

Analysis of Disposal Soil Volume Deviations Using Total Station Surveying and UAV Photogrammetry: A Case Study of the Wulan River Improvement Works Project, Package 2

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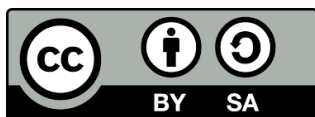
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Abstract

Disposal work is a critical activity in construction projects that requires accurate volume measurements to prevent cost overruns and material waste on-site. In the Wulan River Improvement Works Project, Package 2, disposal and excavated material placement activities are carried out on a large scale, requiring an effective and efficient measurement method. Conventional surveying using a total station provides high accuracy through point-based data acquisition but requires relatively long survey times. In contrast, unmanned aerial vehicle (UAV) photogrammetry enables rapid surface data acquisition over larger areas at potentially lower operational costs. This study aims to analyze deviations in disposal soil volume measurements obtained using total station surveying and UAV photogrammetry. Field data were acquired using a total station to establish reference measurements and a UAV to capture aerial imagery. The aerial images were subsequently processed to generate a digital elevation model (DEM) and an orthophoto, supported by ground control points (GCPs) for georeferencing and spatial accuracy. Soil volumes were calculated using the cut-and-fill method based on the resulting digital surface models, and the measurements obtained from both techniques were compared to determine absolute volume deviations and percentage differences. The findings are expected to assess the accuracy of UAV photogrammetry relative to total station surveying and provide recommendations for selecting an effective and efficient method for measuring disposal soil volumes in similar river improvement projects.



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INTRODUCTION

(Aryadi & Herzanita, 2024) The construction sector is one of the fastest-growing industries in Indonesia. (Wolf et al., 2024) Large-scale infrastructure and construction projects continue to be undertaken to promote equitable development, improve infrastructure efficiency, and enhance the quality of life of communities. As technology advances, sustainable construction practices are increasingly supported by digital transformation. Wolf et al. (2024) demonstrated that integrating technological innovations with lean construction

principles can increase productivity by up to 2% in developed countries where these practices have been adopted. In the construction industry, technology plays a crucial role in addressing project complexity and facilitating information exchange to support more effective decision-making throughout the project lifecycle (Cho et al., 2026).

One of the construction activities requiring a high degree of measurement accuracy is the excavation, disposal, and placement of surplus materials (Mukhlisin et al., 2023). Disposal refers to the removal, transportation, and placement of excess or unwanted materials generated during construction activities, such as excavated soil, sediment, debris, and construction waste, at designated locations in accordance with project specifications and technical requirements (Al-Tahir & Barran, 2020). These materials may include soil, concrete, wood, steel, and other construction debris that cannot be reused. Discrepancies between planned and actual material volumes can result in project cost overruns, schedule delays, and inefficient material management. Therefore, accurate, efficient, and reliable measurement methods are essential for monitoring disposal volumes throughout project implementation (Zhang et al., 2020).

A conventional surveying instrument commonly used for earthwork volume measurements is the total station (Lee et al., 2024). This electronic surveying instrument integrates an electronic theodolite with electronic distance measurement (EDM) technology to determine three-dimensional coordinates (X, Y, Z) with high accuracy. However, total station surveying can be time-consuming because measurements are collected at discrete survey points, particularly when surveying extensive disposal areas with irregular topography.

(Chonpatathip et al., 2023) Advances in geospatial technology have enabled the use of unmanned aerial vehicles (UAVs), commonly known as drones, for acquiring aerial imagery for mapping and surveying applications. According to Maidment, UAVs can support various mapping applications by capturing high-resolution aerial imagery at potentially lower operational costs than conventional surveying methods. UAV technology can be combined with photogrammetry, a technique used to derive geometric and spatial information from overlapping photographic images. (Ghilani & Wolf, 2018) described photogrammetry as a method for measuring and interpreting photographic imagery to obtain information about the shape, dimensions, and spatial positions of objects on the Earth's surface. Integrating UAV technology with photogrammetric processing enables the generation of digital elevation models (DEMs) and orthophotos, which can support efficient and comprehensive surface mapping and earthwork volume calculations (Jafari & Dorafshan, 2025; Cao et al., 2023).

Another technological advancement supporting digital transformation in the construction industry is building information modeling (BIM). (Zheng et al., 2022) BIM facilitates the digital integration, visualization, and exchange of project information throughout the construction lifecycle, including design, three-dimensional modeling, engineering analysis, documentation, and project management. (Dwi Novita & Pangestuti, 2021) BIM applications enable construction professionals to develop and assess digital representations of construction projects before implementation, thereby helping identify potential design conflicts, optimize resource allocation, and reduce cost overruns and material waste (Dwi Novita & Pangestuti, 2021). The integration of UAV technology,

photogrammetry, and BIM presents significant opportunities to improve spatial data management, construction monitoring, and project coordination.

In the Wulan River Improvement Works Project, Package 2, disposal and spoil placement activities are among the primary construction operations requiring regular monitoring and accurate volume control. Considering the extensive disposal areas, variations in terrain conditions, and the need for time and cost efficiency, a comparative assessment of disposal soil volumes measured using conventional total station surveying and UAV photogrammetry is necessary (Zhu et al., 2025). This study aims to quantify the deviations between disposal soil volumes calculated using these two surveying methods and evaluate their relative reliability for earthwork volume measurement. The findings are expected to provide practical insights into the suitability of each method for monitoring disposal activities and supporting more efficient volume measurement practices in river improvement construction projects (Escolà et al., 2023; Deng et al., 2026).

METHOD

Research Flow Diagram

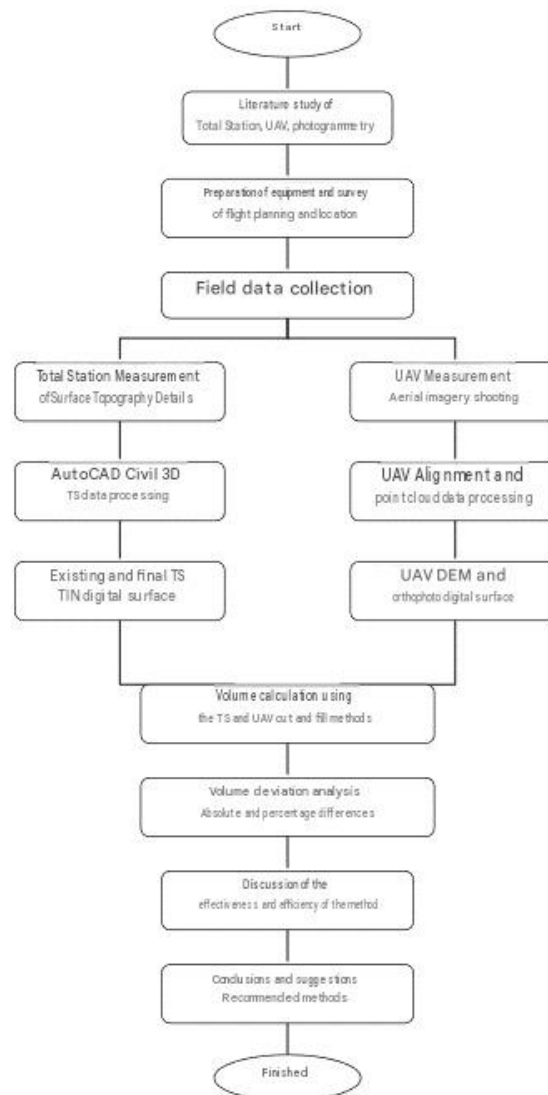


Figure 1. Flow Diagram

Research Location and Time

This research was carried out in the disposal area and disposal expanse of the Wulan River Improvement Works Package 2 Project located along the Wulan River flow, Central Java. Field data collection is carried out in several stages of measurement in accordance with the progress of *disposal work* in the field. The following is a map of the project locations used in the research.



Figure 2. Map of Mijen Village and Mijen District

Research Tools and Materials

This research uses hardware and software. The hardware used includes the Total Station Topcon GM-52 which is equipped with prisms, stats, and measuring signs as conventional measurement instruments. Mavic 3 Enterprise type UAV (Unmanned Aerial Vehicle) for aerial imagery, as well as field support equipment in the form of GCP premarks, wooden stakes, meters, and stationery. Photogrammetry data processing is carried out using a high-spec computer/laptop. The software used consists of Agisoft Metashape to process UAV images into Digital Elevation Model (DEM) and orthophotos, AutoCAD Civil 3D for digital surface modeling as well as cut and fill volume calculations, and Microsoft Excel for data tabulation, statistical analysis, and percentage deviation calculation.

Types and Data Sources

The data used in this study consisted of primary data and secondary data. Primary data was obtained directly through field measurements, including coordinate data (X, Y, Z) from Total Station measurements on the disposal surface, aerial imagery from UAV shooting, as well as Ground Control Point (GCP) and Independent Check Point (ICP) coordinates from Geodetic GPS measurements. Meanwhile, secondary data is in the form of supporting data which includes project location maps, work drawings (shop drawings), and technical planning documents for the Wulan River Improvement Works Package 2 Project.

Research Stages

The research was carried out through six main stages, namely preparation, field data collection, data processing, volume calculation, deviation analysis, and discussion and drawing conclusions.

The preparation stage includes literature studies from various scientific sources related to Total Station, UAV photogrammetry, and volume calculation of the cut and fill method. At this stage, location licensing is also carried out, equipment and materials

preparation, UAV flight planning, and determination of the distribution of GCP and ICP points in the disposal area.

Field data collection was carried out through three measurement methods. Total Station measurement uses the topographic detail method, with taking points at representative locations that describe the shape of the ground surface, including the highest point, lowest point, and break line; The measurement results are in the form of coordinates (X, Y, Z) which are used as reference data. GCP and ICP measurements were carried out using Geodetic GPS with the Real Time Kinematic (RTK) method or short static, where GCP functions as a georeferencing binding point for UAV processed products, while ICP is used to test the accuracy of photogrammetry results. The UAV shooting was carried out at a flying altitude of 80–120 m above ground level with a front overlap of 80%, side overlap of 70%, and a flight speed adjusted to wind conditions in the field, so that an aerial image with an adequate Ground Sample Distance (GSD) was obtained to produce a high-resolution three-dimensional model.

Data processing is carried out separately for both methods. The Total Station data is exported to the AutoCAD Civil 3D software and formed into a digital surface in the form of a Triangulated Irregular Network (TIN). UAV data is processed through a series of stages in photogrammetry software, which include image alignment based on tie points, georeferencing using GCP coordinates, dense point cloud formation, mesh and texture formation as three-dimensional surface models, to DEM and orthophoto preparation as final data. The accuracy test of the UAV results was carried out by comparing the ICP coordinates of the Geodetic GPS results to the ICP coordinates in the photogrammetry model, with the accuracy expressed through the Root Mean Square Error (RMSE) parameter.

The calculation of the volume of soil disposal is carried out using a digital surface-based cut and fill method. The volume is calculated based on the difference in elevation between the existing surface before disposal and the final surface after disposal. Calculations are made for both measurement methods in the same area and measurement period in order to obtain an equal comparison.

Next, the volume values of the two methods are compared to obtain the absolute volume deviation and the percentage deviation, which are calculated using the following equation:

$$\Delta V = V_{TS} - V_{UAV}$$
$$Deviiasi (\%) = \frac{(V_{TS} - V_{UAV})}{V_{TS}} \times 100\%$$

where ΔV is the absolute volume difference (m^3), V_{TS} is the volume of the Total Station measurement (m^3), and V_{UAV} is the volume of the UAV photogrammetry measurement (m^3).

In the final stage, the volume deviation results were analyzed to assess the suitability of the UAV photogrammetry method to the Total Station as a reference method. In addition, a comparative analysis of time and cost efficiency of the two methods was carried out as the basis for recommending the most effective and efficient disposal volume measurement method.

RESULTS AND DISCUSSION

Overview of Research Locations and Data

The research location is in the disposal area of the Wulan River normalization work Package 2 carried out by PT Hutama Karya under the supervision of the Pemali Juana River Area Center (BBWS), stretching from Tugu Village to Mijen Village. The soil excavated from the river cross-section is placed in the disposal area as a heap. In this study, the disposal was chosen in Bandungrejo Village with an estimated distance of 5 km–10 km to facilitate calculation and volume analysis. Terrestrial measurements and aerial image acquisition were carried out at the same relatively same period so that the ground surface conditions were identical for both methods, so that the observed deviation purely reflected the difference in measurement methods.

Results of Data Acquisition and Processing

Data Total Station

Detailed measurements of the situation were carried out using the Total Station Topcon GM-52 which was tied to the BM control point or the auxiliary point that had been determined on the UTM coordinate system of Zone 49S, the WGS 1984 datum. Detailed points are obtained that represent the surface shape of the disposal area. Coordinate data (X, Y, Z) is processed in AutoCAD Civil 3D Software to form a digital surface in the form of a Triangulated Irregular Network (TIN). The base (existing) TIN surface and disposal surface are then used as the basis for calculating the volume of excavation and heap.

Data Photogrammetry UAV

Aerial image acquisition was carried out using DJI MAVIC 3 Enterprise with shooting parameters that have been adjusted to the disposal location. Aerial photos are processed using Agisoft Metashape Professional Software through the stages of photo alignment, formation of dense point clouds, to produce Digital Surface Models (DSM) and orthophotos. Ground Control Points (GCPs) and test points (Independent Check Points) are designed to spread over the mapping area to bind the reconstruction results to the same coordinate system as terrestrial measurements.



Figure 3.Orthophoto of Bandungrejo New Field



Figure 4. Orthophoto Bumdes Bandungrejo



Figure 5. Orthophoto of the Tomb of Bandungrejo Village

Volume Calculation Results

The volume of the cut and fill is calculated using the surface-to-surface composite method in AutoCAD Civil 3D, which compares the base surface with the disposal surface. The net disposal soil volume is obtained from the difference in the volume of the heap to the excavation. A recapitulation of the results of the calculation of the two methods is presented in Table 1, while the details per disposal block are presented in Table 2.

Table 1. Recapitulation of excavated volume, heap, and net disposal volume

Method	Galian / Cut (m ³)	Timbunan / Fill (m ³)	Volume disposal grandson (m ³)
Total Station	10.15	22637.63	22627.48
Photogrammetry UAV	541.1	22842.91	22301.81

Volume Deviation Analysis

The volume deviation is calculated as a percentage of the difference between the volume of the UAV method and the volume of the Total Station method treated as a reference (Equation 1). The results of the analysis of deviation per disposal block are presented in Table 4 and visualized in Figure [2].

$$\text{Deviation (\%)} = (|V_{UAV} - V_{TS}| / V_{TS}) \times 100\% \quad (1)$$

Table 2. Analysis of the deviation of soil volume disposal per block

Blok disposal	Volume TS (m ³)	Volume UAV (m ³)	Selisih Δ (m ³)	Deviation (%)
Bandungrejo Tomb	1633.84	1635.64	1.8	0.11
Bumdes Bandungrejo	6396.30	6548.81	152.51	2.3
Bandungrejo New Square	14607.49	14658.46	50.97	0.3
Total / Rerata	22637.63	22842.91	205.28	2.71 / 0.90

Based on Table 2, the volume deviation in each block ranges from 0.11% (Bandungrejo Tomb Block) to 2.3% (Bandungrejo Bumdes Block), with an average of 0.90%. In aggregate, the total disposal volume of UAV (22,842.91 m³) differed only by 205.28 m³ or 0.91% from the total Station result (22,637.63 m³). This small total deviation value occurs because some of the errors in each block compensate for each other (the difference is marked positive and negative), while the deviation per block provides a more conservative and more accurate picture of the accuracy for assessing the reliability of the method.

The entire deviation value per block is below the 3% threshold commonly used as the tolerance limit for the accuracy of earthwork volume calculations. These results are in line with several previous studies. (Raeva et al., 2016) Report the difference in UAV volume to GNSS measurements of 3–4% in open pit mines and assert that many regulations stipulate the accuracy of volume calculation to $\pm 3\%$ of the total material. Studies of stockpile volume measurements on barges also reported a deviation of about $\pm 2\%$ from manual measurements. Thus, UAV photogrammetry has been proven to be able to produce a volume of soil disposal with accuracy equivalent to the terestis method for project monitoring purposes (Borhan Ahmad Sohibul et al., 2025).

The deviation between the two methods is influenced by several factors. First, the difference in point density and surface formation method. Total Station measurements result in relatively infrequent points so that the TIN triangle is large in size and underrepresents irregular surfaces. In contrast, UAVs produce high-density dense point clouds so that surface interpolation is smoother. (Ekpa et al., 2019)stating that an inadequate number of points enlarges the size of the TIN triangle and lowers the accuracy of the volume, even the terestrix method can overestimate the volume on a given surface. Second, the number and distribution of GCPs affect the georeferencing accuracy of the UAV model. Shows that good addition and distribution of GCP significantly lowers RMSE. Third, surface cover conditions such as vegetation, waterlogging, and the presence of moving objects (heavy equipment) can cause noise in UAV models, while Total Station measurements can selectively avoid these points.

Fourth, the steep surface geometry of the disposal and the presence of berms can cause differences in surface representation between the two methods.

In terms of effectiveness and efficiency, UAV photogrammetry excels over a wide area with a much shorter field acquisition time, less manpower requirements, and lower safety risks because surveyors do not need to reach all unstable disposal surfaces. This method also produces additional products in the form of orthophoto and DSM which are useful for documentation and monitoring of progress. In contrast, Total Station still excels in single-point accuracy and reliability in narrow areas, enclosed with tight vegetation, or when GCP availability is limited, but requires longer field time. For large-scale disposal work such as the Wulan River Improvement Works Package 2 Project, the combination of the two, UAVs for periodic rapid mapping and Total Station for verification of critical areas, is the most effective approach.

With deviations within tolerance limits, the results of the UAV photogrammetry volume can be used as the basis for reliable progress calculation and soil disposal volume estimation in this project, while still considering periodic calibration of the terrestrial measurements to maintain consistency of accuracy throughout the implementation period.

CONCLUSION

This study demonstrates that the net disposal soil volume measured using total station surveying was 22,627.48 m³, whereas UAV photogrammetry yielded a volume of 22,301.81 m³, representing an absolute difference of 325.67 m³ or a relative deviation of 1.44%, with the total station measurements serving as the reference. At the individual disposal block level, volume deviations ranged from 0.11% in the Bandungrejo Tomb Block to 2.30% in the Bandungrejo BUMDes Block, with an average deviation of 0.90%. All observed deviations were below the 3% tolerance threshold adopted for earthwork volume calculations in this study. These findings are consistent with those of Raeva et al. (2016), who reported deviations of 3–4% in open-pit mine volume measurements, as well as a study of stockpile volume measurements aboard barges that reported deviations of approximately $\pm 2\%$ compared with manual measurements. These results indicate that UAV photogrammetry can produce disposal soil volume estimates that closely agree with those obtained through total station surveying, supporting its potential application for volume monitoring in construction projects (Canadian, 2024).

The observed deviations between the two surveying methods may be attributed to differences in survey point density, surface modeling techniques, the number and spatial distribution of ground control points (GCPs), surface conditions such as vegetation cover and standing water, and the complex or steep geometry of disposal areas. In terms of operational effectiveness and efficiency, UAV photogrammetry offers advantages in terms of extensive spatial coverage, rapid data acquisition, reduced labor requirements, and lower exposure of surveyors to hazardous terrain. However, total station surveying remains valuable for verifying measurements in confined areas, locations with dense vegetation, and sites where the availability or distribution of GCPs is limited. Therefore, an integrated approach combining UAV photogrammetry for rapid, periodic mapping with total station surveying for verification in critical areas is recommended as a practical and potentially more efficient

strategy for disposal soil volume measurement in large-scale river improvement projects, including the Wulan River Improvement Works Project, Package 2.

Further research is recommended to systematically investigate the effects of GCP density and spatial distribution on the accuracy of UAV photogrammetry-derived volume estimates, particularly in disposal blocks exhibiting relatively high deviations, such as the Bandungrejo BUMDes Block. Future studies should also conduct quantitative comparisons of survey duration, labor requirements, operational costs, and measurement uncertainty between the two methods. Such investigations would provide a stronger empirical basis for determining the most accurate, cost-effective, and operationally efficient approach to disposal soil volume measurement in similar construction projects.

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