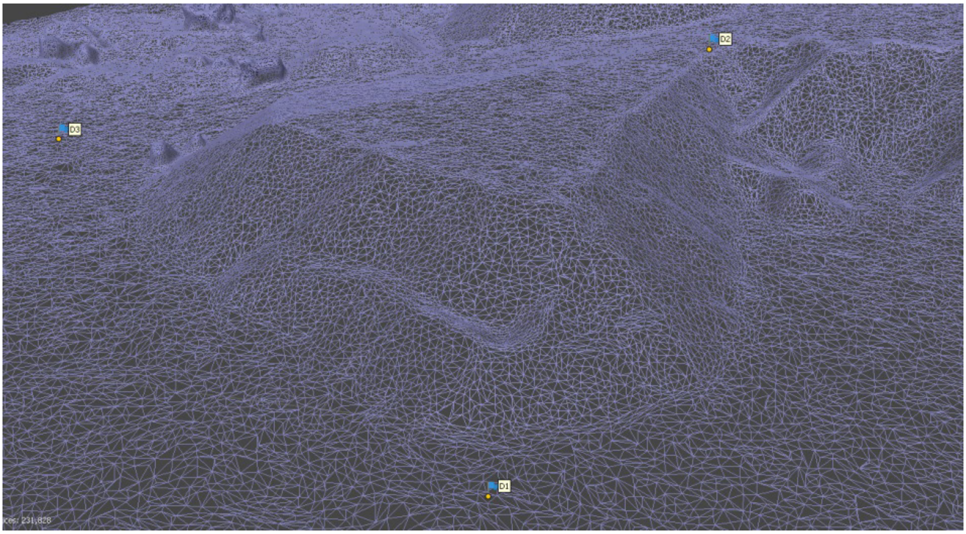


Figure 6. Terrain Model Made of TINs

A geo-statistical terrain model was created with the SURFER software, obtained by the Kriging method, and Figure 7 shows a model for points collected by the aero-photogrammetric method, and Figure 8 shows a model based on points collected by the RTK method. Values of volumes of deposited masses are also presented in Table 10 with the assumption that the disposal started from elevation 249,6.

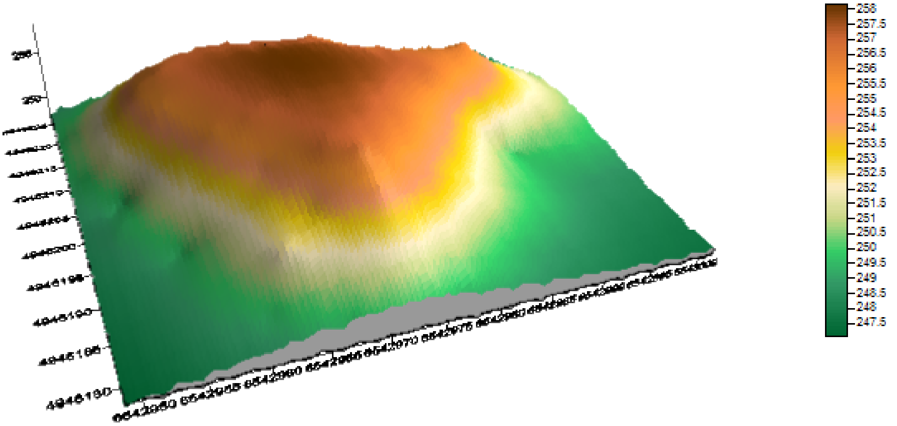


Figure 7. Terrain Model Created with Geo-statistical Software SURFER (Aerophotogrammetric)

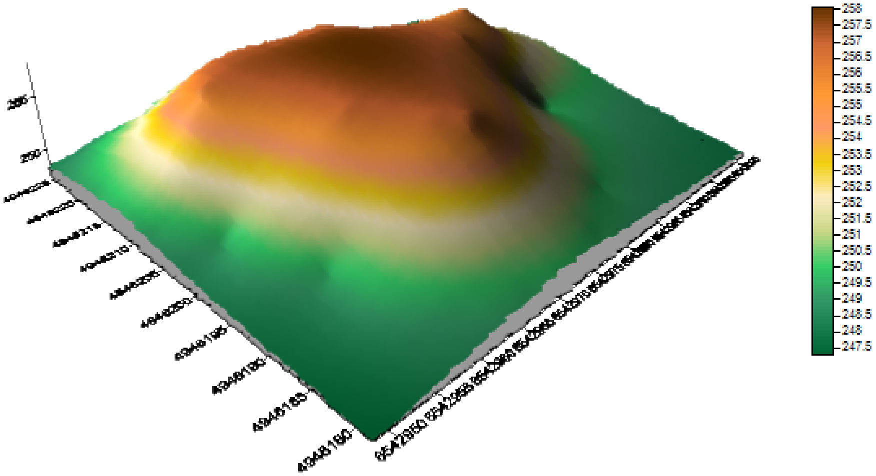


Figure 8. Terrain Model Created with Geo-statistical Software SURFER (GNSS RTK)

Mass-volume calculations were done in AutoCad Civil 3D and SURFER software. First, the mass calculation was done for the model obtained by the aerial photogrammetric method, and then for the model obtained by the GNSS method, the results of which can be found in Table 8 and Table 9.

Table 8. Depot Volumes for the Model Obtained
by Aerial Photogrammetry and GNNS Method

| Method | Aerial photogrammetry | GNSS |
|---|---|---|
| TIN | 6760.68 [$m^3$] | 6721.64 [$m^3$] |
| Cross profiles | 6758.94 [$m^3$] | 6711.81 [$m^3$] |

Table 9. Depot Volumes Obtained by Software SURFER

| Method | Aerial photogrammetry | GNSS |
|---|---|---|
| Trapezoidal Rule | 6982.27 [$m^3$] | 6809.77 [$m^3$] |
| Simpson's Rule | 6983.38 [$m^3$] | 6810.79 [$m^3$] |
| Positive Volume [Cut] | 7610.88 [$m^3$] | 7387.00 [$m^3$] |
| Negative Volume [Fill] | 628.59 [$m^3$] | 577.21 [$m^3$] |
| Net Volume [Cut-Fill] | 6982.28 [$m^3$] | 6809.79 [$m^3$] |

When calculating the volume using a network of irregular triangles, the software creates a model using the points, and calculates the volume based on the model. However, when we calculate the volume through the cross profiles, the body is actually divided into segments, where the curve is approximated along the length. In this paper, the volume was calculated using the method of cross profiles with a distance of 5 m. That the distance between the cross profiles was decreasing, i.e. if we reduced the distance between the profiles to 1 m, the volume obtained by the method of cross profiles would approach the amount obtained by the method of calculating the volume through a network of irregular triangles. In this case, the volume obtained through the network of irregular triangles is different and larger, but this does not mean that the volume over the profile will always be smaller. If the surface is convex, we will have less mass, and if it is concave, we will have more mass.

## CONCLUSION

This paper presents the aerial photogrammetric method of recording the depot with the DJI Phantom 3 Pro drone, and the GNSS method of data collection in order to define the depot in space. On the site, it was necessary to establish a supplementary polygon network, and to perform tachymetry measurements, in order to obtain the data necessary for leveling that network. The data collected by the aerial photogrammetric method were processed in the Agisoft software, and as the final result of the processing, a network model of the depot and a model represented by a network of irregular triangles were presented. During processing, a cloud of points is generated, which counts in millions of points. Certain points were exported and used to create a model, on the basis of which the volume of the depot was calculated. The final result is two models - one obtained by the aerial photogrammetric method and the other obtained by the terrestrial method. For each of those models, the volume was calculated using two methods - the method of cross profiles and the method of the network of irregular triangles. As an additional check, volumes were calculated with geo-statistics software SURFER.

We can conclude that the aerial photogrammetric method has advantages over the GNSS method. The same conclusion is given by the authors Raeva, Filipova, and Filipova (2016) through their research. It enables the collection of detailed information about the subject in high resolution, where we also have small details, which could be missed by some other methods. In addition to a larger amount of data that is collected in a shorter time interval, using this method we have a reduction in costs. Savings are achieved by quick data collection, reducing the need for field research, and thus we need fewer human resources to collect them. This method especially has an advantage over the GNSS method when recording quarries and similar active sites and for safety reasons, because during geodetic recording of the same, we have possible dangers such as landslides, terrain collapse, etc.

It can be concluded that the method of calculating the volume using a network of irregular triangles gives more reliable and realistic results compared to the method of cross profiles. The above statement was confirmed with the use of the geo-statistical package SURFER with the application of the Kriging method for geo-statistical mapping of the collected data, based on which the value of the volume of deposited masses was calculated. The calculation obtained by TIN has more approximate values than with cross profiles.

The obtained values of the calculated amounts of mass deposited at the landfill help in future activities related to the creation of the landfill and forecasting as well as making decisions about the total quantities that can be disposed of at this and future researched locations.

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***Notes on the authors***

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