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INVESTIGATION OF LANDFILL SATURATION BASED ON PERIODIC AERIAL PHOTOGRAMMETRIC MEASUREMENTS

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Abstract: The actuality of the study of saturation in Hungarian landfills is indisputable; its research is definitely justified. In our paper, we undertake this task based on the periodic drone geodetic surveys of the landfill of a medium-population city in Hungary. After evaluating the results of each survey, the expected date of landfill saturation is determined by us, and possibilities for its further specification are also examined.

Keywords: *landfill saturation, periodic surveys with a drone, 3D models, volume computation*

1. INTRODUCTION

Nowadays, it is becoming more and more urgent to find a solution to reduce the amount of the generated waste. Although not the most significant in terms of quantity, municipal solid waste is of paramount importance in terms of its complexity and difficulties in its management. The basic goal is to preserve and improve the condition of both our narrow and wide environment, to ensure long-term living conditions so that not only local interests but also global ones prevail.

The amount of the generated waste needs to be reduced both on the generation side (production, manufacturing, packaging, transport, storage) and by increasing the rate of recycling (e.g. as a secondary raw material). The increasing use of secondary raw materials is also required by the finite amount of raw materials found in nature. Ultimately, the declining rate of landfilling should be a measure of system efficiency. Of course, the landfill takes place under controlled conditions, which are also designed to ensure that the utilization of the landfill is as high as possible. There are several ways to achieve this, such as compaction with heavy vehicles, keeping the moisture content of the waste mixture at an optimal level, and reducing the size of the waste components. Geodetic surveys make it possible to determine the degree of saturation. This is done by calculating the volume of the landfill area surfaces constructed from the results of these periodic measurements (ground or aerial) determined by the base plane or the plane of the previous measurement result and the sidewall provides the desired result. The application of drone surveys to various volume computation tasks is described for example in [1], [2], and [3].

2. THE LEGISLATION OF THIS SPECIAL FIELD

First, let us briefly introduce the legislation governing waste management; the number of these laws also supports the importance of the problem [4], [5], [6]:

Laws:

- Act LIII of 1995 on the General Rules for the Protection of the Environment;
- Act CXL of 2004 on the General Rules of Administrative Authority Procedure and Service;
- Act CLXXXV of 2010 on Waste;
- and approximately
- 19 government decrees;
- 17 ministerial decrees.

Directive 2018/851 of the European Parliament and the European Council (30 May 2018) amending Directive 2008/98/EC on waste contains specific targets whose fulfilment can be partly confirmed by the degree of landfill saturation. Target values are linked to dates as follows:

- by 2025, the amount of municipal waste prepared for re-use and recycled should be increased to a minimum of 55% by weight;
- by 2030, the amount of municipal waste prepared for re-use and recycled shall be increased to a minimum of 60% by weight; and
- by 2035, the amount of municipal waste prepared for re-use and recycled should be increased to a minimum of 65% by weight.

In order to achieve the target values, it is necessary to reduce the amount of the landfilled waste, especially as we are currently far from this goal in Hungary. The National Waste Management Public Service Plan for 2021, based on 2019, states the following values: 3,203,000 tons of municipal solid waste were generated in 2019, of which 2,455,000 tons were landfilled (energy recovery was approximately 600,000 tons). Thus, the weight percentage of the landfilled quantity is 76.6%. The amount of waste which has not been landfilled has not reached 25%, i.e. half of the target value for 2025, while the time available is not enough. The legislation provides for the possibility of postponing dates of achievement, but it is not a solution.

The following is a list of legislation for aeronautical photogrammetric drones [7] in both the European Union and Hungary:

- Commission Implementing Regulation (EU) No. 2019/947 (24 May 2019) on rules and procedures for the operation of unmanned aircraft;

- Commission Regulation (EU) No. 2019/945 (12 March 2019) on unmanned aircraft systems and third country operators of unmanned aircraft systems;
- Act XCVII of 1995 on Aviation law;
- Government Decree 4/1998. (I. 16.) on the use of Hungarian airspace;
- Government Decree 39/2001. (III. 5.) on compulsory aviation liability insurance;
- Decree 26/2007. (III. 1.), on the designation of Hungarian airspace for the purpose of aviation, a GKM-HM-KvVM joint decree; and
- ITM Regulation 6/2021. (II. 5.) on the designation of organizations for the training and examination of remote pilots and on the detailed rules for the training and examination of remote pilots.

Additional relevant legislation in the case of flight (measurement) for remote sensing purposes [8] is Government Decree 399/2012. (XII. 20.) on the procedure for the authorization of aerial remote sensing and the use of remote sensing data.

3. Description of drone surveys

In the following our periodic airborne surveys of a landfill in a city of 40,000 inhabitants will be described. Based on these measurements, we made a 3D model of the final state of the saturated landfill, determined the expected date of saturation in the case that the amount of landfilled waste remained constant, and then checked the degree of saturation with further measurements.

<u>Parameters of the surveying device</u>:

drone:	DJI Phantom4 RTK,
camera model:	DJI FC6310R,
number of images:	590,
flight height:	92 m,
terrain resolution:	0.0270 m,
resolution:	5472 × 3648,
focus distance:	8.8 mm,
sensor size:	13.2 × 8.8 mm,
pixel size:	2.412 μm,
ortofoto size:	387.825 m × 418.275 m,
pixel resolution:	0.025 m.

The drone has an RTK (Real-Time Kinematic) GPS unit and is capable of receiving real-time correction. In order to minimize the uncertainty in the position resulting from the velocity during the flight, Ground Control Points (GCPs) were used for each survey, which were measured by us with a ground RTK GPS device (*Table 1* and *Figure 1*).

A network RTK service was used by us with VRS concept. According to the VRS concept, the mobile receiver first sends the approximate coordinates of its geographical position to the control panel (GGA message), the control panel generates localized measurement results or corrections to this location, and then transmits these fictitious data about the virtual point to the mobile receiver. During the establishment of the control points, the level differences of the area and the shape characteristics of the landfill were taken into account *(Figure 2)*. When choosing the flight speed and altitude (102.8 m), we kept in mind the optimal terrain resolution as well as the maximum terrain level deviation in the area *(Table 2*). The *Table 3* contains various errors related to camera positions.

Table 1

Ground Control Points

Point numbers	Coordinates			Errors [m]				Number of projections
	X	Y	Z	X	Y	Z	3D	
2002	495832.026	121461.284	207.193	0.004	–0.005	0.006	0.008	57
2004	495849.217	21289.1681	200.617	–0.002	0.005	0.011	0.012	57
2006	495996.141	121247.290	186.133	–0.011	0.000	0.000	0.011	91
2008	496126.561	121305.340	186.014	–0.004	0.011	0.004	0.012	103
2012	496054.287	121410.432	188.794	0.007	0.008	–0.012	0.016	89
2014	495912.306	121546.513	207.840	0.005	0.001	0.009	0.010	41
2016	495936.900	121430.386	221.660	–0.003	0.002	–0.007	0.008	53
2018	495879.463	121350.849	217.996	–0.002	–0.002	–0.021	0.021	36
2020	495898.852	121265.816	212.460	0.002	–0.005	0.007	0.009	56
2022	496052.826	121333.072	212.715	0.003	–0.010	0.033	0.034	61

Figure 1

The measured GCPs and their field locations

Table 2
Surveying data

Number of images:	571	**Registered number of images:**	568
Flight altitude:	102.8 m	**Number of the key points per each image / average:**	1167
Terrain resolution:	0.0302 m	**Georeference:**	Yes

Table 3
Camera positions

X error [m]	Y error[m]	XY error[m]	Z error [m]	Total error [m]
0.374	0.309	0.486	0.149	0.508

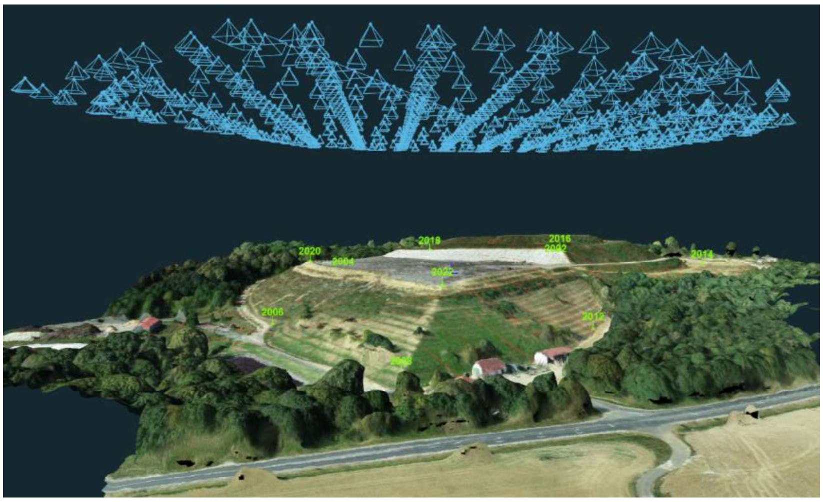

Figure 2
Landfill with control points and drone positions where photographs were taken during the survey

The measuring results were loaded into the 3D Survey processing software (photos, geocodes, telemetric data) together with the coordinates of the measured control points. The software corrected the above-mentioned uncertainty (considering the measured GCPs) in the process and created a digital surface model and a georeferenced orthophoto. We have chosen an optimized (global) processing method for the large amount of data available to us. The photogrammetric survey and processing were performed in a Unified National Projection System, for which we used a Vitel transformation.

Using the 3D survey, we determined the volume difference between each measuring state, which was checked with the Surfer program *(Figure 3)*.

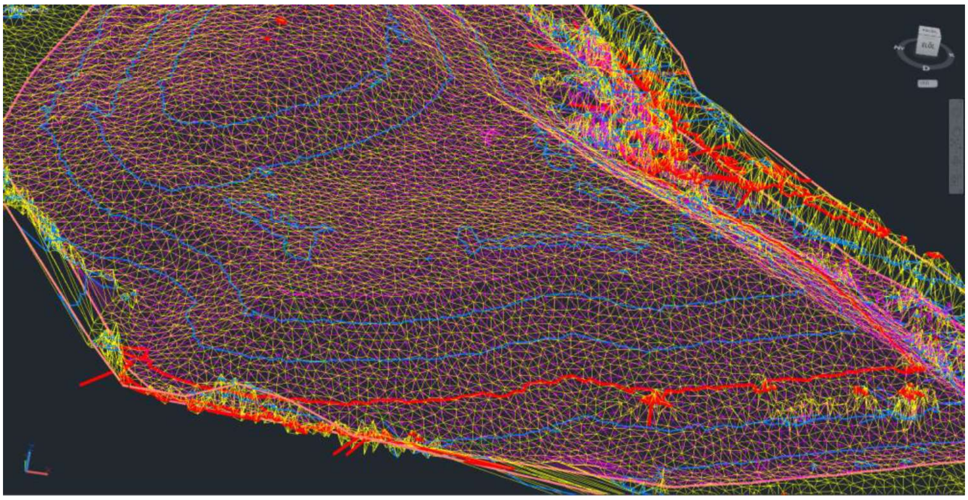

Figure 3
Triangulated Irregular Network (TIN) models made of two successive measurements (first measuring state: yellow, second one: purple) projected on top of each other

<u>Surveying dates:</u>

- first measurement – on September 22, 2020, for lack of a base plane, preparation of the reference surface;
- second measurement – on May 9, 2021, when the first volume computation and the final state model were produced as well as the saturation date calculation;
- third measurement – September 21, 2021, second volume computation.

The volume of the deposited quantity in the elapsed period was computed from the difference of the field levels prepared from the data of two consecutive measurements. The field level of the first (lower) measurement state was subtracted from the field level of the second measuring state, so that the space between the two measurements was obtained, determined by relative heights (level change [m]). The volume computation was not based on the total landfill area, but on the "active" landfill, where the actual disposal takes place. A negative value in some places in the landfill at a later date means that the level was lower than before. This is due to the accumulation of waste in the meantime on the basis of the landfill plan and the elimination of surface irregularities resulting from the compaction. The reason for the level changes appearing on the side of the landfill is the vegetation cover typical in different seasons, which is not included in the volume calculation as a result of narrowing. A triangular and grid model was produced from the point cloud for volume computation, and the landfill was delimited with the help of the orthophoto.

In the following figures the cross-sections drawn from the TIN models of measurements 2 and 3 *(Figure 4)*, the terrain models of the first two measurements (*Figures 5* and *6*), the assumed end-state model after measurement 2 *(Figure 7)*, and the terrain model of measurement 3 *(Figure 8)* are illustrated.

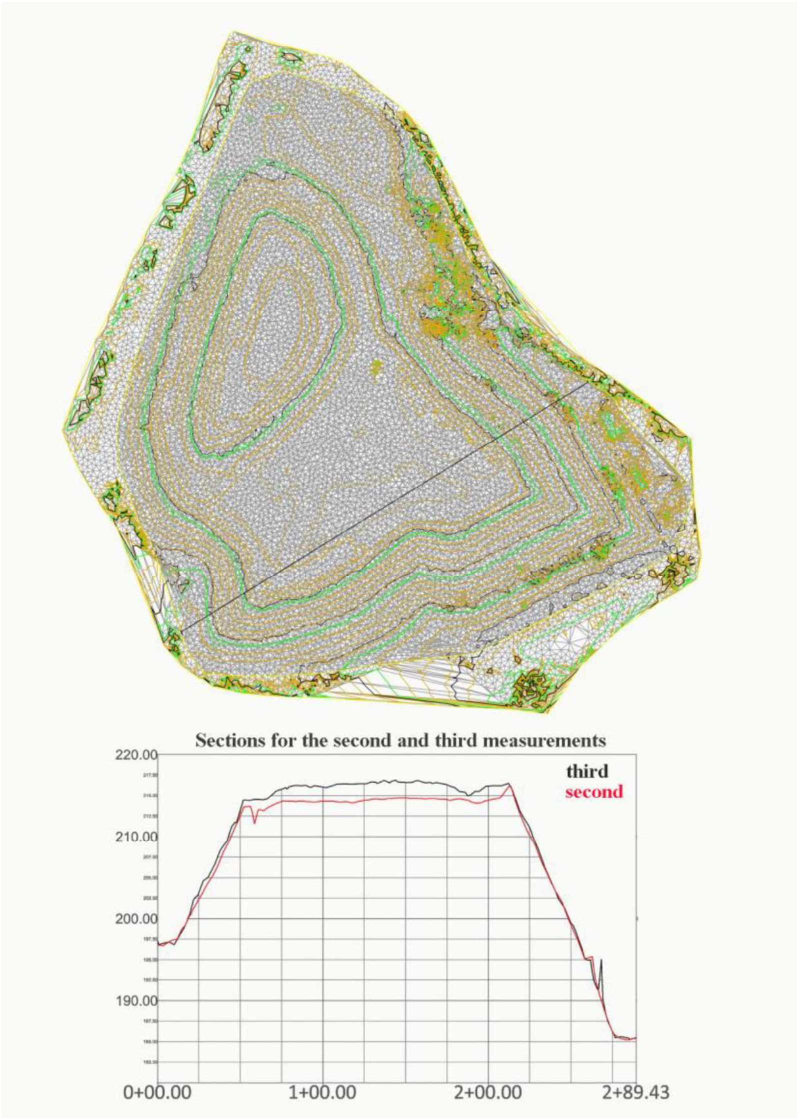

Figure 4
Cross sections made of two TIN models

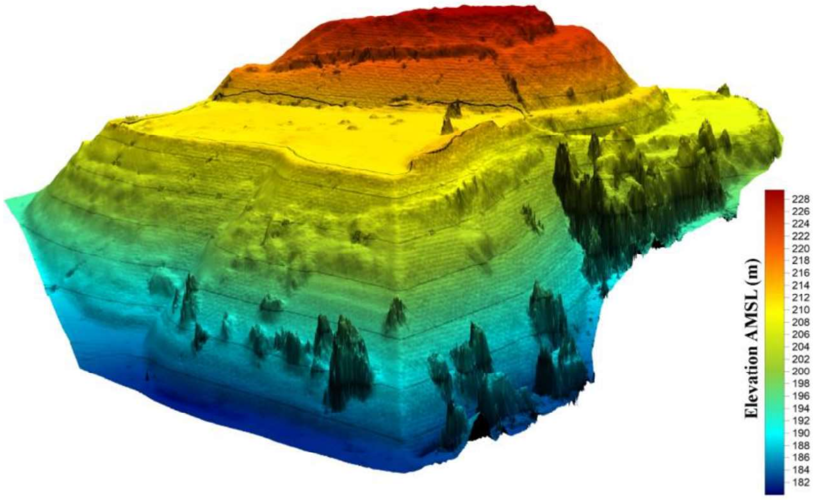

Figure 5
A terrain model of the 1st measurement

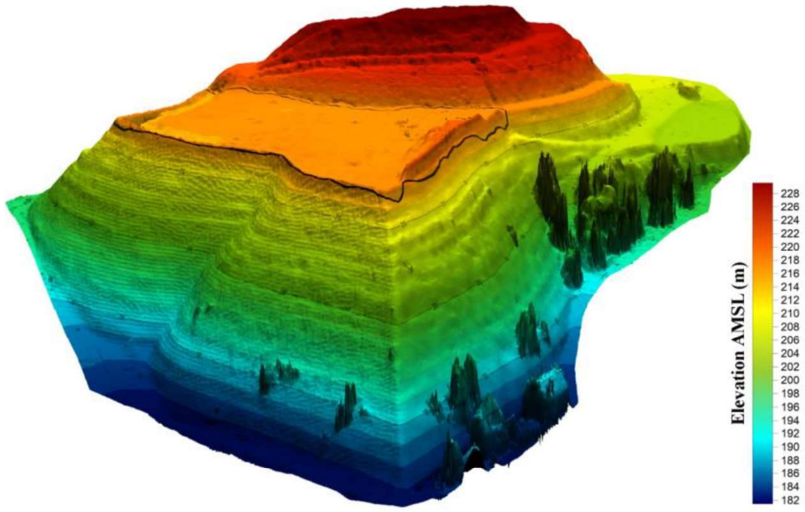

Figure 6
A terrain model of the 2nd measurement

Based on the first two sets of measurement data, a 3D model of the assumed final state of the landfill was created. The sealing level is the upper edge of the insulation on the hillside, with a maximum determined near 222 m (above Baltic Sea level). Subsequently, the difference between the two surfaces (between the second survey state and the assumed final one), i.e. the available free landfill volume, was calculated as before.

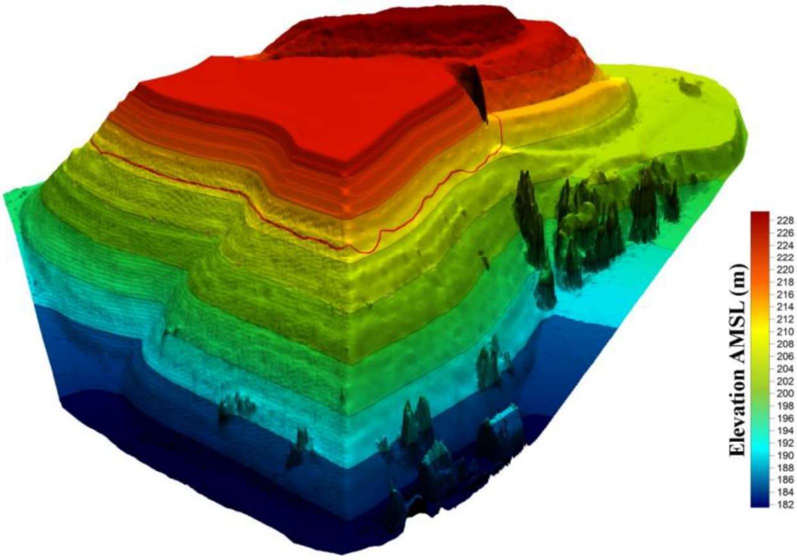

Figure 7
A 3D model of the assumed end state

It is important to note that the highlighted data in *Table 1* below are based on a hypothetical end-state model based on little information (the insulation on the side of the hill gives the final height of the landfill at 222 m Baltic Sea). This estimate includes both the landfilled waste and the landfill material. This should be taken into account when using the data. If more accurate information about the final state is available, the model can be refined, so we can obtain more reliable data.

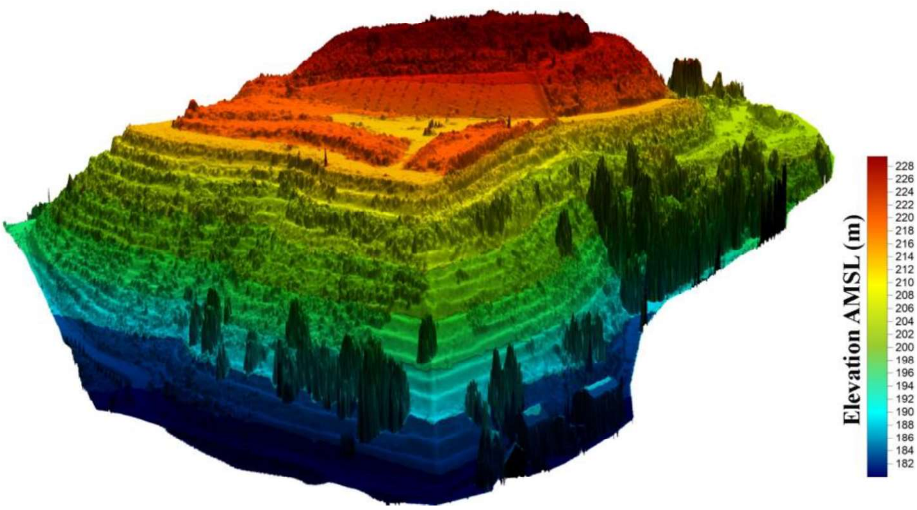

Figure 8
A terrain model of the 3rd measurement

4. DETERMINATION OF VOLUME CHANGES

In *Figures 9* and *11* the volume changes between each measurement time (1–2 and 2–3) and the free volume between the 2nd surveying occasion and the assumed final state can be seen *(Figure 10)*.

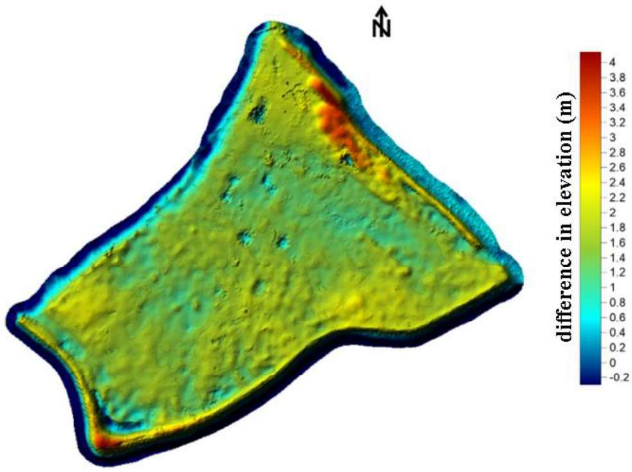

Figure 9
The computed volume (amount of filling) between the two measuring states (22/09/2020 and 09/05/2021): 23,070 m^3

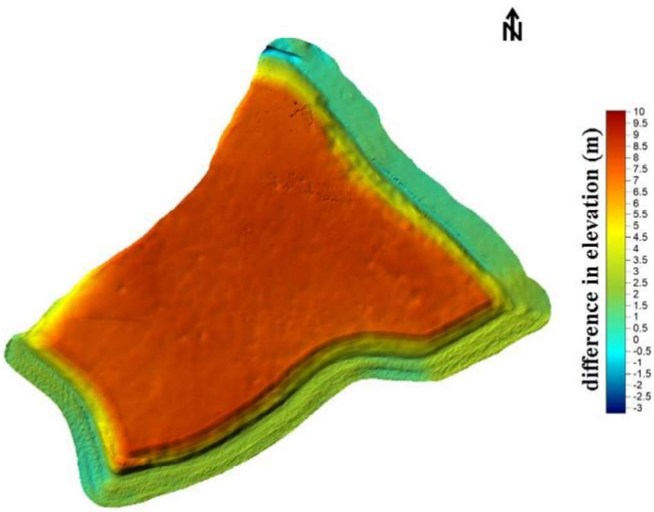

Figure 10
The computed free volume (101,650 m^3, 09/05/2021) available from the 2nd measuring state to the assumed final state level

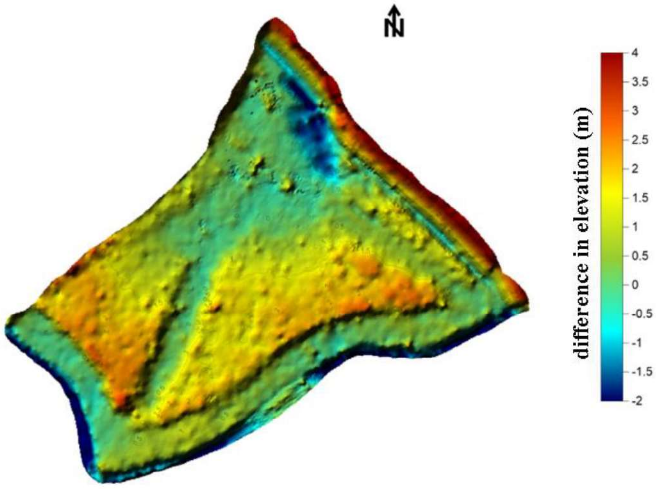

Figure 11
The computed volume (amount of filling) between the two measuring states (09/05/2021 and 21/09/2021): 13,040 m^3

The computer edited surface, as well as the expected saturation date calculated on the basis of the surveying results, calculated as the degree of saturation between the measurements, is given in *Table 4.*

Table 4
The evaluated data of landfill volume surveys (red – calculated values)

measurement 1	**measurement 2**	**volume changes [m^3]**	**number of days**	**m^3/day**
22. 09. 2020	09. 05. 2021	23070	227	101.6
measurement 2	**end state date**	**volume changes [m^3]**	**number of days**	**m^3/day**
09. 05. 2021	**30. 01. 2024**	**101650**	**997**	**102.0**
measurement 2	**measurement 3**	**volume changes [m^3]**	**number of days**	**m^3/day**
09. 05. 2021	21. 09. 2021	13040	128	101.8

The values marked in red in the table are calculated ones. From the first two measurements, a saturation rate for the period (101.6 m^3/day) was determined. The volume available up to the final state was divided by the degree of saturation (the value was rounded up to 102 m^3/day) to obtain the number of days (997) until saturation. This was added to the 2nd measurement date from which the saturation time was derived.

The change in volume between the second and third measurements was also divided by the elapsed number of days in the meantime to determine the degree of saturation for the new period. The value of 101.8 m^3/day is higher than before, which does not support the decreasing trend of the deposited volume. Of course, we measured different periods within a year, winter (heating) and a summer, which also show a difference in the composition of the waste, and the one-year period studied can be considered short to draw this type of conclusion. We plan to continue the surveys if we have the opportunity. More reasonable conclusions can be drawn from comparing several periods within the same year.

However, based on what has been done so far, it appears that the landfill will be saturated before the date of the first EU target, creating a very difficult situation for the region's waste management sector.

5. CONCLUSIONS

In our study, after a short introductory part, we dealt with the Hungarian and EU legislation related to the research work, including the legal regulations related to the applied geodetic method (drone survey). Then we introduced the surveying device used for the measurements, we described each measurement and their processing. Then we gave the data characterizing the saturation of the landfill based on the specified volume change (especially its expected date) in tabular form. Finally, we examined the reliability of this important data and the need for further research for the sake of its refinement as well.

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REFERENCES

[1] Raeva, P. L., Filipova, S. L., Filipov, D. G. (2016). Volume computation of a stockpile – a study case comparing GPS and UAV measurements in an open pit quarry. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLI-B1, 2016, pp. 999–1004, XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic. https://doi.org/10.5194/isprsarchives-XLI-B1-999-2016

[2] Mantey, S., Aduah, M. S. (2021). Comparative Analysis of Stockpile Volume Estimation using UAV and GPS Techniques. *Ghana Mining Journal*, Vol. 21, No. 1, pp. 1–10, eISSN: 0855-210X. https://doi.org/10.4314/gm.v21i1.1

[3] Arango, C., Morales, C. A. (2015). Comparison between multicopter UAV and total station for estimating stockpile volumes. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-1/W4, 2015, pp 131–135, *International Conference on Unmanned Aerial Vehicles in Geomatics*, 30 Aug–02 Sep 2015, Toronto, Canada, https://doi.org/10.5194/isprsarchives-XL-1-W4-131-2015.

Waste management plans, legislation:

[4] *National Waste Management Plan (2021–2027)*, (Base year: 2018), 1704/2021(X. 6.) Government Decision, Ministry of Innovation and Technology, https://kormany.hu/dokumentumtar/orszagos-hulladekgazdalkokodasi-terv_2021_2027.

[5] NHKV National Waste Management Coordinating and Asset Management Private Limiting Company (NWMCAM PLC.). *National Waste Management Public Service Plan 2021*. https://nhkv.hu/wp-content/uploads/2020/09/OHKT_2021.pdf, https://nhkv.hu/vonatkozo-jogszabalyok/.

[6] *National Association of Waste Managers (NAWM), Hungary*. https://www.hosz.org/jogszabalyok/hazai-jogszabalyok

[7] *Drone regulation (Hungary)*. https://mydronespace.hu/; https://www.hungarocontrol.hu/; https://legter.hu/

[8] *Hungarian Defence Forces Geoinformation Service (HDFGS)*. https://honvedelem.hu/alakulat/mh-geoinformacios-szolgalat.html