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Estimation of the Landfill Residual Capacity by UAV Survey Results

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Abstract: This article discusses the important task of landfill current residual capacity assessment, on the example of the landfill site located in the Republic of Tatarstan. The modern methods of high-precision three-dimensional reconstruction were used by the results of unmanned aerial vehicle (UAV) survey, equipped with a global navigation satellite system (GNSS) receiver. The main stages of work were combining the project and field survey data into one coordinate and height system, reconstruction of designed underground and above-ground parts of landfill, project and actual models comparison, the calculation. As a result, the estimation of the landfill residual capacity becomes possible, which allows to develop recommendations for further landfill operation. The proposed approach allows rapid and high-quality active monitoring of the engineered facility. Photogrammetric processing of the results of low-altitude aerial photography makes it possible to obtain objective data on the current actual state of the landfills, to carry out competent and valid management of the landfill functioning. Such studies can significantly extend the landfill's lifetime, minimize the negative impact on the environment and predict the attainment of projected capacity much more accurately.

1 INTRODUCTION

Currently, the overwhelming amount of solid waste in the world is still being stored at landfills. Solid waste disposal is associated with the use of large territories and their exclusion from beneficial use. For the 1 ton of solid waste burial, 3 m^2 of area is required. At the same time, each landfill "eats" from 6 to 50 hectares of land. Existing landfills already occupy vast territories around cities.

In modern conditions, it is necessary to effectively use existing landfills without involving new areas of natural territory for construction (Mondal et al., 2023). At the same time, it is necessary to study and evaluate the processes of the landfill body formation. It is known that solid municipal waste has a high compaction ability under the influence of waste pressure, machinery, and biodegradation (Chen et al, 2009; Van Geel and Murray, 2015). The final changes in the vertical structure of the polygon due to biodegradation processes can be 25-50 % (Bareither et al., 2012; De et al., 2013; Galitskaya et al., 2011), stabilization of garbage masses can continue for several years.

The determination of the actual geometric parameters of the waste dump body is of great practical importance, since a quantitative assessment of the free volume of the landfill site will more accurately assess the achievement of the design dimensions of the landfill and the period of its further operation.

Geoinformation methods of spatial analysis are widely used to determine the state of municipal solid waste (MSW) landfills (Esposito et al., 2018). Modern field research methods allow us to obtain more accurate results (Yermolaev et al., 2014). To determine the volume of waste according to long-term monitoring of the landfill, a stereo camera method is used (Gasperini, 2014). The most common method is the topographic survey of the polygon territory using geodetic instruments such as batter levelers, total stations and terrestrial laser scanners (TLS) (Yermolaev et al., 2021), and more recently,

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GNSS receivers (Baiocchi, 2019). Increasingly, to obtain data on changes in waste volumes at MSW landfills, the survey of an unmanned aerial vehicle (UAV) and obtaining 3D models by photogrammetry post-processing is used (Yoo, 2017; Athirah, 2019). The integration of TLS and UAV technologies demonstrates the high efficiency of the UAV method, which provides high accuracy and efficiency of calculating the volume of waste (Silva et al., 2016; Tucci, 2019; Son, 2020). Especially attractive is the use of inexpensive drones, which allow obtaining accurate landfill models and reservey, providing the necessary data to assess the residual capacity (Incekara, 2019). The presented work continues the study of the residual capacity determination for the existing landfills on the territory of the Republic of Tatarstan (Akhmetzyanova et al., 2021).

2 RESEARCH METHODS

2.1 Landfill Description

The object of the survey is the MSW landfill located in the Kamskoye Ustye district of the Republic of Tatarstan (Russian Federation). The landfill has been operating since 1997.

The design capacity of the landfill is 106 970 m^3. It must ensure its functioning for at least 20 years. The solid waste storage area is designed in the form of a hill, should have a full height of 11.5 m above the ground.

At the time of the survey, the landfill is working, fenced, guarded. The organization of work on the collection, storage, compaction, and isolation of solid waste is determined by the technological scheme and the schedule of operation of the landfill. Solid waste arrives at the landfill in an uncompact state.

2.2 Field and Instrumental Examination

To assess the current state of the landfill, field and instrumental work was carried out in July 2022. Meteorological conditions at the time of survey had the following characteristics: partly cloudy, wind speed - 5m/sec.

The work was carried out using an DJI Phantom 4 PRO v2 UAV, equipped with a 20-megapixel camera. Changes were made to the modification of the quadrocopter – an external EMLID Reach M+ GNSS receiver with a TOPGNSS TOP508 spiral antenna was installed. It allow to record coordinates with a frequency of 1 Hz, and reduce the camera shutter response to 0.05 seconds.

The UAV survey were carried out using the DroneDeploy mobile software. The flight altitude above the take-off point was set as 90 m, the forward and side overlap between images – 75%.

The data from the GNSS receiver was recalculated based on data from the base station of the high-precision positioning service closest to the site. The standard deviations (RMS) of the images projection centers coordinates alignment did not exceed 1 cm. The obtained coordinates of the image projection centers were further compared with the UAV image files.

After that, data were processed in the Agisoft Metashape photogrammetric software, phototriangulation and the creation of a dense point cloud were performed, as a result the digital surface model (DSM) and orthophotomap were created (Gafurov, 2021).

The orthophotomap is made in the UTM coordinate system zone 39 (north) with 0.25 m spatial resolution.

The construction of a relief map based on DSM and transverse profiles through the waste dump area were performed in the Surfer 18 software, a digital terrain model (DTM) was performed with 0.5 m resolution.

3 RESULTS

To estimate landfill residual capacity, the project data were processed. The main source for constructing a 3D model of the waste dump hill were schemes containing the design geometric characteristics of the storage area.

To compare the project characteristics with the current state of the polygon, spatial reference of the scans of the project schemes was carried out by QGIS Georeferencing module. The turning points of the site boundary (fences) and structures appearing on the design data and at the survey data were used as reference points.

During the georeferencing, the polygon sizes indicated in the project schemes were monitored. After the referencing, the schemes were digitized considering the altitude characteristics of the storage area. To compare with the current situation, in addition to the landfill zone, the relief outside the storage area was vectorized. Based on the data obtained, a digital model of the storage area was built in accordance with the project (Fig. 1).

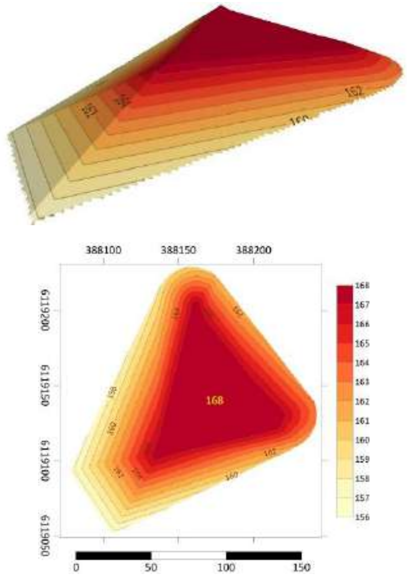

Figure 1: Digital volumetric model and terrain map of the aboveground part of the project hill of the landfill.

Photogrammetric processing of the aerial survey results of the territory of the research object made it possible to use the data obtained to assess the current state of the landfill territory.

The first thing that UAV survey data can reveal is inconsistencies in the organization of the landfill with design solutions and mismatch of the storage area boundaries (Fig. 2).

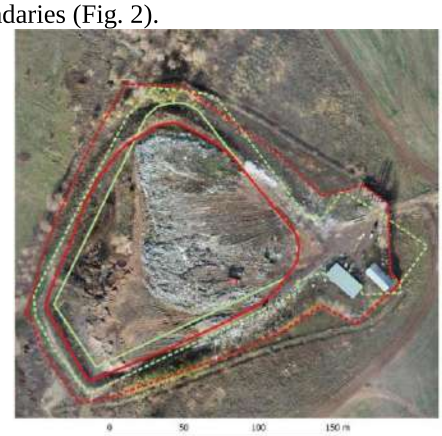

Figure 2: Orthophotomap of the landfill territory (solid green – the project boundaries, solid red - the actual contour of the storage area).

A comparison of the project and actual storage area geometry showed a difference between the project solutions in the south-western and south-eastern parts of the test site.

Based on the results of field survey data processing, a volumetric model of the landfill storage hill was built, as well as a relief map of the aboveground part of the actual storage hill (Fig. 3).

The results of field research allow us to describe in detail the relief of the storage area and compare the altitude characteristics with the project data.

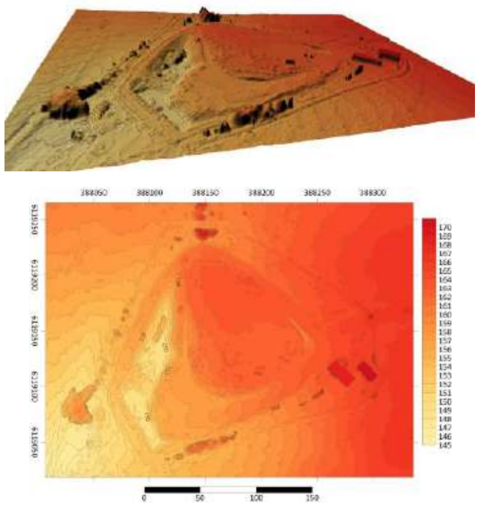

Figure 3: Digital volumetric model and terrain map of the aboveground part of the landfill by field survey data.

At the time of the field survey, the area of the site was 3.3 hectares, the actual area of the landfill storage area was 1.8 hectares. According to the project, the area of the site should be 2.7 hectares, the waste storage area – 1.7 hectares. The storage area has been increased by 5-10 m in the north-west, 8 m in the south-west and 9 m in the south-east directions. The northern corner of the storage area has been reduced by 13 m. The displacement of the storage area along the south-western border is most likely due to the organization of roads for waste unloading.

It was necessary to compare the design data and the results of field work to solve the main task of the study. The main difficulty for this object of study was the poor quality of the schemes, as well as the conditional coordinate system and heights in the project documentation. It should be noted that the most important thing during translation of the design schemes into the world coordinate system is to preserve the geometry and dimensions of the storage area specified in the project.

The original method of referencing is used in the work. The method allows to correlate the design and actual values by finding common points on the initial relief at the project schemes, and DTM, built by the results of modern field research (Gafurov et al.,2021). After transforming the data into a single coordinate system, it becomes possible to estimate the degree of filling of the polygon and its residual capacity.

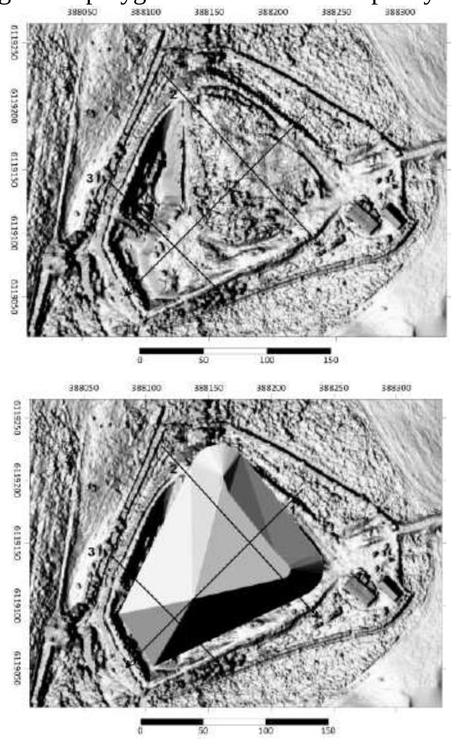

Figure 4: Landfill DSM: top – the actual situation, below – the project (numbers – profiles presented in Fig.5).

Comparison of DSM by building profiles through the storage area allows to assess the situation at each site of the landfill. In addition, the comparison of the digital model of the actual relief of the landfill with the design one clearly demonstrates the exit of the storage area beyond the design boundaries (Fig. 5).

The construction of profiles through the landfill body makes it possible to easily assess the compliance of the storage hill external slopes inclination to the project data. On the actual landfill model slopes are poorly defined and do not correspond to the project ratio.

Usually, the assessment of the residual capacity is carried out at the final stages of the landfill pyramid formation. If field studies confirm the compliance of the landfill organization with the project, it is sufficient to make calculations based on project data and the relief obtained by photogrammetric processing of the field observations. The residual capacity of the landfill can be estimated based on the project volume of the aboveground part of the storage hill and the actual accumulated volume of MSW in the aboveground part of the storage hill.

Figure 5: Transverse profiles through the project and actual storage hill.

At the study landfill, the MSW is stored outside the project boundaries of the storage area, and a simple "subtraction" of the actual relief from the design will lead to a significant measurement error. Therefore, a model of "zero relief" along the perimeter of the storage area was constructed in accordance with the photogrammetric data. Next, the volume of the aboveground part of the pyramid was calculated by subtracting the "zero" relief model from the project and actual relief.

According to the project, the design capacity for this MSW landfill is 106 970 m^3. According to the results of calculations, the residual capacity of the landfill at the moment of field survey is 46 139 m^3 or 43.13% of the project capacity. The obtained value is not so great in comparison with other examined landfill objects by similar approach (Akhmetzyanova et al., 2021).

A value close to 50% indicates that it is possible to continue operating this MSW landfill without involving new lands for waste storage.

According to the results obtained, it is necessary to bring the morphology of the relief of the landfill body in accordance with the project: to form the slopes of the landfill body, bring the boundaries of the storage area to the project position. Municipal services need to develop and plan adjustments to the territorial waste management scheme.

3 CONCLUSIONS

The use of a remote sensing method based on the results of data processing of low-altitude aerial photography makes it possible to obtain objective data on the current actual condition of MSW landfills. The analysis of orthophotomap and DTM allows to identify deviations in the implementation of project solutions, breaking the rules of waste storage operation and makes it possible to estimate the residual capacity of landfills, even in case of non-compliance with the landfill organization project.

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