VOL. 6, NO. 2 (August 2026) 174-191
https://jagst.utm.my

JAGST
Journal of Advanced Geospatial Science & Technology

Unmanned Aerial Vehicle (UAV) Photogrammetry for Soil Erosion Mapping: Integrating USLE and GIS in Construction Sites

Mohd Dhiya Hafreez Kamil[1], Faridahanim Ahmad[1]*, Anees Ahmed Vighio[2], Suhaida Ahmad[3]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
[2]Department of Civil Engineering, Mehran University of Engineering & Technology, Jamshoro 76062, Pakistan
[3]RN Technologies Sdn. Bhd., No 28-A Jalan Horizon Perdana 3, Horizon Avenue Commercial Centre, 79100 Iskandar Puteri, Johor, Malaysia

*Corresponding author: faridahanim@utm.my

Abstract - Soil erosion at construction sites poses significant environmental and economic risks, yet its assessment is often neglected due to short project timelines and limited monitoring practices. This study presents an integrated approach combining unmanned aerial vehicle (UAV) photogrammetry, the Universal Soil Loss Equation (USLE), and Geographic Information Systems (GIS) to enhance spatially explicit soil erosion assessment and support erosion and sediment control planning (ESCP). High-resolution aerial imagery acquired with a DJI Phantom 4 Pro drone was used to derive detailed topographic and land-cover information, while rainfall erosivity and soil erodibility factors were obtained from established literature sources. These datasets were processed in ArcGIS to generate high-resolution soil erosion maps for a 10.5-acre construction site in Port Dickson, Malaysia. The results indicate a 7% reduction in maximum predicted soil erosion following the implementation of targeted control measures, including slope regrading and surface covering. The findings demonstrate that UAV–GIS–USLE integration enables precise identification of erosion-prone zones and provides a quantitative basis for evaluating the effectiveness of erosion control measures. This improves decision-making for construction site management and strengthens compliance with Department of Irrigation and Drainage (DID) guidelines. Overall, the proposed methodology enhances ESCP effectiveness by enabling data-driven monitoring, improved spatial analysis, and systematic evaluation of soil erosion mitigation strategies.

Keywords *– Soil Erosion; Unmanned Aerial Vehicle; Universal Soil Loss Equation; Geographic Information System; Erosion and Sediment Control Plan*

Article History: Received 16 January 2026, Accepted 16 June 2026, Published 31 August 2026

How to cite: Kamil, M. D. H., Ahmad, F., Vighio, A. A. and Ahmad, S. (2026). Unmanned Aerial Vehicle (UAV) Photogrammetry for Soil Erosion Mapping: Integrating USLE and GIS in Construction Sites. Journal of Advanced Geospatial Science and Technology. 6(2), 174-191. DOI: https://doi.org/10.11113/jagst.v6n2.129

1.0 Introduction

Soil erosion is a natural process in the hydrologic cycle (El Jazouli et al., 2017); however, its rate and spatial extent are significantly amplified by anthropogenic disturbances, particularly construction activities, due to rainfall exposure, poor site management, and inadequate erosion analysis (Kaufman, 2000). Uncontrolled soil erosion can adversely affect construction projects in terms of time, cost, and quality, and contribute to environmental issues such as landscape degradation and water pollution (Issaka & Ashraf, 2017). In congested areas, these impacts can be particularly severe, as increased sediment transport may compromise drainage systems and slope stability, potentially causing damage to public property or even loss of life if appropriate control measures are not implemented.

To mitigate these risks, the Department of Irrigation and Drainage Malaysia (DID) has published guidelines for erosion and sediment control at construction sites, including design procedures and calculations for estimating soil erosion (Department of Irrigation and Drainage Malaysia, 2000). These guidelines use an average topographic factor to predict erosion rates, which assumes uniform terrain conditions across the site and therefore provides only a generalised assessment with limited site-specific precision. As a result, more detailed erosion assessments at multiple points across a construction site are necessary to enhance Best Management Practices (BMPs) by identifying high-risk areas and optimising erosion control strategies. Such spatially explicit assessments are particularly critical for complex construction sites characterised by rapid terrain modification. Although previous studies have demonstrated the usefulness of integrating UAV photogrammetry, GIS, and the Universal Soil Loss Equation (USLE) for soil erosion assessment, most of these applications have been conducted at watershed, agricultural, or laboratory-controlled scales. Limited attention has been paid to their application in highly dynamic construction-site environments, where rapid terrain modification and short project durations require high-resolution, timely monitoring approaches.

Furthermore, existing studies often focus solely on erosion estimation, with less emphasis on evaluating the effectiveness of implemented erosion control measures within a real-world operational ESCP framework. In contrast, this study advances current research by applying UAV-derived high-resolution topographic data within a GIS-based USLE modeling framework specifically for a construction site. Further, it quantifies the impact of implemented erosion control measures through comparative erosion mapping. This provides a practical decision-support approach for erosion monitoring, mitigation assessment, and compliance with ESCP requirements in construction projects.

A detailed erosion assessment can be visualised through soil erosion mapping, which serves as a forensic and diagnostic tool to investigate the causes of excessive soil loss and sedimentation. Furthermore, erosion mapping can support the monitoring of Erosion and Sediment Control Plans (ESCP) to ensure compliance with DID guidelines (Asnor et al., 2020). From a management perspective, erosion maps also enable proactive decision-making by prioritising mitigation measures based on quantified risk levels rather than qualitative judgment alone. However, conventional soil erosion analysis is often limited by time-consuming field surveys, fragmented data integration, and manual processing, which restrict its applicability for continuous monitoring and timely intervention, making effective erosion risk management challenging.

This study addresses these limitations by leveraging Unmanned Aerial Vehicle (UAV) photogrammetry and Geographic Information Systems (GIS) to automate topographic data acquisition and generate detailed soil erosion maps (d'Oleire-Oltmanns, 2012). Similar applications in the Malaysian context have demonstrated the feasibility of UAV-based photogrammetry for erosion-related analysis. Recent studies have increasingly demonstrated the effectiveness of integrating UAV-based photogrammetry with GIS and erosion modeling techniques for high-resolution assessment of soil erosion. UAV-derived Structure-from-Motion (SfM) photogrammetry has been widely adopted to generate high-accuracy Digital Elevation Models (DEMs), enabling detailed characterisation of micro-topographic changes relevant to erosion processes. These high-resolution datasets have been effectively coupled with soil erosion models such as the Universal Soil Loss Equation (USLE) and its revised form (RUSLE) to improve spatially distributed soil loss estimation. For example, UAV-based time-series analysis has been successfully used to quantify field-scale erosion dynamics and evaluate model performance, showing that erosion model predictions can be significantly improved when calibrated with UAV-derived observations (Meinen & Robinson, 2021). Similarly, UAV-SfM techniques have proven effective in capturing sediment redistribution and terrain changes at fine spatial scales, supporting validation of erosion models under natural rainfall conditions (Dai et al., 2022). Recent research has also demonstrated that UAV-derived DEM differencing approaches can quantify annual sedimentation with high accuracy and provide reliable benchmarks for comparing model outputs such as RUSLE and PESERA (Alexiou et al., 2023).

For example, Azli and Yong (2022) applied UAV photogrammetry combined with GPS RTK to estimate soil volumetric erosion at Universiti Teknologi Malaysia, highlighting the capability of UAV-derived elevation models to quantify erosion-induced surface changes with acceptable accuracy. UAV-derived datasets provide high spatial resolution and rapid data acquisition, enabling accurate representation of site-specific topographic variability. The Universal Soil Loss Equation (USLE) is employed to quantify erosion rates by integrating spatially variable factors, including topography and land cover derived from UAV imagery, with static parameters such as rainfall erosivity and soil erodibility obtained from established literature (Wischmeier & Smith, 1978; Alewell et al., 2019). GIS plays a crucial role in processing and analysing these spatial datasets, enabling the overlay of different USLE factors to produce high-resolution, site-specific erosion risk maps (Rachmawati & Kim, 2022). Through GIS-based spatial modeling, critical erosion-prone zones can be systematically identified, allowing erosion control measures to be spatially optimised and aligned with actual on-site risk conditions rather than assumed averages. Therefore, the objective of this study is to evaluate existing ESCP conditions at a construction site by integrating UAV-based photogrammetry and GIS-based USLE modeling to generate high-resolution orthomosaic imagery, digital elevation models, and soil erosion maps, thereby improving the identification, assessment, and management of erosion-prone areas.

2.0 Methodology

This study employs UAV photogrammetry, Digital Elevation Model (DEM) analysis, and a GIS-based Universal Soil Loss Equation (USLE) modeling approach to facilitate spatially explicit soil erosion estimation at a construction site. This combined working environment enables high-resolution characterisation of topography and surface conditions, which are essential parameters affecting soil erosion processes during construction work.

UAV photogrammetry was chosen as the primary method of data collection because it can swiftly survey site-specific terrain with high-resolution data once site clearing is complete. UAV-based data collection will save significant field time compared with traditional land surveying techniques and provide good spatial coverage for detailed slope and elevation analysis. The resulting DEM enabled accurate derivation of the slope and slope length parameters, which directly affect the LS factor in the USLE model.

The study utilised a UAV-based photogrammetry approach integrated with Pix4Dcapture for mission planning. A pre-planned flight mission was designed to ensure consistent image overlap and complete spatial coverage of the study area. The UAV survey was conducted at a flight altitude of 122 m with approximately 80% forward overlap and 70% side overlap. A DJI Phantom 4 Pro drone equipped with a 20 MP mechanical-shutter camera captured high-resolution nadir images under stable weather conditions, in compliance with Civil Aviation Authority of Malaysia (CAAM) regulations.

The secondary climate and geological data, incorporating the elements of rainfall erosivity (R) and soil erodibility (K), enable the model to account for regional environmental conditions while remaining computationally efficient for a relatively small study area. Concurrently, the land use and surface cover data obtained from UAV imagery enable the active reflection of cropping management (C) and support practice (P) variables based on real site conditions rather than presumed values.

The C factor was derived from UAV orthomosaic imagery through visual interpretation and classification of land cover conditions, including bare soil, partially vegetated areas, and constructed surfaces, with values assigned based on established USLE literature. The P factor was determined based on observed on-site erosion control practices, such as slope regrading and surface protection measures, reflecting actual construction-site management conditions rather than assumed standard values.

Through the application of the USLE model in a GIS setting, spatial overlay and analysis of all contributing factors were performed, and the resulting soil erosion risk map was high-resolution. All USLE factors (R, K, LS, C, and P) were converted into raster format and standardised to a common spatial resolution in ArcGIS. The Raster Calculator tool was used to implement the USLE equation in a cell-by-cell spatial analysis, enabling precise spatial estimation of soil loss across the study area. The resulting output was classified into erosion severity zones to interpret and identify high-risk areas. The spatial modelling method will be used to identify areas of erosion at the construction site more efficiently, enabling erosion and sediment management to be directed towards its main objectives. In general, the suggested methodology enhances the accuracy, effectiveness, and suitability of soil erosion evaluation in construction site management and implementation of ESCP. Figure 1 shows the flowchart of the study's research methodology.

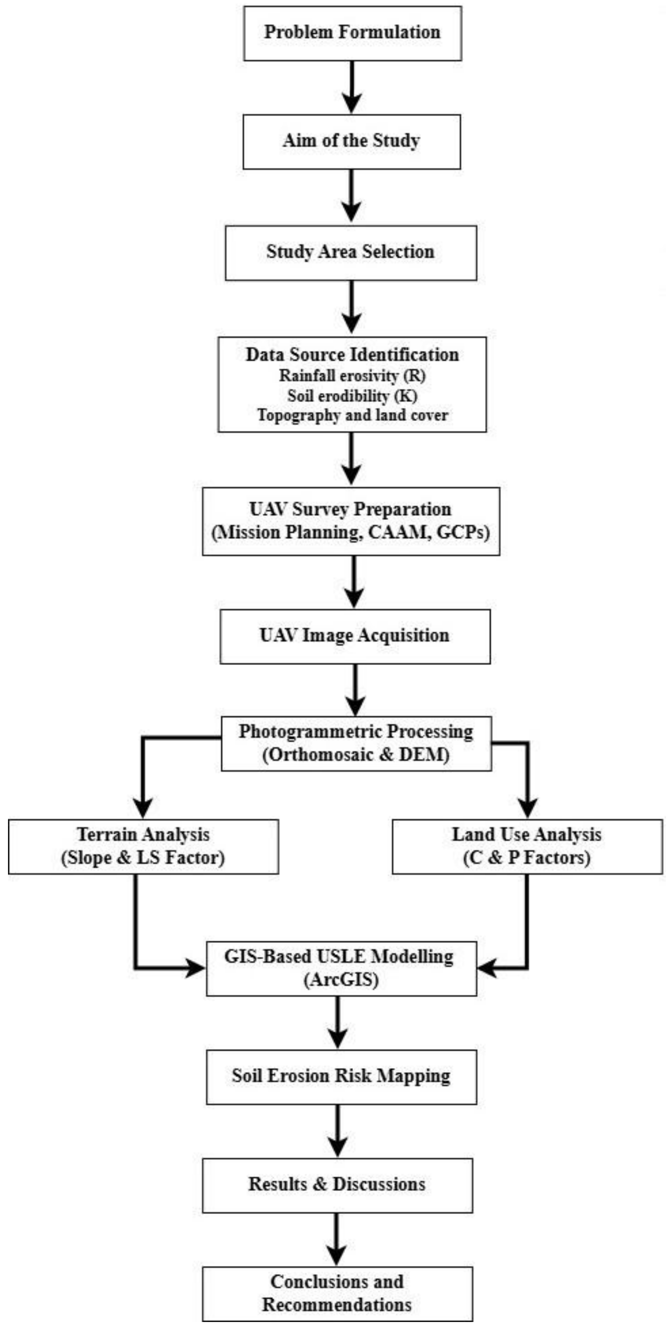

Figure 1: Flow chart of research methodology

2.1 Study Area

The site represents a typical low-rise residential construction project undergoing extensive earthworks, making it suitable for soil erosion assessment. UAV mapping was performed post-site clearing to ensure unobstructed ground visibility. This timing minimised the effects of surface obstruction on elevation modelling and slope derivation. The site is shown in Figure 2.

Figure 2. Construction site used as study area

2.2 Soil Loss Calculation

This study employed the Universal Soil Loss Equation (USLE) to estimate soil loss (A) (Wischmeier & Smith, 1978). The model has been used widely for soil conservation purposes (Alewell et al., 2019), particularly for estimating sheet and rill erosion at the site scale. The USLE formula is given by Eq. (1).

$$A = R \cdot K \cdot LS \cdot C \cdot P \qquad \text{Eq (1)}$$

where:

A is the average annual soil loss (tons ha-1 year-1),

R is the rainfall erosivity (MJ mm ha-1 h year),

K is the soil erodibility factor (tons ha-1 R unit-1),

LS is the topographic factor (dimensionless),

C is the cropping management factor (dimensionless), and

P is the practice support factor (dimensionless)

The USLE framework was selected because it allows integration of spatially distributed factors within a GIS environment, enabling site-specific erosion assessment rather than relying on generalised averages.

2.3 Data Acquisition and Processing

This study adopted the UAV photogrammetry method previously implemented by Meinen and Robinson (2021), which demonstrated the effectiveness of UAV-based photogrammetry for estimating soil loss in agricultural areas. Although originally applied in agricultural settings, the method is transferable to construction sites due to similar exposure of bare soil surfaces. This approach was chosen in this study because UAV-based photogrammetry provides high-resolution, site-specific topographic data, making it suitable for accurate estimation of soil erosion at construction sites. The framework of this study is shown in Figure 3.

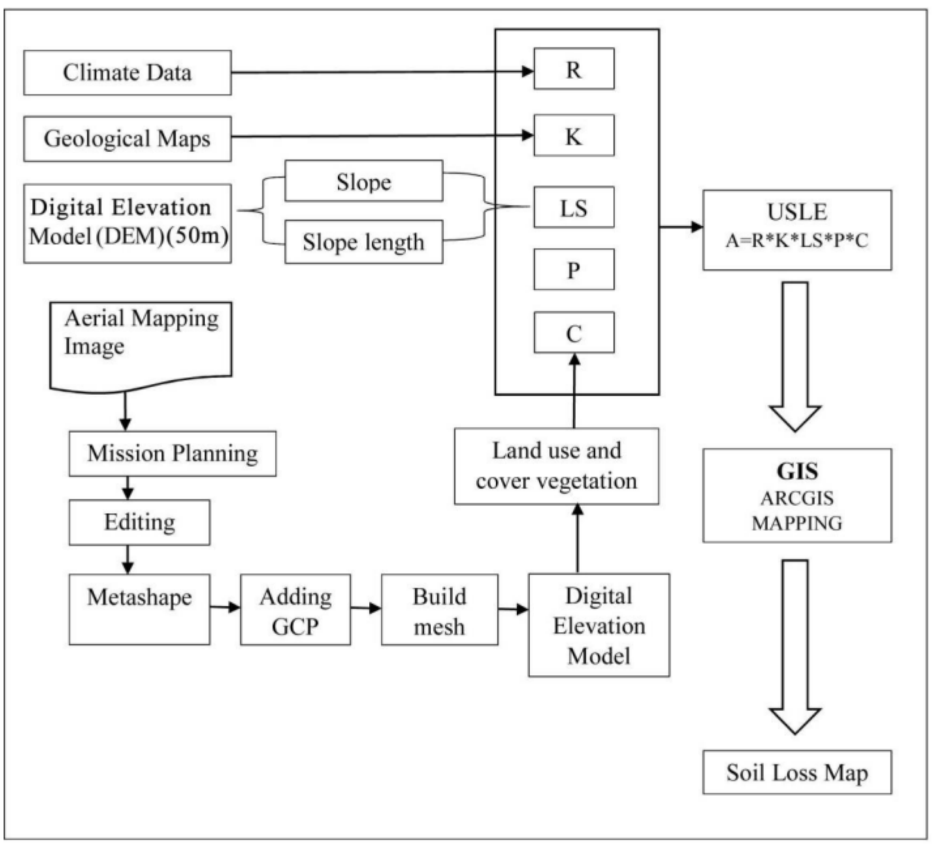

Figure 3. Framework of this study

As shown in Figure 3, data for this study were gathered from different sources. Climate data and geological maps were obtained to determine the rainfall erosivity (R) and soil erodibility (K) factors. These datasets were obtained from secondary sources and were assumed to be spatially uniform across the study site due to its limited area. Additionally, aerial imagery was captured using an Unmanned Aerial Vehicle (UAV) to generate high-resolution geospatial data.

The study utilised an UAV-based photogrammetry approach integrated with Pix4Dcapture for mission planning. The flight ensured consistent image overlap and coverage. A DJI Phantom 4 Pro drone equipped with a 20MP mechanical-shutter camera captured nadir-oriented images at an altitude of 122m, in accordance with Civil Aviation Authority of Malaysia (CAAM) regulations. The UAV captured overlapping high-resolution aerial images, which were subsequently processed using Agisoft Metashape to generate aerial maps and a Digital Elevation Model (DEM). Ground Control Points (GCPs) were incorporated to improve the spatial accuracy of the photogrammetric outputs. The DEM was further used to extract slope and slope-length parameters, which are used to calculate the LS factor.

In addition to topographic data, land-use and vegetation cover data were extracted from aerial imagery to determine the C and P factors. These factors reflect the site's surface condition and existing erosion control practices at the time of data capture. All spatial layers representing USLE factors were processed in ArcGIS, where raster conversion and normalisation were performed to ensure uniform resolution. The Raster Calculator tool was used to compute pixel-wise soil loss estimation using the USLE equation, and the final erosion map was classified into severity classes for analysis. The methodology enables rapid, repeatable, and spatially explicit erosion assessment to support targeted ESCP decision-making at construction sites.

The practical contribution of this framework lies in its application to construction-site erosion management, where frequent terrain modifications and limited monitoring often hinder effective erosion control. By integrating UAV-derived topographic information with GIS-based USLE modelling, the framework provides a practical tool for assessing erosion risks, prioritising mitigation measures, and evaluating ESCP effectiveness throughout the construction lifecycle.

3.0 Results and Discussion

3.1 Photogrammetry Accuracy

The aerial imagery was captured using a Phantom 4 Pro drone and processed with Agisoft Metashape, resulting in an orthomosaic, as shown in Figure 4.

Figure 4. Orthomosaic photograph taken on 25 September 2021

To evaluate the accuracy of aerial mapping, the photogrammetric data were compared with conventional survey measurements obtained using a total station. A total of 50 distance measurements were analysed, and the results are summarised in Table 1.

Table 1. Photogrammetry accuracy assessment

No.	Description	Date	
		25 September 2021	25 November 2021
1	Maximum Difference	47.2210 mm	25.0710 mm
2	Minimum Difference	0.1990 mm	1.5260 mm
3	Mean	6.1917 mm	6.4322 mm
4	Standard Deviation	20.3678 mm	12.2375 mm

The mean difference in measurements is below 10 mm, indicating that the photogrammetry technique provides a reliable level of accuracy. In terms of geospatial accuracy, sub-centimetre mean error values are acceptable for terrain modelling, slope derivation, and earthwork analyses at construction sites. The observed reduction in maximum error and standard deviation between the two survey dates indicates improved surface regularity following partial site alteration and the implementation of erosion control, rather than degradation in photogrammetric functionality. These findings indicate that UAV photogrammetry is sufficiently robust to be utilised for time-series assessments and can detect subtle topographical variations that directly affect erosion-related measurements, including slope gradient and slope length. Such precision confirms that it can serve as a reliable data source for erosion modelling and ESCP evaluation, especially when frequent conventional surveys are impractical due to time, cost, or safety constraints. Therefore, this method can be effectively used for soil erosion analysis, serving as an indicator for Best Management Practices (BMPs) to control soil erosion and sedimentation at construction sites.

The results obtained in this study are consistent with previous research demonstrating the reliability of UAV-based photogrammetry for high-resolution terrain analysis in environmental and construction applications. Studies have reported that UAV-derived Digital Elevation Models (DEMs) can achieve centimetre-level accuracy when validated against conventional surveying techniques, making them suitable for slope and erosion-related analyses (Eltner et al., 2016; James et al., 2017). In addition, previous research has shown that integrating UAV-derived spatial data with GIS-based USLE modelling significantly improves the identification of erosion-prone zones compared with traditional ESCP methods based on generalised topographic assumptions (Meinen & Robinson, 2021; Alexiou et al., 2023). The observed reduction in soil erosion following the implementation of control measures is also consistent with earlier studies highlighting the effectiveness of slope regrading and surface protection techniques in reducing runoff velocity and soil detachment in construction environments (Dai et al., 2022; García-Ruiz et al., 2013).

3.2 Soil Erosion Mapping

This study evaluates soil erosion by generating soil erosion maps of the construction site to enhance ESCP management in compliance with DID guidelines. The erosion model was developed using the USLE method based on data from literature reviews, construction documents, site observations, and photogrammetry techniques. The initial analysis was conducted on 25 September 2021.

Based on the soil erosion mapping results, control measures were implemented to mitigate areas with high predicted erosion levels. Two critical areas, Area 1 and Area 2, were identified in the soil erosion map, as highlighted in Figure 5.

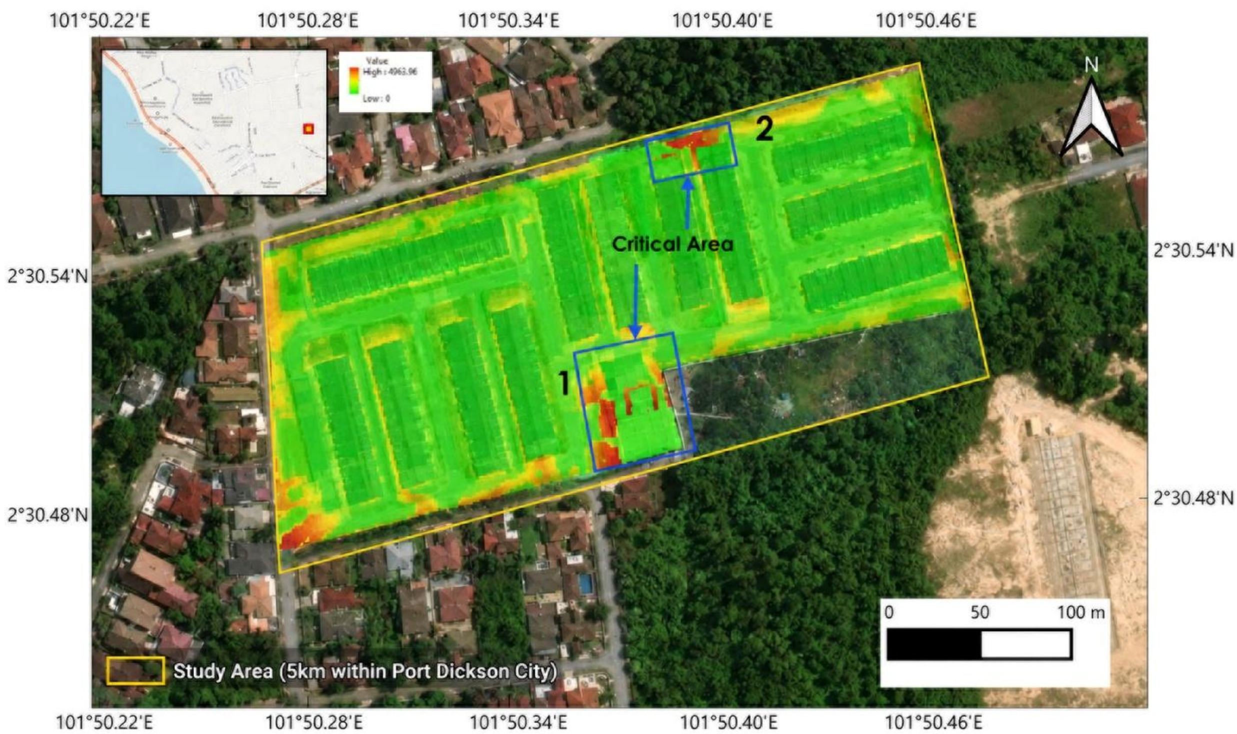

Figure 5. Soil Erosion Map on 25 November 2021 (Before Control Measures Implementation)

The identification of erosion hotspots across discrete spatial scales highlights the advantage of spatially explicit GIS-based erosion modelling over traditional ESCP approaches, which often rely on averaged topographic assumptions. This allows mitigation priorities to be established based on quantified erosion risk rather than qualitative assessment.

To control soil erosion at Area 1, the construction manager decided to reduce the existing ground level. This helped reduce the LS factor by decreasing the slope, thereby minimising the risk of erosion. Figure 6 illustrates the earthwork performed at Area 1. By directly modifying the topographic driver of erosion, this measure effectively reduced runoff velocity and the potential for soil detachment. From an engineering management perspective, slope regrading is a cost-effective, proactive approach, as it incorporates erosion control into earthworks maintenance without requiring additional structural solutions.

Figure 6. Earthwork performed at Area 1

To control soil erosion at Area 2, the control measure involved covering the slope with concrete gunite, effectively reducing soil erosion in that section. The implementation is shown in Figure 7. The use of gunite mainly affected the cover-management (C) and support practice (P) factors within the USLE framework, which is especially effective on steep or geometrically constrained slopes where vegetative cover is challenging to implement or maintain during the construction active stages.

Figure 7. Gunite Application for Slope Stabilisation at Area 2

Both control measures directly influenced the factors in the USLE model. Figure 8 presents the soil erosion map after the implementation of the control measures. The effectiveness of these measures was evaluated by comparing soil erosion values before and after implementation, as summarised in Table 2.

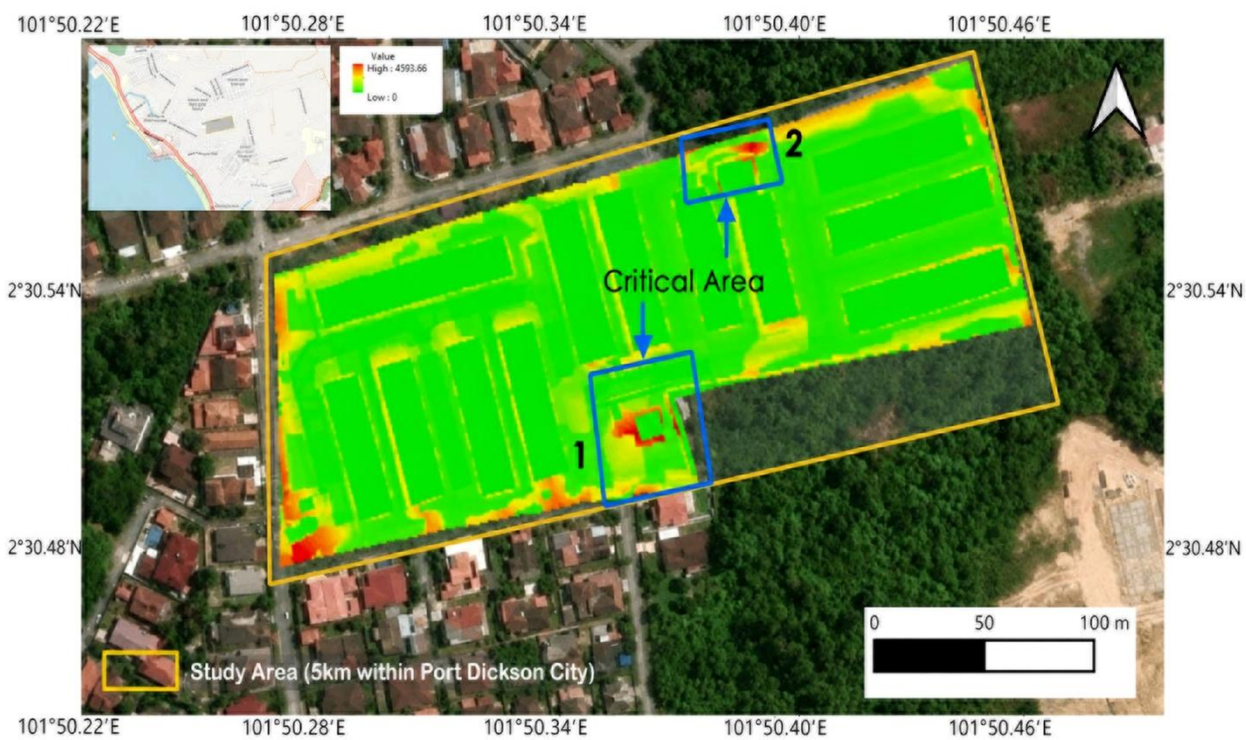

Figure 8. Soil Erosion Mapping on 25 November 2021 (After Control Measures Implementation)

Table 2. Soil erosion values pre- and post-control measures

No.	Description	Analysis on 25 September 2021 (Pre-control)	Analysis on 25 November 2021 (Post-control)
1	Maximum Soil Erosion Value (ton ha^{-1} $year^{-1}$)	4963.96	4593.66
2	Minimum Soil Erosion Value (ton ha^{-1} $year^{-1}$)	0.00	0.00
3	Mean (ton ha^{-1} $year^{-1}$)	447.61	437.77
4	Standard Deviation	893.74	780.06

Initial mapping identified two critical zones with maximum erosion of 4,963.96 tons ha^{-1} $year^{-1}$. Post-implementation of slope reduction and concrete gunite covering, maximum erosion decreased by 7% to 4,593.66 tons ha^{-1} $year^{-1}$. The mean erosion value also decreased slightly from 447.61 to 437.77. Although the percentage reduction appears moderate, the absolute reduction in erosion magnitude is substantial at the site scale, particularly when considered over the cumulative duration of construction activities. Moreover, the reduction in standard deviation indicates decreased spatial variability, suggesting that erosion hotspots were effectively mitigated rather than displaced across the site.

These findings confirm that implementing ground-level reduction and slope stabilisation techniques can significantly control soil erosion in construction areas. While the reduction in erosion values may appear moderate, it is crucial to note that erosion control is a continuous process. Additional measures, such as vegetation cover, drainage improvement, and sediment barriers, could further enhance the effectiveness of soil conservation efforts. Structural measures alone may not fully suppress erosion risk under variable rainfall conditions. Therefore, integrating these interventions with complementary measures such as temporary vegetation, surface drainage optimisation, sediment traps, and perimeter controls is expected to yield synergistic erosion reduction effects.

This study advances erosion monitoring methodologies by demonstrating how UAV and GIS technologies can enhance the accuracy and efficiency of soil erosion assessments. Importantly, the ability to conduct periodic UAV surveys enables quantitative evaluation of erosion control effectiveness, facilitating adaptive ESCP management and evidence-based decision-making during construction.

4.0 Conclusion

The integration of UAV-based photogrammetry with GIS applications and the USLE model provides a powerful approach for soil erosion monitoring in construction sites. This method aligns with DID requirements and can be implemented as a best management practice to enhance erosion and sediment control planning (ESCP). The application of this research in construction sites offers several key benefits, including the identification of root causes of high erosion occurrences and sedimentation in nearby drainage systems, continuous monitoring of soil erosion following ESCP implementation, facilitation of work programme adjustments by prioritising high-erosion areas, and quantitative assessment of the effectiveness of implemented control measures in reducing soil erosion.

While this study demonstrates a positive impact on construction-site erosion management, further improvements could enhance the approach's accuracy and reliability. These include quantifying the effectiveness of control measures through runoff water sampling or sedimentation assessment, validating model outputs by comparison with other established erosion models, and analysing the relative weightage of contributing factors to better understand their role in erosion reduction. Addressing these aspects would support further refinement of soil erosion prediction and mitigation strategies, contributing to more effective, systematic, and data-driven ESCP management in construction projects.

Acknowledgement

The authors would like to acknowledge the financial support from the Contract Grant (R.J130000.7622.4C861).

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Reference

Alewell, C., Borrelli, P., Meusburger, K., & Panagos, P. (2019). Using the USLE: Chances, challenges and limitations of soil erosion modelling. International Soil and Water Conservation Research, 7(3), 203–225. https://doi.org/10.1016/j.iswcr.2019.05.004

Alexiou, S., Efthimiou, N., Karamesouti, M., Papanikolaou, I. D., Psomiadis, E., & Charizopoulos, N. (2023). Measuring annual sedimentation through high accuracy UAV-photogrammetry data and comparison with RUSLE and PESERA erosion models. Remote Sensing, 15(5), 1339. https://doi.org/10.3390/rs15051339

Asnor, A. S., Rahman, R. A., & Ahmad, S. W. (2020). Causal factors in implementing environmental regulation: Evidence from the erosion and sediment control plan in Malaysia. International Journal of Engineering Technology and Sciences, 7(1), 1–10.

Azli, A. D. Y., & Yong, C. Z. (2022). Estimation of soil volumetric erosion using GPS and unmanned aerial vehicle: A case study at Universiti Teknologi Malaysia, Johor. Journal of Advanced Geospatial Science & Technology, 2(2), 27–41.

Dai, W., Qian, W., Liu, A., Wang, C., Yang, X., Hu, G., & Tang, G. (2022). Monitoring and modeling sediment transport in space in small loess catchments using UAV-SfM photogrammetry. CATENA, 214, 106244. https://doi.org/10.1016/j.catena.2022.106244

Department of Irrigation and Drainage Malaysia. (2000). Guidelines for erosion and sediment control in Malaysia.

d'Oleire-Oltmanns, S., Marzolff, I., Peter, K. D., & Ries, J. B. (2012). Unmanned aerial vehicle (UAV) for monitoring soil erosion in Morocco. Remote Sensing, 4(11), 3390–3416.

El Jazouli, A., Barakat, A., Ghafiri, A., El Moutaki, S., Ettaqy, A., & Khellouk, R. (2017). Soil erosion modeled with USLE, GIS, and remote sensing: A case study of Ikkour watershed in Middle Atlas (Morocco). Geoscience Letters, 4(1), 25. https://doi.org/10.1186/s40562-017-0091-6

Eltner, A., Kaiser, A., Castillo, C., Rock, G., Neugirg, F., & Abellán, A. (2016). Image-based surface reconstruction in geomorphometry – merits, limits and developments. Earth Surface Dynamics, 4, 359–389. https://doi.org/10.5194/esurf-4-359-2016

Filchev, L., & Kolev, V. (2023). Assessing soil erosion risk through geoinformation sciences and remote sensing: A review. arXiv. https://doi.org/10.48550/arXiv.2310.08430

García-Ruiz, J. M., Nadal-Romero, E., Lana-Renault, N., & Beguería, S. (2013). Erosion in Mediterranean landscapes: Changes and future challenges. Geomorphology, 198, 20–36. https://doi.org/10.1016/j.geomorph.2013.01.001

Issaka, S., & Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: A review. Geology, Ecology, and Landscapes, 1(1), 1–11. https://doi.org/10.1080/24749508.2017.1301053

James, M. R., Robson, S., & Smith, M. W. (2017). 3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry. Earth Surface Processes and Landforms, 42(12), 1769–1788. https://doi.org/10.1002/esp.4125

Kaufman, M. M. (2000). Erosion control at construction sites: The science-policy gap. Environmental Management, 26(1), 89–97. https://doi.org/10.1007/s002670010073

Meinen, B. U., & Robinson, D. T. (2021). Agricultural erosion modelling: Evaluating USLE and WEPP field-scale erosion estimates using UAV time-series data. Environmental Modelling & Software, 137, 104962. https://doi.org/10.1016/j.envsoft.2021.104962

Rachmawati, T. S. N., & Kim, S. (2022). Unmanned aerial vehicles (UAV) integration with digital technologies toward construction 4.0: A systematic literature review. Sustainability, 14(9), 5708. https://doi.org/10.3390/su14095708

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: A guide to conservation planning. U.S. Department of Agriculture, Science and Education Administration.