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Enhancing Stockpile Inventory Management through UAV- Based Volume Estimation: A case study of Salt Stockpiles in Hambantota Mahalewaya

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Abstract

Accurate volume estimation of stockpiles is crucial in industries such as Mining, Construction, salt, and Agriculture to optimize resource utilization. This study evaluates the effectiveness of Unmanned Aerial Vehicles (UAVs) compared to Differential Global Positioning System (DGPS) and Total Station (TS) methods for volume estimation of outdoor salt stockpiles in Hambantota Mahalewaya, Southern province of Sri Lanka. The inventory identified two stockpiles, stockpile 1 and stockpile 2, with volumes of 1832.25 m^3 and 819 m^3, respectively. An optimal elevation of 55m was utilized for UAV surveys, and the results were compared with DGPS and TS measurements. UAV surveying factors affecting errors, including image resolution, Ground Control Points (GCPs), and image processing software, were assessed for both stockpiles. Survey time and cost for each method were also analyzed. Pix4dMapper and Agisoft Metashape software processed UAV images, while Civil3D software processed DGPS and TS data. Results indicated that increasing UAV survey elevation reduced volume error percentages for both stockpiles, with and without GCPs. For Stockpile 1, UAV volume estimation showed a 0.88% difference from the actual volume, compared to 4.81% for DGPS and 3.35% for TS. Conversely, for Stockpile 2, UAV estimation differed by 0.95%, while DGPS and TS showed differences of 0.56% and 0.10%, respectively. UAV surveys proved efficient in terms of survey time and labor intensity. Despite technological advancements, challenges remain, particularly in addressing topographical variations for accurate volume estimation. To improve UAV-based estimation, addressing bottom elevation discrepancies by establishing fixed benchmarks on flat terrains was suggested. Nonetheless, UAV-based approaches offer fast and relatively reliable results, indicating their potential for widespread adoption.

Keywords: Differential Global Position System; Total Station; Ground Control Points

1. Introduction

Accurate measurements of stockpiles are very essential for industry inventory management. Due to inaccuracies of traditional methods like truckload counting have led to research of the use of new technologies such as photogrammetry and LIDAR. In the industry, methods like Stockpile Monitoring and Reporting Technology (SMART) platforms that used a similar way by using camera and data – fusion techniques to measuring and calculating of the volumes of stockpile which gives 1% relative error [1]. There are many ways of doing the same thing in the industry. Examples such as, Topcon Imaging Station (IS) and Digital close-range photogrammetry are some two methods which gives an accurate measurement instantly [2] With the modern geomatic technologies like Unmanned Aerial Vehicles (UAVs) , Terrestrial Laser Scanning, and Differential Global Positioning Systems (DGPS) have more advancement than the traditional methods when focusing on accuracy, efficiency and relatively safety procedures and these methods reduce disadvantages of traditional survey methods such as time consuming, labor-intensive and subject to human error in stockpile volume estimation workings [3]. From reason studies the estimated volume of stockpiles are effective and efficient by using UAV-based photogrammetry. As an example one study shows that by using a ground control point- free UAV-based method was utilized and it has been developed to use the vessels geometry to create a custom frame work for volume estimation caried on barges, with a small deviation of ±2% from conventional manual measurements [4]. Volume computation of waste stockpiles with UAV and Terrestrial Laser Scanning technologies have achieved more accurate and efficient method it also improved in a one study [3]. This improvement proved effective for stockpiles with uneven 3D terrain or irregular shapes. because of the accuracy and practicality for different types of aggregate stockpiles with UAV and terrestrial Lacer scanning have more advantages more than traditional TS measurements and the study of point cloud data acquisition techniques has also highlighted in their study [5].

Another study shows that, by using UAV method for stockpile volume estimation have achieved less than 3% error compared with reference volumes for stockpile survey [6]. Estimating stockpile volume by TS have 2.88% difference and by using UAV have -0.67% inconsistency. By comparing this it provide numerical evidence for UAV has more accuracy in stockpile volume estimation[7]. Another research on stockpile volume estimation by UAVs have 0.002% relative error in that case it is confirm that this method is accurate and efficient [8]. A study of examining the efficiency and accuracy for measuring stockpile volumes in open pit mining and Quarry industries with UAV and compared to the traditional methods, UAV based method showed more accuracy in calculating stockpile volumes compared to the global navigation satellite system terrestrial laser scanning and Global Navigation Satellite System (GNSS) technology [9]. A similar study which was conducted in a open pit and quarry mining industry said that UAVs can be used to collect measurements rapidly and accurately [10].

This study of geomatic procedures for salt stockpiles in volume estimation, with a particular significance on UAVs, DGPS, and TS . Even though the data which was provided from UAVs are accurate and within a acceptable error range rather than DGPS and TS. There can be mistakes in certain stockpile designs, for small stockpile between 200 and 900m^3, and for massive stockpiles over 1700 m^3. This research shows us how the error changes for every geomatic techniques for two different stockpile configurations for each method also discussed. As a result, the study goal is to spot the error causing reasons of these survey techniques in volume estimation for salt stockpiles. The study seeks to determine what affecting and data accuracy to decrease the inaccuracies. By analyzing the ways, compare their accuracy and discuss concerning how these technologies will impact stockpile inventory management in the future.

2. Materials and Methods

2.1 Study Area

Mahalewaya is the focus site on this research, and it is in Hambantota district, Southern province in Sri Lanka. It is showed in Figure 1, and this is an outdoor salt stockpile storage facility. Geographically it is located on Latitude 6.143479° N of the equator and Longitude 81.142156° E of the Greenwich Meridian.

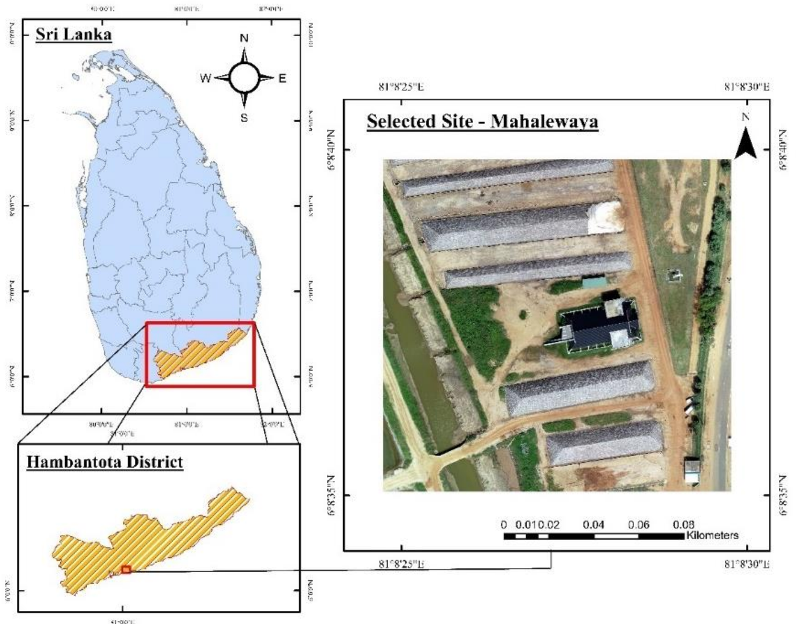


Figure 28 Selected site at Mahalewaya

2.2 Instrumentation and software

To estimate the stockpile volume, DJI P4 Multispectral UAV, Leica FlexLine TS06 Total Station, Stonex DGPS were utilized to survey the stockpiles in order to gather the spatial data needed. Talking about the UAV, it is a lightweight instrument weighing 468 g that includes a GNSS sensor for real time positioning and the capability to gather geotagged photos. Furthermore a total station which was utilized in the survey weighing 5.1 kg and it containing EDM option and it was used to collect the location data of the stockpiles in order to create a point cloud and estimate the volume of the stockpiles . Throughout the surveying stage the global navigation system (GNSS) and real time kinematic (RTK) were utilized to determine the accurate location utilizing the STORNEX DGPS device. the primary three parts of this DGPS system are the Controller Rugged phone (UT12P), The Base (S980A) and the Receiver (S850A) This device is capable for a wider area augmentation (CORSNET) as along with as local area augmentation (base mode). Geotagged images was taken by the UAV platform were processed by the help of digital photogrammetric software Pix4DMapper and Agisoft Metashape, whereas the spatial data collected via the Total Station and DGPS was analyzed by using Civil3D software.

2.3 Methodology

The graphical chart of the chosen methodology, which extends from data collection to analysis, can be seen in Figure 2. GCPs were set up at random strategic locations near to the stockpiles to ensure the accuracy of the measurement taken by the UAV. The actual volume of the stockpiles was compared with the results they were also compared with values collected to DGPS and TS survey.

The UAV was flown at three different heights which are 45 m, 55 m and 65 m to analyze both stockpiles in Figure 3. Due to the closeness of the near structures to the UAV when flying, minimum elevation 45 m were determined for the safety of UAV and GCPs were used continuously for both stockpiles to create georeferenced 3D models to acquire accurate volume measurements.

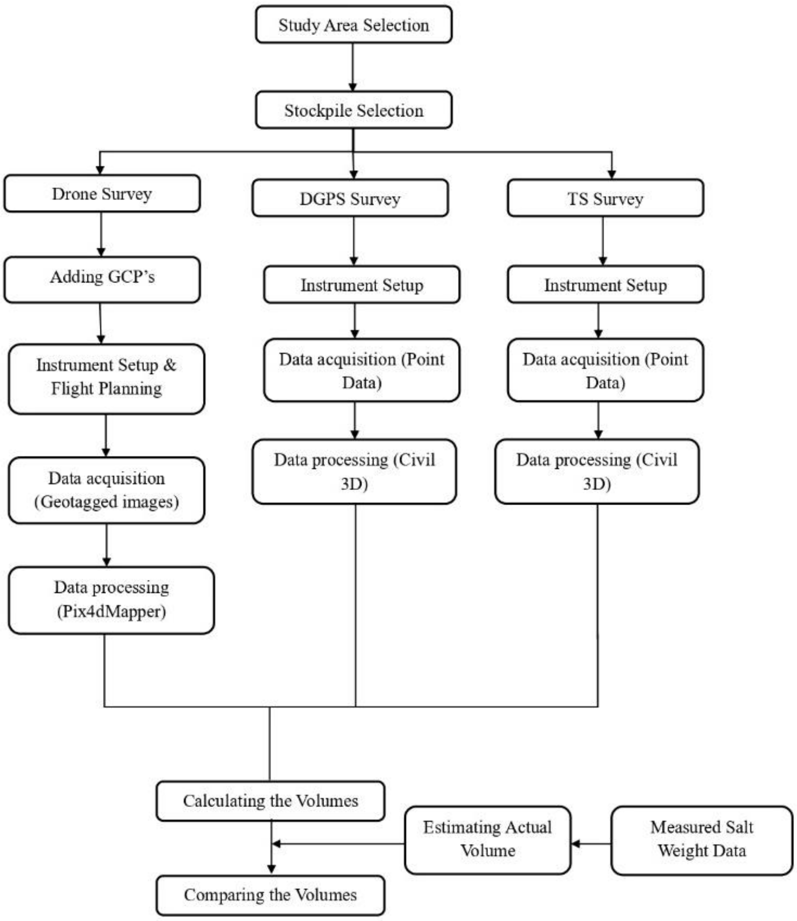


Figure 29 Extended Methodology

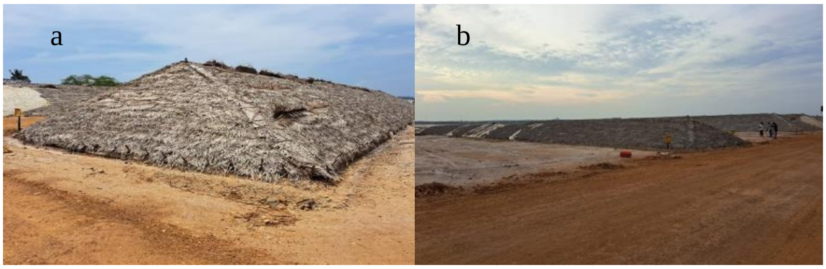


Figure 30 Selected stockpiles a) Stockpile 1 b) Stockpile 2

Table 1 shows the number of images captured with respect to their elevation for both stockpiles and the flight parameters for each stockpile.

Table 14 Flight Parameters and number of images acquired for each elevation

Stockpile No.	Number of images	Flight elevation (m)	Time spent (min)	Front overlap	Side overlap	Camera angle	Speed (m/s)
Stockpile 1	128	45	12	90%	70%	-90^0	4.5
	121	55	11				
	127	65	12				
Stockpile 2	130	45	14				
	134	55	13				
	135	65	15				

The same distance of less than one meter was maintained for both stocks in the TS survey for stockpile 1 and stockpile 2 respectively 255 and 180 points were provided. for both, three station were selected and the survey was conducted out methodically. in the one-meter regular interval DGPs survey, stockpile 1's top and surroundings got 255 points while stockpile 2 earned 190 points. To make sure that the stockpiles were not impacted by the natural depletion of salt carried on by the hot weather, each of the three surveys processes were took place on the same day for both stockpiles.

2.4 Volume estimation from UAV Data

After uploading images into the Pix4DMapper and Agisoft Metashape software platforms, and the stockpiles' dense point cloud, Orthomosaics, and Digital Elevation Models were created. Processing time was completely dependent according to the computer specifications, and because of that the construction parameter which was used to generate the dense point cloud and the quality was set to "medium”. The entire survey was conducted using the WGS84 44N coordinate system. To estimate the volume, "The best fit plane " was chosen as a reference plane. accurate model georeferencing was then finished by using GCP coordinates, which was determined from highly accurate DGPS data. Figure 4 displays the 3D dense cloud for stockpile 1, which was made using both softwares.

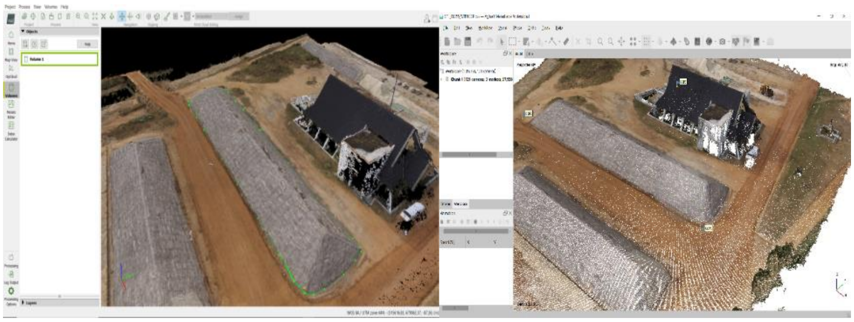


Figure 31 3D dense clouds by Pix4DMapper & Agisoft Metashape

2.5 Volume estimation from TS, DGPS Data

Several methods, which include the Simpson method, the Hermite Cubic Formular and the Trapezoidal Method, can be used to calculate the volume of stockpiles using traditional survey methods [9]. During this study a computer technique was taken to avoid human computing errors. The data obtained by the TS and DGPS was created models using Civil3D. Following a triangulation method, continuous surface representation of the point cloud was transformed into a special data structure. for both survey methods, the stockpile volume was estimated, and this process was performed out for both stocks.

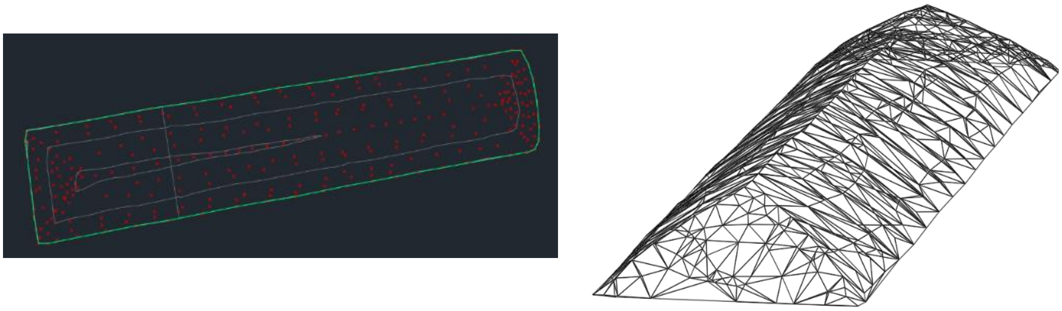


Figure 32 Contour and Triangulated Surface of stockpile 1 by Civil 3D

2.6 Actual volume estimation of Salt Stockpiles

The methodical method used at Hambanthota Mahalewaya was applied to figure out the actual volume. With the assistance of weighbridge, truckloads were carefully measured to calculate the weight in metric tons(mt) after following dispatched to the salt factory. a known volume of wooden boxes filled with in the stockpiles serve for taking actual density measurements. the box is then removed, and the hole is then filled with known identified material then actual bulk density for salt stockpiles is then calculated one can obtain an accurate estimation of the stockpile by using the information collected at various points.

Absolute error and the error percentage was compared for all three methods according to Eq. (1) and Eq. (2). Each method was compared with the actual volume of the respective stockpiles.

$$Absolute\ error\ = |Observed\ Volume - Actual\ Volume| \quad (1)$$

$$Percentage\ error = \frac{|Observed\ Volume - Actual\ Volume|}{Actual\ Volume} \times 100\% \quad (2)$$

3. Results and Findings

3.1 Comparison of estimated stockpile volumes for UAVs

In UAV approach to measure the volume of the two stockpiles, the geotagged images which was acquired for each elevation was processed by using two software platforms which were Pix4DMapper and Agisoft Metashape. By using the coordinates of GCPs accurate models was generated and the measurements was taken for each elevations from these two software platforms.

The measured volume of two stockpiles was affected by the presence of coconut leaves that covered the top of the salt stockpile heaps. While in other survey methods were unaffected by the coconut leaves because the in DGPS and TS the direct contact of the rover end, prism end to the salt inside the coconut leaves of the heaps was utilized when taking the coordinates on the top of salt stockpiles. In this study for UAV, the 3D surface area data was accounted for the volume decrement due to the coconut leaves and an assumption of 0.05 meters of thickness for a unit area was taken according to get the measured volume by UAV. Table 2 provides corrected UAV based volume estimations for different elevations according to different software which was Pix4DMapeer and Agisoft Metasape.

Table 15 Corrected volume measurements by Pix4DMapper and Agisoft Metashape

Software	Stockpile No.	Elevation	Measured Volume (m^3)	3D Surface Area (m^2)	Volume Reduction (m^3)	Corrected Volume measurement (m^3)
Pix4D Mapper	01	45 m	1939.53	1060.98	53.05	1886.48
		55 m	1901.35	1060.41	53.02	1848.33
		65 m	1859.98	1060.42	53.02	1806.96
	02	45 m	860.70	867.10	43.36	817.35
		55m	854.52	865.61	43.28	811.24
		65 m	852.15	866.32	43.32	808.83
Agisoft Metashape	01	45 m	1946.1	1060.98	53.05	1893.05
		55 m	1932.7	1060.41	53.02	1879.68
		65 m	1910.3	1060.42	53.02	1857.28
	02	45 m	883.09	867.10	43.36	839.73
		55 m	853.41	865.61	43.28	810.13
		65 m	842.16	866.32	43.32	798.85

Table 16 Absolute and Error Percentage for Pix4DMapper and Agisoft Metashape for both stockpiles

			Pix4DMapper			**Agisoft Metashape**		
Stockpile No.	Actual Volume (m^3)	Elevation	Corrected Volume (m^3)	Absolute Error (m^3)	Error Percentage (%)	Corrected Volume (m^3)	Absolute Error (m^3)	Error Percentage (%)
Stockpile 01	1832.25	45 m	1886.48	54.23	2.96	1893.05	60.80	3.32
		55 m	1848.33	16.08	0.88	1879.68	47.43	2.59
		65 m	1806.96	25.29	1.38	1857.28	25.03	1.37
Stockpile 02	819.00	45 m	817.35	1.65	0.20	839.73	20.73	2.53
		55 m	811.24	7.76	0.95	810.13	8.87	1.08
		65 m	808.83	10.17	1.24	798.85	20.15	2.46

Table 3 illustrates how the percentage error varies according to the Pix4DMapper and Agisoft Metashape softwares for both stockpiles.

According to Table 3 the error percentages for each stockpiles were at an acceptable range below 5% and with these data clear visualization can be seen according to the elevation. When increasing the elevation, the measured value gets decreased due to the Ground Sampling Distance (GSD) getting increased according to the elevation and because of this a one pixel covers a larger area on the ground. Higher elevations result a less detailed imagery, which can smooth over small variations in the surface height of the stockpile. Because of this loss of detail, It can lead to a underestimation of the estimated volume as the software also may cannot capture the full complexity and height variations of the surface on the stockpiles. Other parameters like side overlap, front overlap was set as constant through the mission plans for different elevations and because of that GSD is getting increased according to the increment of elevation is obvious. These results suggested that the flight elevation has big impact on volume estimation. However, due to safety considerations of the UAV it is not possible to fly the UAV in a lowest elevations due to the obstructions like tree and buildings are rapid in this area, may made it more difficult to choose the elevation for a high resolution photography. Therefore, an optimal elevation level must be carefully considered to balance the resolution for a high accurate volume estimation during the UAV operations.

Figure 6 and Figure 7 shows the corrected volume measurements which was taken by Pix4DMapper and Agisoft Metashape for different elevation and the actual booked quantity also can be seen and the deviation for the estimated volume measurement also can be visualize for each stockpile.

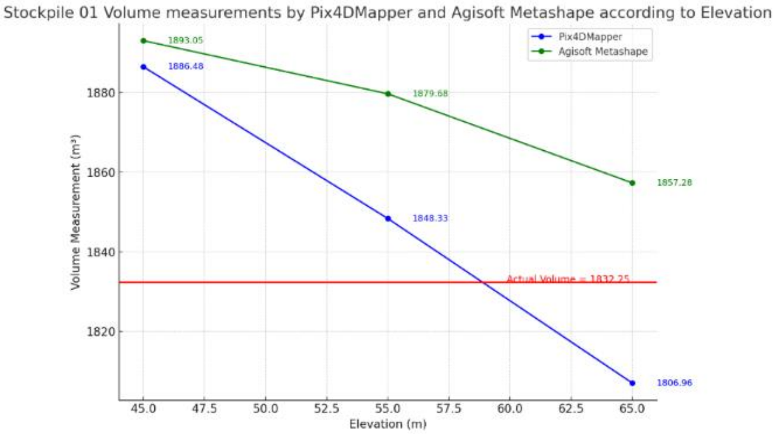


Figure 33 Stockpile 1 Volume measurements according to the Elevation

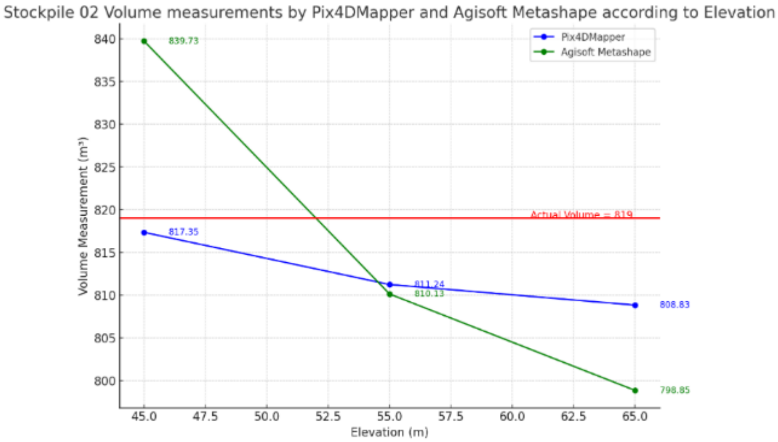


Figure 7 Stockpile 2 Volume measurements according to the Elevation

3.2 Comparison of estimated stockpile volumes for UAVs vs DGPS and TS

When considering UAV volume estimations which was taken by Pix4DMappper and Agisoft Metashape and the volume estimations which was taken by using the Civil 3D by processing the spatial data which was acquired by DGPS and TS was compared in Table 4 and it shows how the measurements vary according to the instrument used. For this study optimal elevation of 55m was considered for UAV.

In analyzing the volume measurement accuracy when measuring stockpiles using different surveying methods, the error percentages for UAV measurements by using Pix4Dmapper and Agisoft Metashape were found that to be 0.88% and 2.59% respectively for the stockpile 1 and for the stockpile 2 it was about 0.95% and 1.08%. These comparatively low percentage errors indicate that the UAV photogrammetry, especially when the geotagged images were processed with Pix4Dmapper, typically gain more level of accuracy. This is probably because due to the software's robust image processing algorithms which can efficiently handle overlapping images and 3D reconstruction.

Compared with the traditional survey techniques which was DGPS and TS, the errors were significantly higher for the first stockpile, which gave 4.81% for DGPS and 3.35% for TS, while for the second stockpile the error which was 0.56% for the DGPS and for the TS it is about 0.10% for the second stockpile. This variation in error percentages compared with different survey techniques indicate the factors such as the setup accuracy, the precision and the accuracy of the instruments and the methodological execution plays a critical role. Due to the complex topographical nature on the top of the stockpiles and the less ideal setup conditions was impacted the DGPS and TS measurements considerably than UAV method for both stockpiles.

Table 17 Absolute and Error percentages for different techniques stockpile 1 and stockpile 2

Method		Stockpile 01			Stockpile 02		
		Estimated Volume (m^3)	Absolute error (m^3)	Percentage Error (%)	Estimated Volume (m^3)	Absolute error (m^3)	Percentage Error (%)
UAV	Pix4D	1848.33	16.08	0.88	811.24	7.76	0.95
	Agisoft	1879.68	47.43	2.59	810.13	8.87	1.08
DGPS	Civil 3D	1920.38	88.13	4.81	814.45	4.55	0.56
TS		1893.63	61.38	3.35	818.2	0.8	0.10

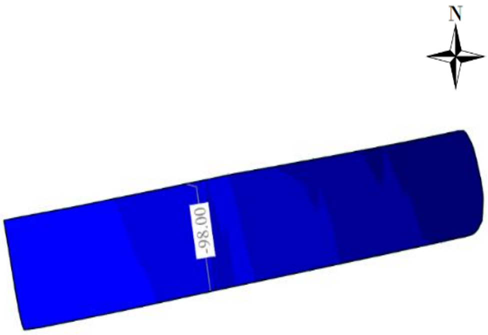
A critical aspect which need to consider in volume estimation for stockpiles was the topographical error, particularly the error which was caused by the base level of the stockpiles. Such topographical errors can significantly affect the accuracy of the volume estimations which was done by different geomatics. The base level of a stockpile cannot be accurately captured by any geomatic technology, whether there was a uneven ground that wasn't properly accounted for, the estimated volume can deviate substantially from the actual volume. This is especially important in the areas where the ground conditions are complex and changeable as these error might have a greater impact on geomatic based volume estimations.

The best fit plane was utilized when volume estimation was done by using Pix4Dmapper and Agisoft Metashape and it was somehow able to assess the underlying topography accurately. Civil 3D's processing of DGPS and TS data established a base surface by using the boundary points of the stockpiles but however it was failed to assess the underlying topographical changes at the base which leading to a higher error rates when increasing the area of the stockpile. When the volume of the stockpile is getting increased, the spread of the material on the terrain expands which leading to greater variations in the underlying topography and resulting higher error percentages.

Figure 7 and Figure 8 shows the two base contour sections illustrating the stockpile base which was created by using the base boundary elevations that was extracted by using the dense clouds created by Pix4Dmapper and to create the surface profiles Autodesk Recap Pro and Civil3D software was utilized.

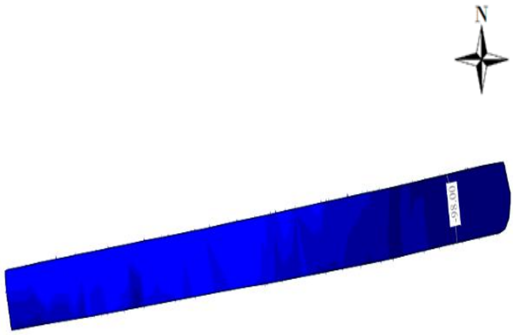
4. Conclusion

This study compares volume estimation techniques employing UAVs, DGPS and TS to enhance the efficiency of UAV-based surveys in salt stockpile inventory management at Hambantota Mahalewaya, UAVs, although relatively new in the field, demonstrated significant potential in enhancing the accuracy and efficiency of stockpile volume estimation. The analysis revealed that while TS and DGPS methods provided high-precision data, their accuracy was notably dependent on the number of survey points collected, leading to longer survey times compared to UAVs.



Elevations Table				
Number	Minimum Elevation	Maximum Elevation	Area	Color
1	-98.82	-98.47	86.77	
2	-98.47	-98.17	156.66	
3	-98.17	-97.90	186.60	
4	-97.90	-97.69	175.00	
5	-97.69	-97.46	156.95	
6	-97.46	-97.19	119.96	
7	-97.19	-97.03	21.85	

Figure 34 Base contour for stockpile 1



Elevations Table				
Number	Minimum Elevation	Maximum Elevation	Area	Color
1	-98.87	-98.62	109.93	
2	-98.62	-98.55	169.53	
3	-98.55	-98.50	98.34	
4	-98.50	-98.39	114.18	
5	-98.39	-98.24	95.03	
6	-98.24	-97.88	107.50	
7	-97.88	-97.61	44.59	

Figure 35 Base contour for stockpile 2

In UAV-based estimation, critical factors such as flight parameters, image resolution, and the use of Ground Control Points (GCPs) significantly influenced the results due to the reliance on photogrammetry and associated software. It was found that increasing the elevation during UAV surveys decreased the volume estimated for both stockpiles by using GCPs. For Stockpile 1, the UAV method showed a 0.88% difference from the actual volume, whereas DGPS and TS had differences of 4.81% and 3.35% respectively. For stockpile 2, the UAV method exhibited a 0.95% difference, with DGPS and TS showing differences of 0.56% and 0.10%, respectively. Challenges such as topographical variations and discrepancies in bottom elevation were identified as areas that required improvement. To enhance UAV-based volume estimation, it was proposed to prepare stockpile surfaces with fixed benchmarks on flat terrains to mitigate bottom elevation inconsistencies. These challenges and the optimization of operational parameters, such as flight elevation, were recommended to further enhance the accuracy and efficiency of UAV-based volume measurement techniques and further research need to be done to assess those parameters. So, looking at all those considered factors UAV is an ideal technological solution for volume estimation for different stockpile configurations not only in salt, but also in other industries like mining, construction, agriculture etc.

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