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Estimation of Soil Volumetric Erosion Using GPS and Unmanned Aerial Vehicle: A Case Study at Universiti Teknologi Malaysia, Johor

Ahmad Danial Yusuf Azli[1], and Yong Chien Zheng[1,2]*
[1] Geoinformation Department, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia
[2] Geomatic Innovation Research Group, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia
*Corresponding author: chienzheng.yong@utm.my

Abstract - In modern times, Global Positioning System (GPS) and Unmanned Aerial Vehicle (UAV) are widely used in surveying. Both types of equipment can be used in volume determination. The calculation of land volume is one of the essential engineering works (i.e., construction sites, quarries/mines, landfills) that rely on the topographic survey. The UAV and GPS are two contemporary survey techniques for acquiring topographic data and later for soil volume estimation. This research aims to compare GPS and UAV aerial photos to estimate the soil eroded volume. The study area of this project is *Persiaran Satelit*, Universiti Teknologi Malaysia (UTM), where the data collection was conducted using GPS Real-Time Kinematic (RTK) and UAV photogrammetry. The GPS RTK technique is utilised to conduct a topographic survey, while UAV photogrammetry, on the other hand, performs an aerial photo survey. A GPS static technique of two hours of observation is performed to estimate more reliable referenced coordinates to be used as the ground control points (GCPs) for the aerial photos. This project utilises AutoCAD Civil 3D and Pix4D Mapper to analyse the data for GPS and UAV, respectively. Both methods show different results in land volume up to 2.59% due to the different densities of spatial data and survey points interpolation. In addition, the Digital Elevation Model (DEM) and analysis of soil erosion in this study have demonstrated the total volume loss throughout the six months of study is 0.55% and 1.47% for GPS-RTK and UAV, respectively. Hence, this study concludes that soil volume estimation using UAV photogrammetry and GPS RTK method is feasible in soil erosion monitoring.

Keywords - Volume estimation, Soil erosion, UAV, GPS, Topography

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1. Introduction

The emerging technology enables using the Global Positioning System (GPS) and Unmanned Air Vehicle (UAV) in land surveying. One of the applications of these surveying technologies is to estimate land volume. Through the variation in time, we can monitor the change in land volume resulting from soil erosion. Soil erosion can be defined as the movement of the upper layer of soil. It can occur through many factors such as climate, soil structure and composition, vegetation, and topography. The rate can be fast or slow, depending on the excessiveness of the activity exploited on the land [1]. Anthropogenic factors such as intensive agriculture, deforestation, biomass burning and others. This phenomenon can cause various damages, such as productive crop loss, sedimentation of land, infrastructure destruction and biodiversity loss [2]. Heavy rainfall is also one of the catalysts that cause soil erosion to occur [3].

The key to soil erosion monitoring is determining the rate of change in soil volume. UAV is used to capture aerial images of the area. The development of DEM through UAV has been used in displaying topographic data to analyse the terrain for physical surfaces [4]. This technology produces an easy way of generating DEM in high resolution with a centimetre accuracy [5]. The net volume loss for soil can be estimated using the DEM model produced by UAV aerial photos [6]. DEM differences can show the decreasing terrain through negative values and sedimentation through positive values [7]. A study estimates the lost soil volume and generates Digital Elevation Model (DEM) utilising the aerial photogrammetry method [8]. Another study implemented GPS RTK to identify the soil erosion occurrence of the Yellow River [9]. The use of a UAV made a job faster by almost two times rather than using a total station in performing a topographic survey [10].

GPS RTK is used to collect the ground level through a topographic survey. This technique allows for accurate positioning in real-time, similar to what can be achieved by static GPS positioning [11]. It can also generate accurate, high-resolution DEMs and topographic data [12]. The volume of land can be used to assess soil erosion through the generated Triangular Irregular Network model to calculate the volume. Elevation difference through DEM was used to monitor soil erosion from the initial and final topographic data. The measurement is accurate enough to detect topsoil spatial distribution [13]. GPS RTK technique has been used in research regarding soil erosion for a long time [14].

Other methods can also be used, such as levelling method, which requires transferring height from one point to another. One of the researchers suggested using precise levelling, which utilises the time-lapse data of height differences in monitoring the surface deformation of the land [15]. A terrestrial laser scanner (TLS) can also be used that utilises dense point clouds to generate a 3D model with a millimetre level of accuracy [16]. This method allows for examining the shape change of the terrain in the vertical axis, horizontal axis and spatial arrangement [17].

This study aims to compare GPS RTK and UAV aerial photos in estimating the volume of soil erosion. The objectives are 1) To estimate the soil eroded volumetric using GPS RTK and UAV photogrammetry methods, 2) To evaluate the discrepancies in soil volume estimation between both methods and 3) To conduct a volumetric assessment of soil erosion of the study area using DEM.

2. Methodology

This section discusses the flow of the study from work planning until the conclusion starting from work planning, such as the GCP and flight planning, followed by data acquisition using GPS and UAV. Data processing is performed for both methods, the processed results are analysed, and a summary with conclusions is drawn. Figure 1 shows the research methodology for this study.

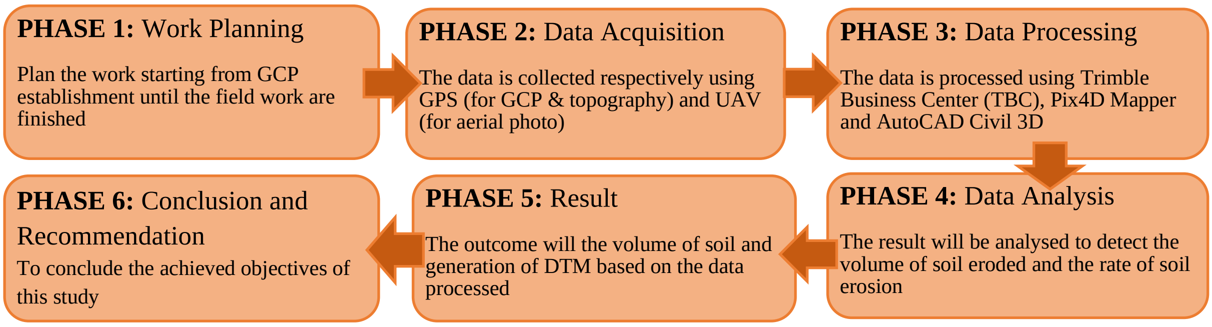

Figure 1. Research methodology is arranged in five phases: (1) Work planning, (2) Data acquisition, (3) Data processing, (4) Data analysis, (5) Result and (6) Conclusion and recommendation

2.1 Phase 1: Work Planning

2.1.1 Study Area

Figure 2 illustrates the study area of this study in *Persiaran Satelit*, Universiti Teknologi Malaysia. The area consists of a 25° slope and 90% grassy terrain, while the remaining covers bare land. There was also a water passage at the top to avoid water retention.

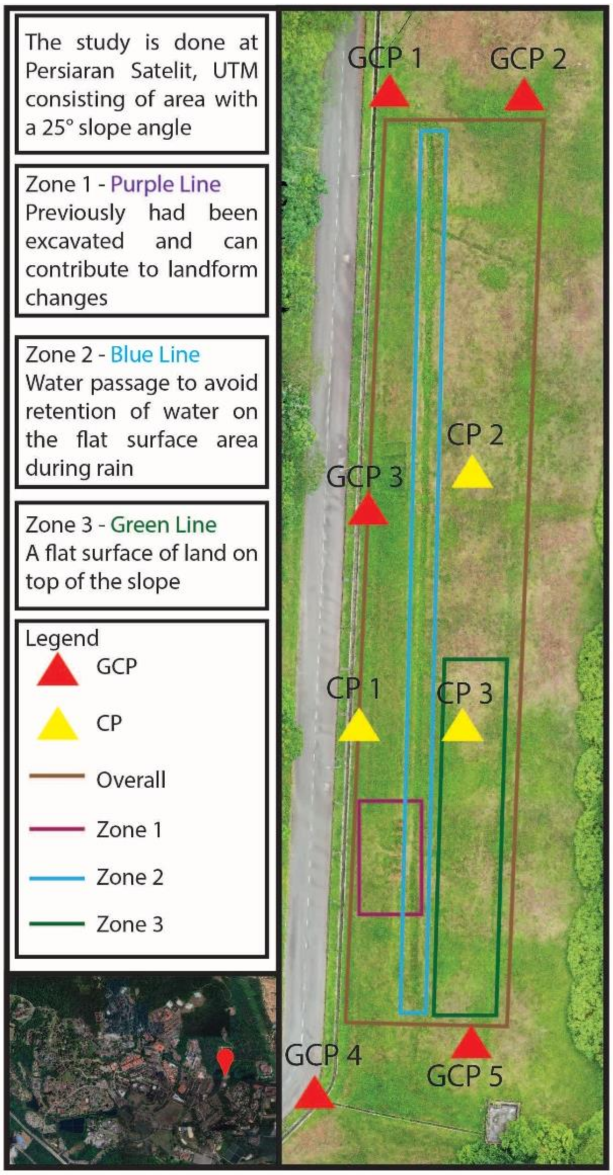

Figure 2. Ground Control Points (GCPs), Check Points (CPs), and inspection zones in the *Persiaran Satelit*, Universiti Teknologi Malaysia

2.1.2 Equipment and Software

This study utilises the UAV Mavic 2 Pro, a multirotor drone with a high-resolution sensor of 20 megapixels to capture aerial images of the area. Topcon Hiper-HR GPS receivers were used to conduct static observation for control points and topographic survey using the RTK technique, which has the accuracy of ±3mm for static and ±5mm for RTK, respectively. DroneDeploy is software to aid in flight planning and settings for the flight mission, such as the flying height, location, side/overlap, and more. Trimble Business Centre was used to process the network baseline for the static observations. The aerial images were processed using Pix4D Mapper to generate DTM, orthophoto and calculate volume, while AutoCAD Civil 3D processed the GPS RTK topographic data.

2.2 Phase 2: Data Acquisition

The data acquisition consists of three parts: GCPs and CPs establishment, UAV photogrammetry and GPS RTK topographic survey. Throughout the six months of this study, the rainfall precipitation volume was approximately 154.32 mm to 279.63 mm [18].

2.2.1 Establishment of the GCPs and CPs

Ground Control Points (GCPs) are the reference points for aerial photo geo-referencing. Meanwhile, the Check Points (CPs) are to validate the coordinates from the aerial photos after being geo-referenced. The establishment of GCPs and CPs is to determine the reference coordinates of the aerial photo taken by the UAV based on the designated coordinate system, which is Rectified Skew Orthomorphic (RSO). The observation consists of two sessions which took two hours for each session. There are a total of five GCPs and three CPs covering the study area, as shown in Figure 3. Then, GCPs are geo-referenced with Pix4D Mapper and base stations in GPS RTK topographic survey. Two epochs of static observation were conducted to verify the positions of the points. The time interval between the first and second epoch of the static observation is about six months.

2.2.2 Data Acquisition Using UAV

A flight planning, shown in Figure 4, was composed beforehand using DroneDeploy to change the settings for the flight mission. Before the flight mission, the aerial photo camera has been calibrated to ensure all components and settings are in good condition. The flying height is 30m to avoid obstacles in the study area. The properties of the flight mission are shown in Table 1.

Figure 4. The flight path of UAV in DroneDeploy

Table 1. Specification of flight

Setting	Properties
Flying height	30 meters
Estimated time of flight	15 minutes
Front/Side overlap ratio	80% / 75%
Course angle	90°
Resolution	20 megapixels

2.2.3 Data Acquisition Using GPS RTK

RTK technique is used to perform the topographic survey. GCP2 was chosen as the base station, whereby the remaining GCPs and CPs were examined with the stakeout survey to ensure the conditions of the positions. For a much more accurate representation, it is crucial to collect dense data with more measurements on the uneven surface of the study area.

2.3 Phase 3: Data Processing

2.3.1 GPS RTK Data Processing for GCPs and CPs

The static GPS data is being processed using Trimble Business Centre (TBC) utilising the network baseline processing. The coordinates are in Geocentric RSO Peninsular Malaysia. The points are used as reference coordinates for the UAV photogrammetry and GPS RTK to collect topography.

2.3.2 UAV Data Processing

The aerial photos were processed in Pix4D Mapper to generate orthophotos, Digital Surface Model (DSM) and Digital Elevation Model (DEM). An orthophoto is the corrected and combined aerial images geometrically. The DSM, a representation of a surface that includes both natural and man-made objects, was used to calculate the volume of the study area. The DEM represents the area's bare land used to show the elevation difference. The CP was also assessed to obtain the accuracy of the points based on the static observation.

2.3.3 GPS RTK Data Processing

Topographic data went through interpolation in AutoCAD Civil 3D to generate the Triangulated Irregular Network (TIN) for the volume calculations. This software can also generate Digital Elevation Model (DEM) based on the TIN model produced. The DEMs were used to analyse the change in elevation of the study area.

3. Result and Discussion

This section highlight the results and discussion acquired from the data processing stage. This includes an accuracy assessment to verify the positions of the GCPs and CPs. It is also to discuss the assessment of soil erosion based on volume loss and the difference in value between each method. Lastly, the DEMs generated were discussed to assess the soil erosion based on the elevation change.

3.1 Accuracy Assessment

The Root Mean Square Error of every epoch of static observations is given in Table 2. Table 3 discusses the RMSE of the RTK technique. Table 4 depicts the RMSE of CPs after being geo-referenced in Pix4D Mapper. The purpose of this assessment was to verify whether the condition of the control points is good and can be used. It was also to check the control points periodically since this study took six months.

Table 2. Root Mean Square of the GCPs and CPs for every epoch of static observation

Station	RMS of Northing (m)	RMS of Easting (m)	RMS of Mean Sea Level Height (m)
GCP 1	-0.005	0.016	0.036
GCP 2	-0.003	0.001	0.018
GCP 3	0.004	0.014	0.012
GCP 5	-0.003	-0.002	0.001
CP 1	-0.001	0.006	0.001
CP 2	0.000	-0.002	0.002
CP 3	-0.005	0.005	0.020
RMSE	0.003	0.008	0.016

Note: The GCP 4 has no second epoch of observation because of the dysfunctionality of equipment at that moment.

Table 2 shows that the RMSEs for the static observations are below 1 cm for horizontal components and 2 cm for vertical components. Higher deviation occurred due to the points being exposed to multipath errors such as trees and slopes, which caused it to have a higher difference than the others. However, it is still under the standard tolerances by JUPEM, which are 3 cm for horizontal and 6 cm for vertical components [19].

Table 3. Root Mean Square Error of the GCPs and CPs with GPS RTK technique

Station	ΔN (m)	ΔE (m)	Δh (m)
GCP 1	0.007	-0.001	-0.027
GCP 3	0.006	0.006	-0.012
GCP 4	-0.001	-0.007	-0.030
GCP 5	0.002	-0.013	-0.032
CP 1	0.006	0.001	-0.017
CP 2	-0.005	0.004	-0.021
CP 3	0.007	0.001	-0.030
RMSE	0.005	0.006	0.025

The GCP 2 was chosen as the base station because it has a clear sky view and is far from any potential multipath sources (Figure 3). As seen in the table above, it is evident that the RMSs of the RTK technique in this study are 5 mm and 6 mm for Northing and Easting, respectively, and 2.5 cm for vertical components, which are still under the standard tolerances allowed.

Table 4. Root Mean Square Error of the CPs from Pix4D Mapper checking

Epoch	**Station**	**ΔN (m)**	**ΔE (m)**	**Δh (m)**
1st	CP 1	-0.025	-0.020	-0.022
	CP 2	0.013	0.014	-0.021
	CP 3	-0.017	-0.011	-0.023
2nd	CP 1	0.001	-0.006	0.017
	CP 2	0.004	-0.007	-0.013
	CP 3	0.005	-0.021	0.001
3rd	CP 1	0.006	0.009	0.015
	CP 2	0.012	-0.004	0.014
	CP 3	0.022	-0.010	0.016
	RMSE	0.014	0.013	0.017

Based on Table 4, the RMSE for all epochs of CPs assessment were under good conditions. However, the first epoch shows a higher difference than the other epochs. This is due to some of the images with low resolution. This resulted in the marking of CPs during the geo-referencing process being harder. Overall, the RMSE for the three assessments does not exceed the standard tolerance of 3 cm and 6 cm for horizontal and vertical components, respectively.

3.2 Soil Erosion Assessment Based on Volume Discrepancy

This section discusses the assessment of soil erosion based on volume. The soil volume was acquired through GPS RTK and UAV photogrammetry methods in the data acquisition stage. Tables 5 and 6 show the assessment of soil erosion through volume loss using GPS RTK and UAV, respectively.

Table 5: Soil erosion assessment based on the volume change using GPS RTK

	(Epoch 2-1)		(Epoch 3-2)		(Epoch 3-1)	
	(m^3)	%	(m^3)	%	(m^3)	%
Zone 1	-3.54	-0.85	3.91	0.94	0.37	0.09
Zone 2	-4.75	-0.23	-33.72	-1.66	-38.47	-1.90
Zone 3	-2.29	-0.25	2.80	0.31	0.51	0.06
Overall	-10.58	-0.17	-22.73	-0.38	-33.31	-0.55

Table 5 shows that there was 33.31 m^3 of volume loss throughout the six months of this study. It can be said that 0.55 % were lost during this study commenced. Zone 1 shows an inconsistent volume change due to the landform change occurring in that area due to sedimentation (Figure 5). Zone 2 is a water passage leading to a decrease of 1.9 % in volume. Lastly, Zone 3 is nearly a flat surface, indicating that the volume loss is inconsistent. The different point interpolations for each epoch caused it to be inconsistent since the points collected are not precisely at the same places as before.

Figure 5. The condition of Zone 1 before (left) and after (right) six months

Table 6. Soil erosion assessment based on the volume using UAV photogrammetry

	(Epoch 2-1)		**(Epoch 3-2)**		**(Epoch 3-1)**	
	(m^3)	%	(m^3)	%	(m^3)	%
Zone 1	-5.15	-1.23	-1.36	-0.33	-6.51	-1.56
Zone 2	-28.5	-1.37	2.02	0.1	-26.48	-1.28
Zone 3	-8.49	-0.93	-0.88	-0.1	-9.37	-1.02
Overall	-77.69	-1.28	-11.62	-0.19	-89.31	-1.47

Based on Table 6, the overall loss of volume acquired using UAV photogrammetry is 1.47 % throughout the study. All three selected zones have a consistent volume loss from the first to the third epoch. However, Zone 1 shows the most difference, unlike the other two zones. Compared to the other two, Zone 1 has a smaller area coverage which means that it suffers more volume loss. The volume loss in Zone 2 is due to the purpose of that area to prevent water retention. However, the estimated volume is lesser with the GPS RTK method than with UAV photogrammetry since the soil volume calculations with the Digital Surface Model of the UAV photogrammetry method have accounted for vegetation.

3.3 Volume Difference

The volume difference assesses how much each method differs from the other. Table 7 shows the difference in volume and percentage. The table shows that the maximum volume difference for each method is 2.59 %, with a minimum of 0.05 %. The differences were due to the different ways each process works. The RTK technique collects data on the ground level, and the UAV obtain data from the surface depending on the vegetation.

Table 7. The volume difference between UAV and GPS RTK methods

	Epoch	Different in volume (m³)	Different in percentage (%)
Overall	1st	59.99	0.98
	2nd	-7.12	-0.12
	3rd	3.99	0.07
1st zone	1st	1.84	0.44
	2nd	0.23	0.06
	3rd	-5.04	-1.21
2nd zone	1st	40.86	1.97
	2nd	17.11	0.83
	3rd	52.85	2.59
3rd zone	1st	10.92	1.19
	2nd	4.72	0.52
	3rd	1.04	0.11

3.4 Soil Erosion Assessment Based on DEMs.

The soil erosion was assessed based on the DEMs generated by GPS RTK and UAV. In general, the developed models went through raster analysis to produce the difference in elevation in the study area. Figure 6 shows the difference in GPS RTK and UAV DEMs, respectively. Both of them were assessed between the first and third epochs.

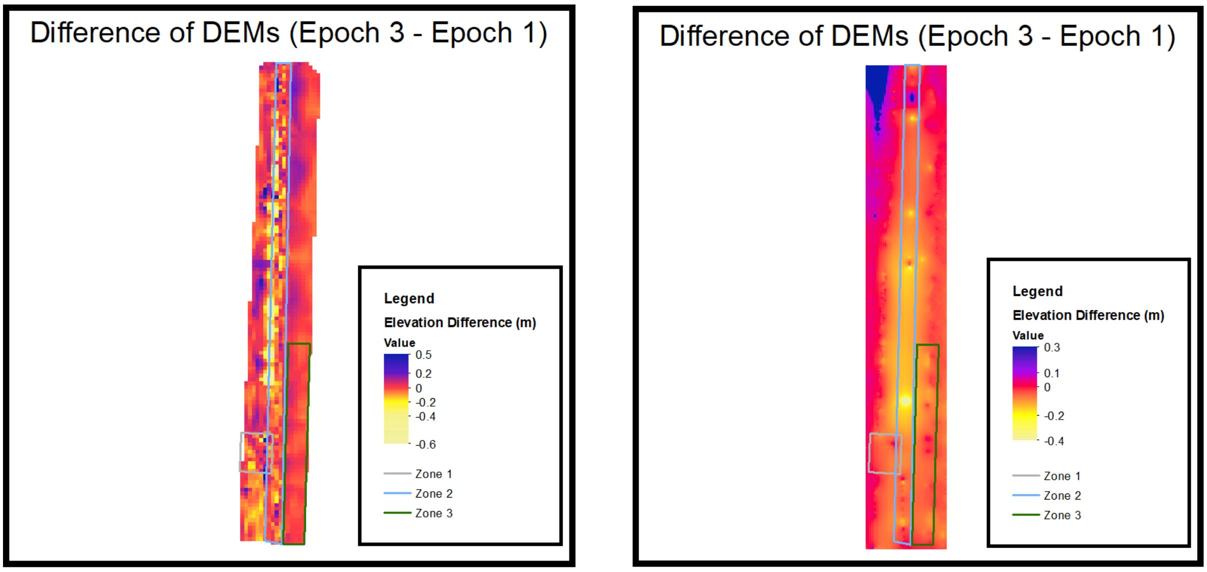

Figure 6. The DEM elevation difference between the last and the first epoch for GPS RTK (left) and UAV (right)

The left side of the figure above illustrates a maximum of up to 0.6 m elevation difference. However, it is being overestimated due to the first and second epochs' ground-level data not being dense enough compared to the third epoch. However, it still shows that the long yellow spots show that erosion occurred in Zone 2. Zone 3 shows an inconsistent change due to the sedimentation of land. The area's slopes seem to have not changed much throughout the study. The increase in elevations was due to the different interpolations based on the density of points collected.

The right side of the figure shows Zone 2 had a 0.2 to 0.4 m decrease in elevation. Zone 3 does not change much since the initial epoch. It is the same as the slope area, which does not show much elevation change.

4. Conclusion

Soil volume estimation using UAV photogrammetry and GPS RTK method is feasible in soil erosion monitoring. There were 1.47 % and 0.55 % of volume loss, respectively, using the UAV and GPS RTK methods. The difference in volume for each technique was up to 2.59 % due to the spatial density of observation points of the UAV method being denser than the GPS RTK method. The monitoring of soil erosion can also be assessed using the DEMs estimated with both UAV and GPS RTK methods. The difference in DEMs at different time stamps can estimate the elevation change due to soil erosion. It is evident in the results where both ways show 0.3 m and 0.6 m of elevation difference after a six months gap.

This study can further be improved by using other surveying methods such as terrestrial laser scanning. Other than that, lower flying height for UAV flight missions can help improve the accuracy of the DEM generated. Lastly, a monitoring site with less vegetation coverage can expect a better outcome in determining the volume loss and elevation change.

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