Assessment of Unmanned Aerial Vehicle Versus Terrestrial Method of Topographic Surveying

*[1]Ibrahim A., [2]Afonja Y. O., [3]Omale D., [2]Idoko I. A., [1]Alagbe A. O., [1]Oduyemi A. T., [1]Akintuyi O. B., [1]Ibrahim R. O. & [1]Azeez Z. O.

[1]Department of Cartography and GIS, Federal School of Surveying, Oyo, Nigeria
[2]Department of Surveying and Geoinformatics, Federal School of Surveying, Oyo, Nigeria
[3]Department of Surveying and Geoinformatics, Confluence University of Science and Technology, Osara, Nigeria
*****Corresponding author: brawnabdulibrahim@fss-oyo.edu.ng

Received: 16/02/2025 Revised: 18/04/2025 Accepted: 12/05/2025

Advancement in technology gave birth to different survey methods. This study conducted a comparative analysis of topographic survey methods, focusing on the effectiveness of Unmanned Aerial Vehicle (UAV) and traditional terrestrial method for surveying the topography over accessible and inaccessible areas within Awe High School in the Afijio Local Government Area of Oyo State. The terrestrial survey involved implementing conventional survey methods to establish three second-order control points, conduct boundary surveys, spot height measurements, detail surveys, and strategical positioning of six ground control points (GCPs) for UAV observation. Measurements and observations for the conventional method utilized the Global Navigation Satellite System (GNSS) receiver, ensuring precision with Static mode and Real-Time Kinematic (RTK mode) for dynamic observations, while UAV data was captured using the DJI Phantom 4 Pro drone at an altitude of 54 meters. All data were processed and plotted on a scale of 1:2000 using AutoCAD, Pix4D, and ArcGIS Pro. The terrestrial method produced Contour Maps and Detail Maps, while the UAV method generated Contour Maps and Orthomosaic Maps. A detailed comparison and analysis followed, revealing accuracy, personnel requirements, cost and time frame. UAV surveys achieved a 52% cost reduction primarily due to reduced personnel, transportation, and equipment expenses. Additionally, UAV surveys reduced project duration by 45.45%. Accuracy assessment confirms high horizontal precision, with Pearson correlation coefficients of 0.99999999 for Easting, 0.99999998 for Northing, and 0.99999939 for Height. Despite minor vertical variations in vegetation areas. The study recommends that UAVs are a reliable and efficient alternative for large-scale topographic mapping. Both methods proved accurate for topographic surveys, with UAV having some advantages over terrestrial methods. The study recommends a combination of both methods for inaccessible areas, as the accuracy of the UAV depends on the conventional GNSS terrestrial method in such cases.

Keywords: Topographic Survey, Unmanned Aerial Vehicle (UAV), Orthomosaic, Contours

Introduction

The rapid advancement in geospatial technology has revolutionized the surveying field, introducing innovative tools such as Unmanned Aerial Vehicles (UAVs). These technologies offer significant potential for improving topographic data acquisition, which is fundamental to various applications, including land-use planning, infrastructure development, environmental monitoring, and disaster management (Rahman & Faizuddin, 2025; Quamar *et al.*, 2023). Traditional terrestrial survey methods, characterized by their precision and reliability, have been widely utilized over the years. However, these methods are often challenged by time constraints, high operational costs, and limited accessibility in rugged or inaccessible terrains. As UAV-based surveying gains traction, there is a growing need for comparative studies to establish its efficacy relative to conventional terrestrial methods, particularly in terms of accuracy, cost-efficiency, and operational flexibility (Emmanuel, 2025; Jiménez-Jiménez *et al*, 2021).

Existing literature reveals a growing body of research on the application of UAVs for topographic surveying across the globe. Studies in Europe and North America have demonstrated UAVs' ability to produce high-resolution orthomosaic maps and accurate digital elevation models (DEMs) with significantly reduced time and cost. For instance, researchers have highlighted UAVs' potential to outperform terrestrial methods in large-scale projects and inaccessible areas (Nieuwenhuis *et al.*, 2022; Moravec *et al.*, 2017). In Africa, UAV-based surveys are gradually gaining adoption in infrastructure projects and natural resource management, where they have shown promise in addressing accessibility challenges (Ajayi *et al.*, 2017). However, much of this research remains at a nascent stage, with limited focus on direct, side-by-side comparisons of UAV and terrestrial methods in varying terrains and contexts.

In Nigeria, the adoption of UAVs in topographic surveying is still emerging, primarily limited to urban planning, agricultural mapping, and environmental studies. While these applications have shown encouraging results, significant gaps remain in the evaluation of UAV efficiency compared to conventional methods, particularly in rural and semi-urban settings with mixed terrain (Aminobiren *et al.*, 2022; Olayinka-Dosunmu *et al.*, 2021; Abiodun, 2021). Most studies within the Nigerian context focus on isolated use cases without comprehensive analysis of performance metrics such as area coverage, accuracy, time efficiency, and cost implications. Additionally, few studies incorporate the role of ground control points (GCPs) in enhancing UAV data accuracy, leaving questions about their optimal integration in UAV workflows (Ukwueze *et al.*, 2024; Muhmad *et al.*, 2023).

These gaps underscore the need for a focused investigation into the comparative performance of UAV and terrestrial survey methods, particularly in areas with a mix of accessible and inaccessible terrains. This study addresses these gaps by conducting a detailed comparative analysis of both methods within Awe High School, Afijio Local Government Area, Oyo State, Nigeria. It evaluates critical parameters such as area coverage, accuracy, personnel requirements, time frame, and cost efficiency. By leveraging tools like GNSS receivers for terrestrial surveys and the DJI Phantom 4 Pro drone for UAV data acquisition, this research aims to provide insights into the complementary strengths and limitations of both methods.

Study Area

Awe High School, situated along Oyo-Iwo road, Awe area Afijio Local Government Area, Oyo State. It lies between latitude 07^0 49’ 35N to 07^0 49’ 36’’N of the equator and longitude 03^0 57’ 25”E to 03^0 57’ 26”E of the Greenwich Meridian as shown in Figure 1, covering an approximate area of 12.95 hectares of land (Akanbi *et al.*, 2023). The current Afijio Local Government was established in May 1989 following the division of the former Oyo Local Government Area. Afijio, encompassing key towns like Awe, Fiditi, and Ilora, covers approximately 800 square kilometers in central Oyo, characterized by deciduous forest vegetation (Jatto *et al.*, 2020). It has an average temperature of 28.5°C, receives about 2100 mm of rainfall annually and generally experiences warm and humid weather. The dry season lasts from November to March, while the wet season spans from April to October. Agriculturally rich, major crops include maize, yam, and cocoa, and it boasts robust infrastructure and social amenities.

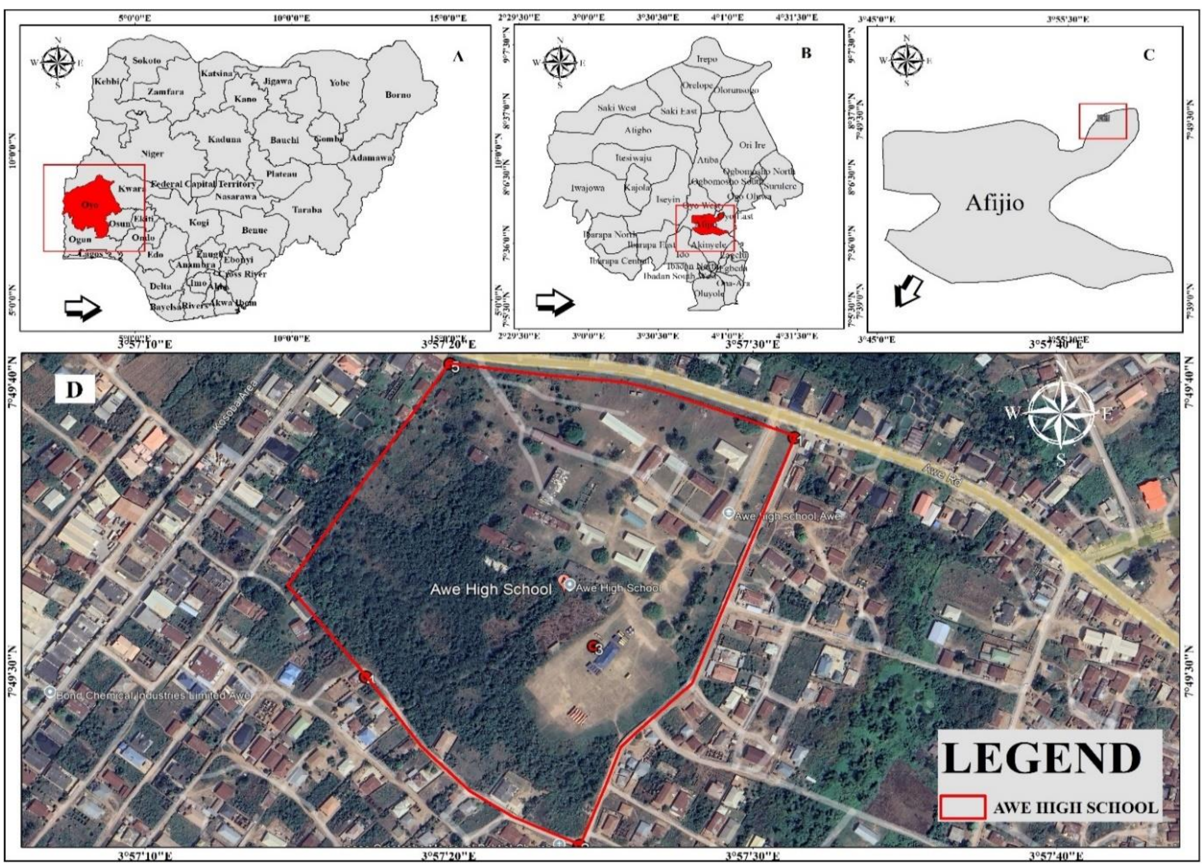

Figure 1: Study Area ***(A = Nigeria, B = Oyo State, C = Afijio LGA, D = Awe High School)***

Materials and Methods

The data required for this study dictated the choice of instrumentation used for data acquisition. Figure 2 provides a comprehensive overview of the workflow sequence, detailing the methods and data types utilized at each stage of the study. This figure encapsulates the entire process, ensuring clarity and understanding of the research methodology and data handling from the initial stage to the outcome.

Materials

The Google Earth was used for reconnaissance and planning, and a South GNSS Receiver and its accessories were employed for second order control establishment, Ground Control Point (GCP) establishment, perimeter surveying, and detailing. DJI Phantom 4 Pro Drone was then used to capture images of the study area, with flight plans organized using Drone Deploy, see Table 1. GNSS data was subsequently processed using the South Geomatics office tools. ArcGIS was utilized for geospatial analysis, and AutoCAD for spot height gridding and the production of final plans. Pix4D processed the drone images, and surfer was employed to produce contour maps. The overall workflow is summarized in Figure 2.

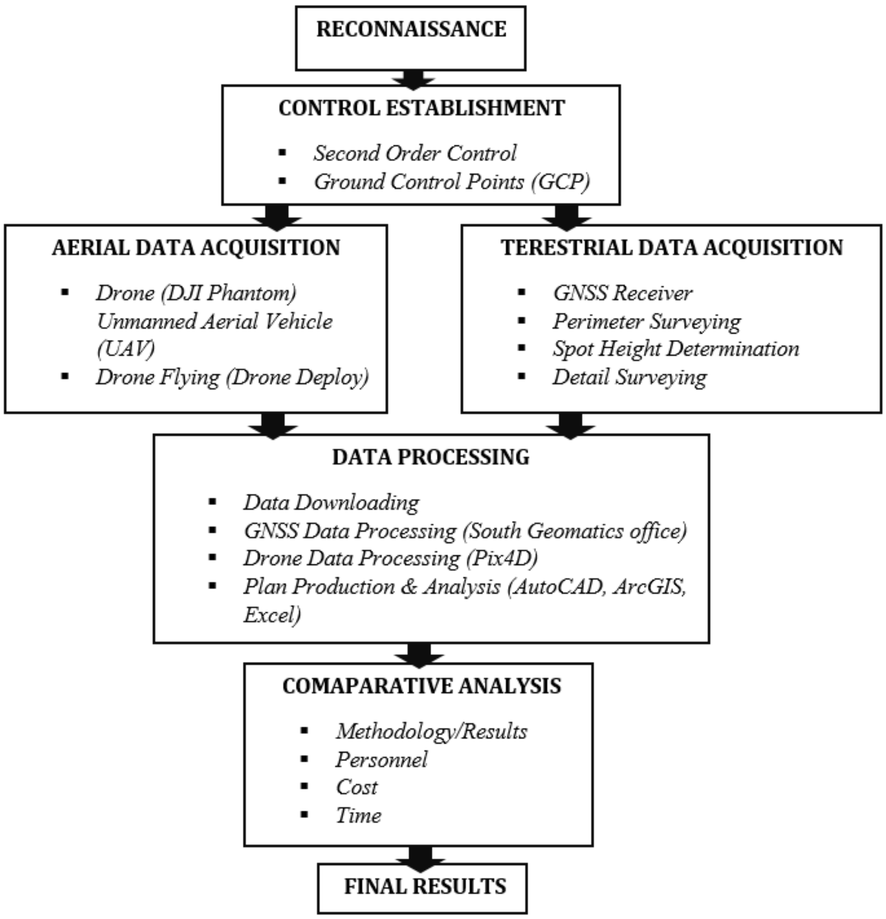

Figure 2: Workflow Diagram

Table 1: DJI Phantom Specification

SN	Specifications	DJI Phantom 4
1	Weight (g)	1380
2	Max speed (m/s)	20
3	Gimbal Stabilization	3-axis
4	Sensor	$\frac{1}{2{\cdot}3''}$ (CMOS) 12.4 Mpx
5	Lens	FOV 94°

Methods

The method involved reconnaissance, establishment of ground control points (GCPs), monumentation, and data acquisition using GNSS and UAVs. GPS (in Static & RTK) and drone surveys collected perimeter, detailing, and elevation data. Equipment, including GNSS receivers, UAVs, and software (ArcGIS, Pix4D), was calibrated and used for data processing, respectively. GNSS data were refined with the South Geomatics Office, and drone imagery was processed in Pix4D to create orthomosaics, digital models, and elevation data for a topographical plan.

Spot-heights, detailing and perimeter survey

The perimeter survey was conducted to determine the extent, dimensions, and boundary limits of the study area using Real-Time Kinematic (RTK) GPS. The base receiver was positioned on an existing second-order control point (FSS2/AWE23/30), and necessary adjustments such as centering, leveling, and instrument height measurements were made. Once the system was configured to Minna Datum and displayed a FIXED status, the rover receiver was used to collect boundary points. Similarly, a detailing survey was performed to capture the location, extent, and shape of features in the study area. Ground Control Points (GCPs) were established for georeferencing and drone processing, coordinated using Differential GPS. After data collection, coordinates were downloaded for further processing. Spot-heighting involved gridding the plotted perimeter at 10m intervals, exporting data to a GPS logger, and setting out points on-site. All observations were recorded, downloaded, and processed for analysis. Distances and bearings between points were computed using the Euclidean distance derived from Pythagoras theorem and the inverse tangent principles (Mohd & Malina, 2024; Pırtı *et al.*, 2009; Pırtı, 2007).

Distance = $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ _ _ _ _ _ *Equation (1)*

Where: $(x_2 - x_1)$ and $(y_2 - y_1)^2$ = Changes or differences in Eastings and Northings coordinates, respectively.

Bearing = $tan^{-1}\left(\frac{\Delta x}{\Delta y}\right)$ _ _ _ _ _ *Equation (2)*

Where: Δx and Δy = Changes or differences in Eastings and Northings coordinates respectively.

Perimeter = $\sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}$ _ _ _ *Equation (3)*

Where: x_i *and* y_i = Coordinates of points along the perimeter.

Unmanned aerial survey

Flight planning for the aerial survey was conducted using the Drone Deploy app, where the study area was outlined, and flight lines were automatically generated. The unit was set to metric, with a flight altitude of 54m and an image resolution of 1.8cm. The total area covered was 13 hectares, requiring four batteries and an estimated 46-minute flight time. Since a single flight could not cover the entire area, the survey was divided into three sections, see figure 3. The UAV (Mavic Pro) was connected to the mobile device via USB, placed on level ground, and pre-flight checks were completed. The UAV then ascended to the set altitude, followed the planned flight path, and captured images, which were stored on its memory card. After the flight, the images were ready for downloading and processing on the computer (Wang, 2022). As shown in Figure 3. The flight was divided into three sections A, B and C and each of these sections were covered individually after which they were combined to form the complete coverage of the whole area.

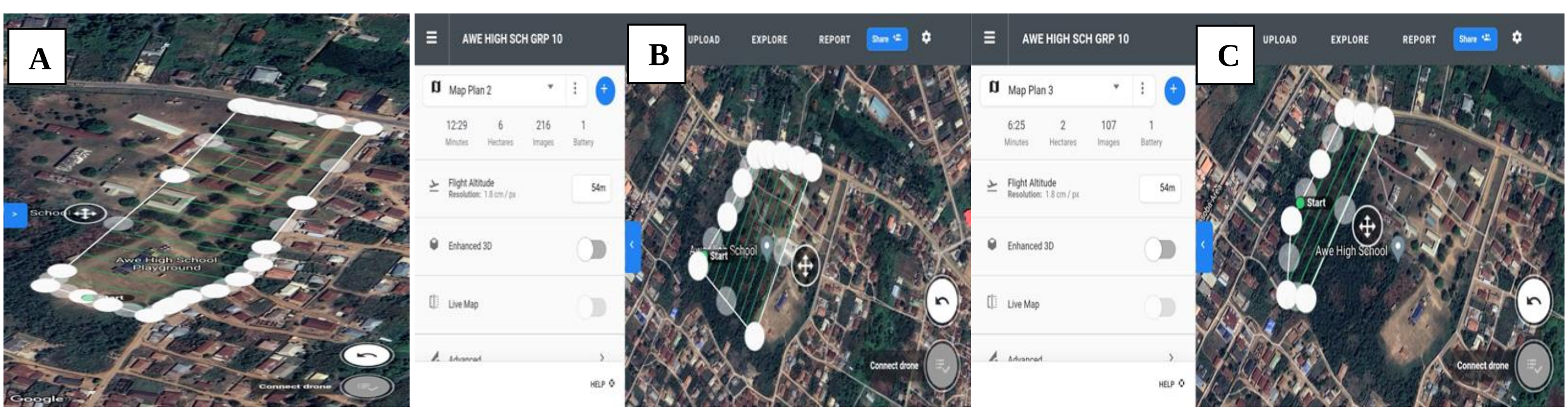

Figure 3: Flight planning for three different flight sections

Collinearity equation

The collinearity equation was pivotal in processing UAV imagery for georeferenced outputs like orthomosaics, contour maps, and 3D models. Camera calibration provided intrinsic parameters, while Ground Control Points (GCPs) surveyed using GNSS enabled accurate georeferencing. Exterior orientation parameters were refined through bundle block adjustment using the equation. The triangulation of tie points generated a dense point cloud for creating orthomosaics and Digital Surface Models (DSMs). Accuracy was validated by comparing computed and surveyed coordinates of check points. This workflow effectively transformed UAV data into precise topographic maps, showcasing its superiority in mapping inaccessible areas with high precision and efficiency (Benassi, 2017; Mian *et al.,* 2015; Gabrlik, 20150. It is given as

$$x - x_0 = - f \cdot \frac{r_{11}(X-X_S)+r_{12}(Y-Y_S)+r_{13}(Z-Z_S)}{r_{31}(X-X_S)+r_{32}(Y-Y_S)+r_{33}(Z-Z_S)} \quad ---- \quad \textit{Equation (4)}$$

$$y - y_0 = - f \cdot \frac{r_{11}(X-X_S)+r_{12}(Y-Y_S)+r_{13}(Z-Z_S)}{r_{31}(X-X_S)+r_{32}(Y-Y_S)+r_{33}(Z-Z_S)} \quad ---- \quad \textit{Equation (5)}$$

Where:

x,y = Image plane coordinates of the projected point, x_0, y_0= The principal point coordinates on the image plane, *f* = Focal length of the camera, *X,Y, Z* = Ground space coordinates of the object point and *Xs,Ys,Zs* = Coordinates of the camera perspective center in the object space.

Kriging and inverse distance weighting

Kriging and Inverse Distance Weighting (IDW) were employed for spatial interpolation of spot heights to generate continuous elevation surfaces. Kriging used a variogram model to account for spatial autocorrelation, providing statistically optimized predictions with minimal error. IDW estimated unknown values by weighting nearby points inversely proportional to their distance, ensuring smoother transitions in elevation. Both methods generated Digital Elevation Models (DEMs), which were validated against surveyed data for accuracy. Kriging produced more reliable results in areas with sparse data, while IDW was computationally simpler. The comparison highlighted their effectiveness, aiding in precise contour mapping and terrain analysis (Munyati & Sinthumule, 2021; Kim *et al.,* 2010).

Kriging = $z_i = f(x_i, y_i)$ _______*Equation (6)*

Where:

z_i = The height at point (x_i, y_i) and *f* = interpolation function

IDW = $z_i = \frac{\Sigma_j^n=1\, z_j \cdot w_j}{\Sigma_j^n=1\, w_j}$ _______ *Equation (7)*

Results and Discussion

In comparison, terrestrial GNSS surveying methods demonstrated superior accuracy, particularly in terms of both horizontal and vertical precision. While UAVs were able to collect a substantial number of points within the study area, they exhibited little discrepancies in areas with dense vegetation, such as tall trees and plants.

On the other hand, the terrestrial survey method provided accurate measurements of the actual ground surface. As a result, while conventional surveying methods continue to produce higher-quality data in terms of terrain representation, UAV-derived data required additional processing, including classification, to effectively generate a reliable Digital Terrain Model. This was successfully achieved using Pix4D Mapper Pro software and ArcGIS Pro, demonstrating that UAV technology can be enhanced with post-processing techniques to yield comparable outcomes for terrain modeling.

The comparative analysis of conventional and UAV-derived coordinates shown in Table 2 reveals that the UAV system provides highly accurate Easting and Northing values, with discrepancies generally within a few millimeters across all points. The height discrepancies, while slightly more variable, remain within acceptable limits, with deviations ranging from -0.005 m to +0.011 m. Notably, the largest discrepancy in Northing values occurred at PT5, where the deviation was +0.06 m, potentially due to environmental factors. Overall, the UAV system demonstrates strong performance in horizontal accuracy, and although vertical discrepancies are slightly higher, they remain within a reasonable range, making the UAV a reliable tool for geospatial data collection, with potential for further refinement through post-processing.

Table 2: Error Matrix between Terrestrial and UAV coordinates

	Terrestrial Coordinates			UAV Coordinates			Error Matrix		
Pid	Eastings (m)	Northings (m)	Height (m)	Eastings (m)	Northings (m)	Height (m)	ΔE	ΔN	ΔH
PT1	605786.728	865202.805	307.229	605786.725	865202.803	307.228	+0.003	+0.002	+0.001
PT2	605727.611	865064.800	314.623	605727.609	865064.802	314.612	+0.002	-0.002	+0.011
PT3	605728.413	865063.789	314.643	605728.410	865063.782	314.639	+0.003	+0.007	+0.004
PT4	605681.465	864943.322	318.443	605681.469	864943.316	318.446	-0.004	+0.006	-0.003
PT5	605609.296	864874.99	321.543	605609.303	864874.93	321.535	-0.007	+0.06	+0.008
PT6	605600.242	864859.265	322.094	605600.225	864859.260	322.099	+0.017	+0.005	-0.005

The Pearson correlation coefficients for Eastings (0.99999999), Northings (0.99999998), and Height (0.99999939) indicate a nearly perfect positive correlation between the terrestrial and UAV coordinates. The correlation graph further confirms this consistency, as the data points closely align with the 1:1 reference line, demonstrating the high accuracy of UAV measurements compared to terrestrial coordinates as shown in Figure 4.

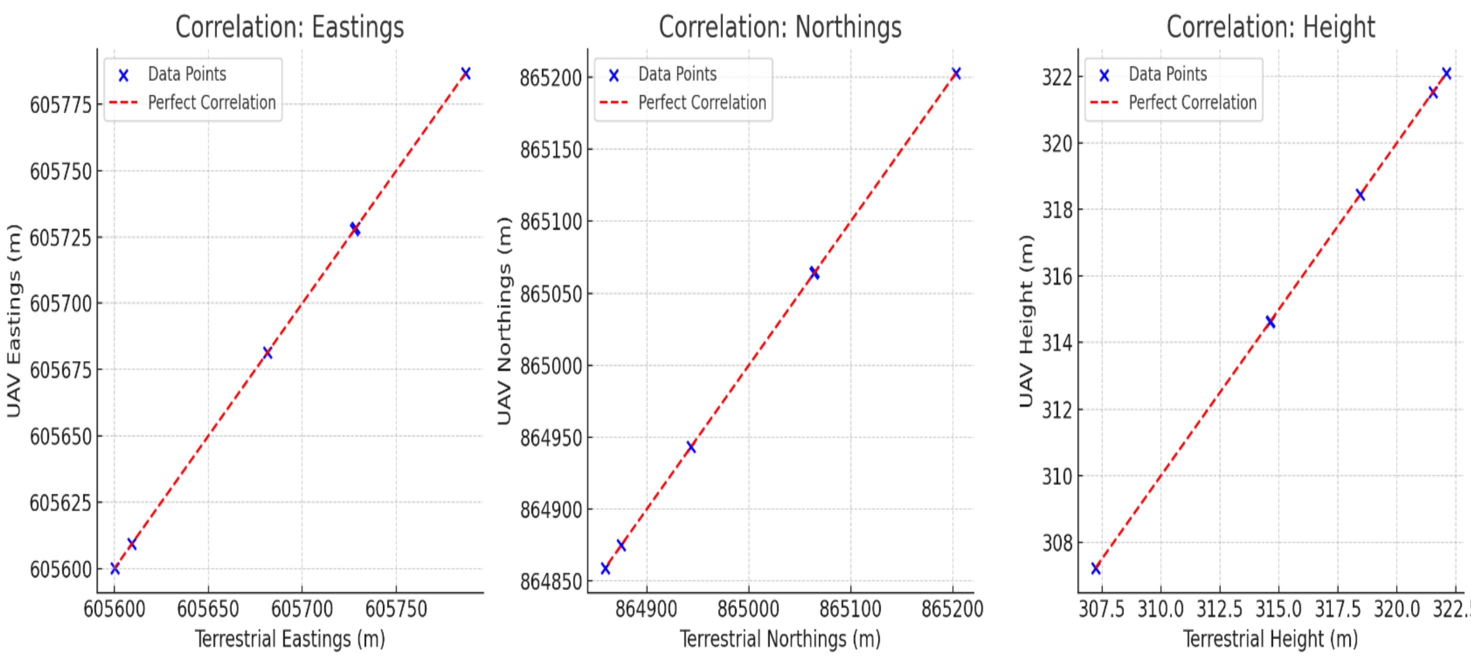

Figure 4: Correlation graph for Eastings, Northings, and Height

The comparative cost analysis between terrestrial GNSS and UAV-based methods for topographic surveying highlights a significant cost reduction when using UAV technology, as shown in Table 3. The total project cost for the terrestrial method is 2,666,525.51 NGN, whereas the UAV method costs 1,277,003.75 NGN, representing an approximate 52% savings. This cost reduction is primarily due to lower personnel requirements, as UAV surveys eliminate the need for multiple surveyors, assistants, and extensive field labour. Additionally, equipment and transportation costs are significantly reduced with UAVs, as they require fewer workers associated with terrestrial operations. The UAV method also enhances efficiency, as data collection is faster, covering large areas in significantly less time compared to the traditional method, which requires ground-based point-by-point measurements. This efficiency not only reduces direct project costs but also minimizes operational risks and improves logistical feasibility in challenging terrain.

Table 3: Cost and Personnel for Terrestrial Surveying Project Components

Project Components	Personnel/Cost Parameter	Qty	Day(s)	Cost/Unit	Total/Day
Reconnaissance (Office and Field)	Surveyor	1	1	15,189.11	15,189.11
	Asst. Technical Officer	1		10,849.37	10,849.37
	Survey Technologist	2		4,734.3	9,468.6
	Labour	3		4,734.3	14,202.9
	Transportation (Field vehicle + Driver/Mechanic + Fuel)	1		46,027.61	46,027.61
	Sub-Total				**95,737.79**
In-Situ Check and Control connection	Surveyor	1	1	15,189.11	15,189.11
	Technical Assistance	1		15,189.11	15,189.11
	Asst. Technical Officer	2		10,849.37	21,698.74
	Survey Technologist	2		10,849.37	21,698.74
	Labour	2		4,734.3	9,468.6
	GNSS Receiver	1		50,000.00	50,000.00
	Vehicle Lease	1		46,027.61	46,027.61
	Sub-Total				**179,271.91**
Perimeter Survey	Surveyor	1	2	15,189.11	30,378.22
	Technical Assistance	1		15,189.11	30,378.22
	Asst. Technical Assistance	2		10,849.37	43,397.48
	Survey Technologist	2		10,849.37	43,397.48
	Labour	3		4,673.43	28,040.58
	GNSS Receiver	1		50,000.00	100,000.00
	Vehicle Lease	1		46,027.61	92,055.22
	Sub-Total				**367,647.2**
Data Processing	Surveyor	1	2	15,189.11	30,378.22
	Technical Assistance	2		15,189.11	60,756.44
	Computer & Accessories	1		49,315.28	98,630.56
	Sub-Total				**189,765.22**
Detailing	Surveyor	1	2	15,189.11	30,378.22
	Technical Assistance	1		30,378.22	60,756.44
	Asst. Technical Assistance	2		10,849.37	21,698.74
	Survey Technologist	2		4,734.300	18,937.2
	Labour	3		4,734.300	18,937.2
	GNSS Receiver	1		50,000.00	100,000.00
	Transportation (Field vehicle + Driver/Mechanic + Fuel)	1		46,027.61	92,055.22
	Sub-Total				**342,763.02**
Plan Preparation/Plotting	Surveyor	1	2	15,189.11	30,378.22
	Technical Officer	1		15,189.11	30,378.22
	Computer & Plotter	1		65,753.7	131,507.4
	Sub-Total				**192,263.84**
Total (Before inflation)					**1,367,448.98**
Inflation at 30%					410,234.69
Total (After inflation)					**1,777,683.67**
Contingencies (10% of the cost of the survey project)					177,768.37
Professional Development and Administrative fee at 25%					444,420.92
VAT (5% of Survey project)					88,884.18
MOB/DEMOB (10% Cost of Survey Project)					177,768.37
Grand Total					**2,666,525.51**

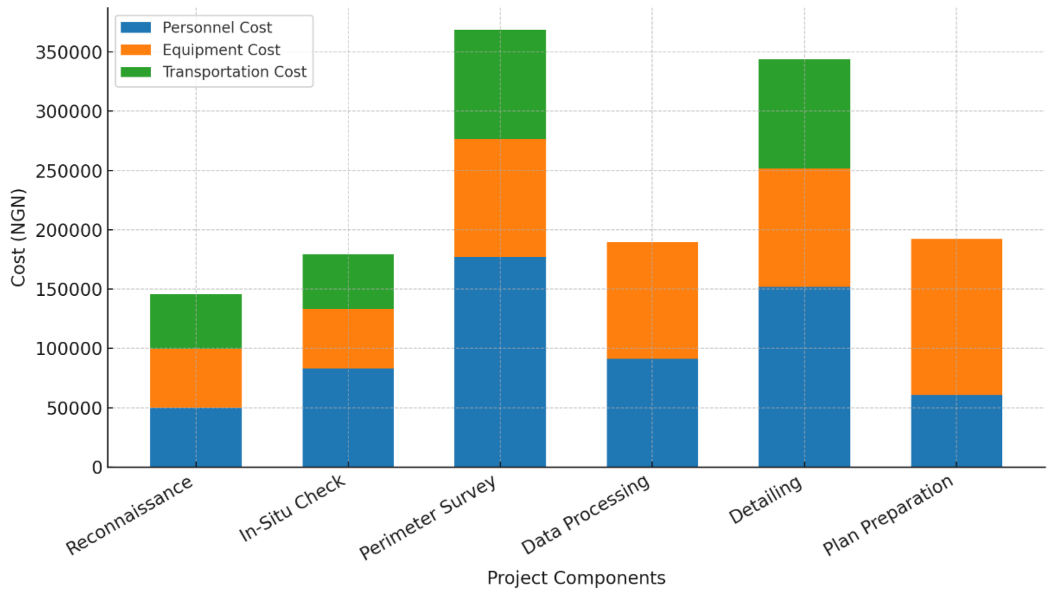

Figure 4: Cost breakdown for terrestrial survey method

Table 4: Cost and Personnel for Terrestrial Surveying Project Components

Project Components	Personnel/Cost Parameter	Qty	Day(s)	Cost/Unit	Total/Day
Reconnaissance (Office and Field)	Surveyor	1	1	15,189.11	15,189.11
	Asst. Technical Officer	1		10,849.37	10,849.37
	Survey Technologist	2		4,734.3	9,468.6
	Labour	3		4,734.3	14,202.9
	Transportation (Field vehicle + Driver/Mechanic + Fuel)	1		46,027.61	46,027.61
	Sub-Total				**95,737.79**
UAV Survey	Surveyor	1	1	15,189.11	15,189.11
	Technical Assistance	1		15,189.11	15,189.11
	Labour	1		4,673.43	4,673.43
	GNSS Receiver	1		50,000.00	50,000.00
	Drone	1		46,000.00	46,000.00
	Vehicle Lease	1		46,027.61	46,055.22
	Sub-Total				**177,106.87**
Data Processing	Surveyor	1	2	15,189.11	30,378.22
	Technical Assistance	2		15,189.11	60,756.44
	Computer & Accessories	1		49,315.28	98,630.56
	Sub-Total				**189,765.22**
Plan Preparation/Plotting	Surveyor	1	2	15,189.11	30,378.22
	Technical Officer	1		15,189.11	30,378.22
	Computer & Plotter	1		65,753.7	131,507.4
	Sub-Total				**192,263.84**
Total (Before inflation)					**654,873.72**
Inflation at 30%					196,462.12
Total (After inflation)					**851,335.84**
Contingencies (10% of the cost of the survey project)					85,133.58
Professional Development and Administrative fee at 25%					212,833.96
VAT (5% of Survey project)					42,566.79
MOB/DEMOB (10% Cost of Survey Project)					85,133.58
Grand Total					**1,277,003.75**

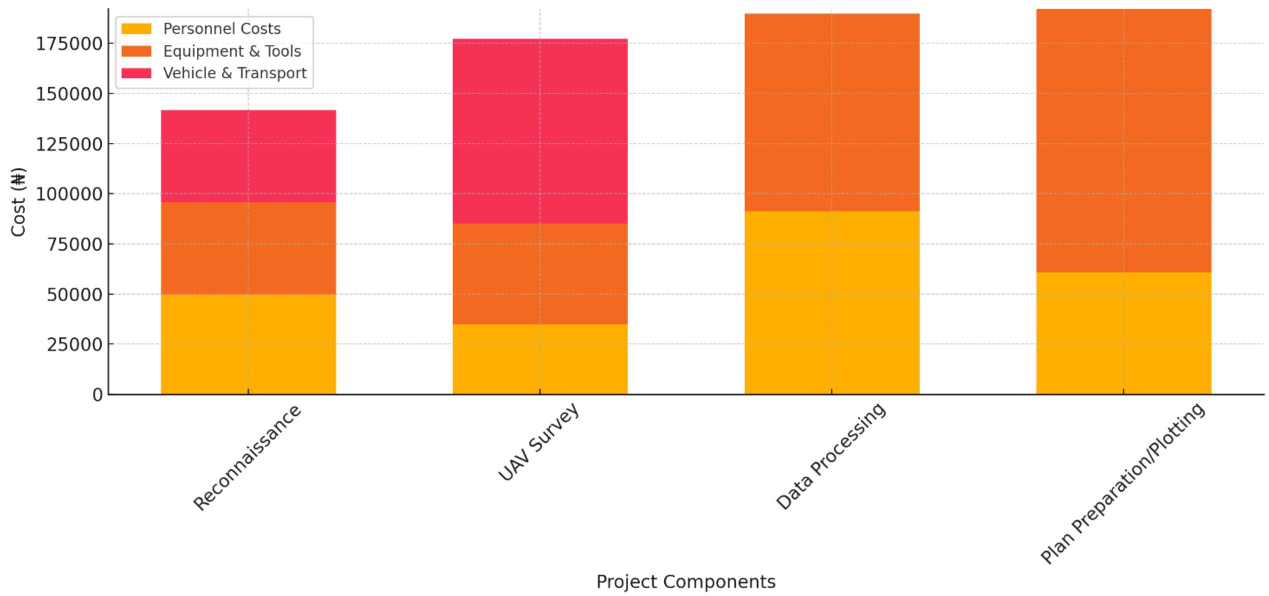

Figure 5: Cost breakdown for UAV survey method

Table 5: Summary of cost comparison between Terrestrial and UAV method

Cost Component	Terrestrial GNSS ($)	UAV Survey ($)	% Reduction (UAV vs GNSS)
Reconnaissance & Field Work	95,737.79	95,737.79	0%
Data Collection	889,682.13	177,106.87	80.10%
Data Processing	189,765.22	189,765.22	0%
Plan Preparation	192,263.84	192,263.84	0%
Total Before Inflation	1,367,448.98	654,873.72	52.10%
Grand Total	**2,666,525.51**	**1,277,003.75**	**52.10%**

Ultimately, both the terrestrial GNSS and UAV methods produce similar topographic representations, ensuring reliable and accurate mapping (see Figures 6 and 7. However, the UAV method demonstrates a notable advantage in terms of efficiency and level of detail, especially for larger areas (see Figure 8. UAVs capture a higher density of data points in a shorter timeframe (see table 5), resulting in a more refined and comprehensive topographic plan with a photorealistic output. Additionally, the effectiveness of each method depends on the scale of the survey project. For small-scale mapping, UAVs are the preferred choice due to their cost-effectiveness, reduced manpower requirements, and faster data acquisition. In contrast, terrestrial GNSS surveys, while still accurate, tend to be more time-consuming and resource-intensive, making them less suitable for rapid or large-area data collection.

Table 6: Summary of time comparison between Terrestrial and UAV method

Survey Method	Reconnaissance (Days)	Surveying (Days)	Data Processing (Days)	Plan Preparation (Days)	Total Days
Terrestrial GNSS	1	5	2	2	10
UAV Survey	1	1	2	2	6
Time Saved (%)	-	80%	0%	0%	40%

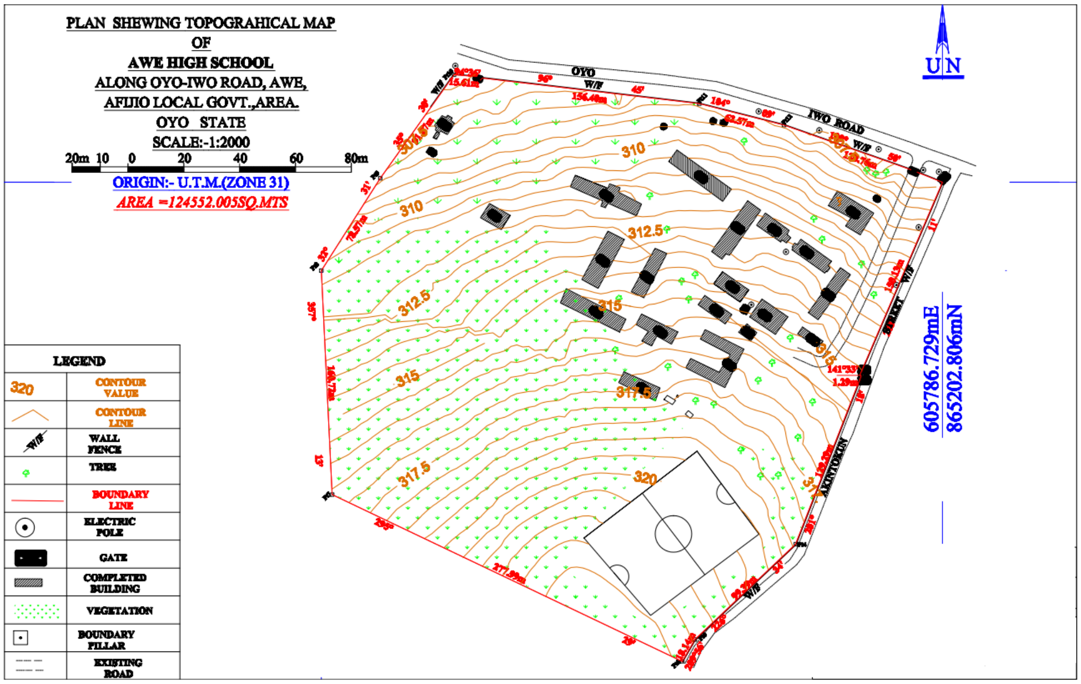

Figure 6: Topographic map produced from terrestrial method

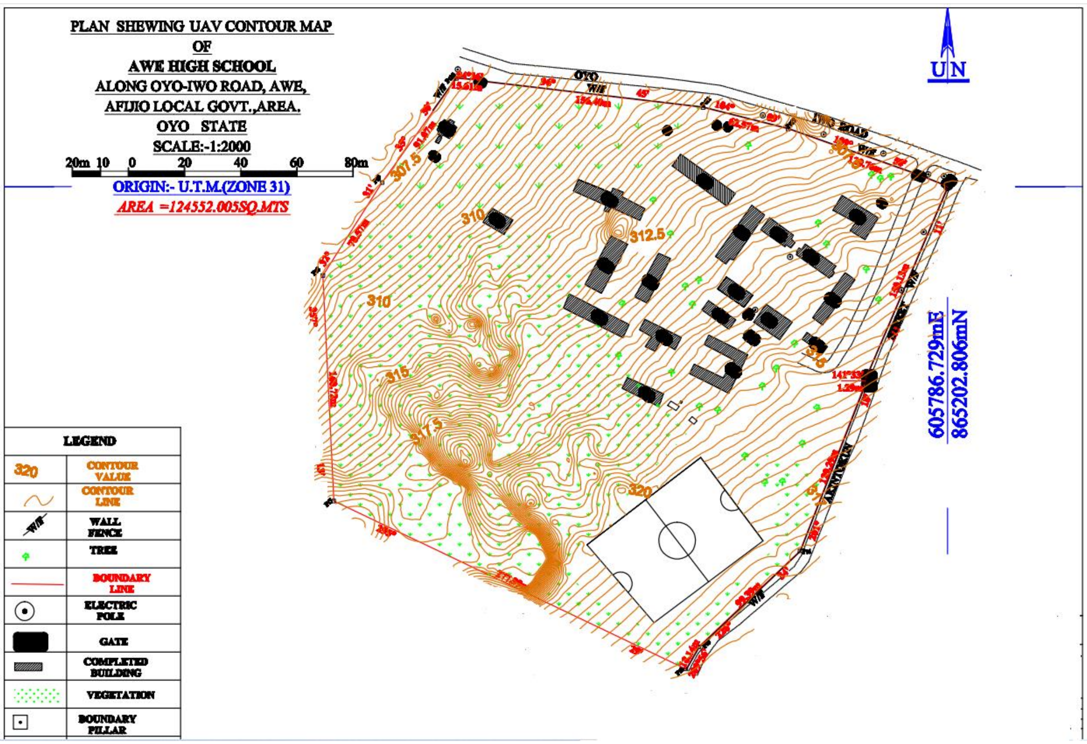

Figure 7: Topographic map produced from UAV method

Figure 8: UAV Orthomosaic map

Conclusion

This study has provided a comparative analysis of terrestrial and UAV methods for topographic surveying, highlighting the significant advantages of UAV technology in terms of cost efficiency, operational productivity, and time savings. The findings reveal that UAV method surveys result in a 52% cost reduction, with a total project cost of 1,277,003.75 NGN, compared to 2,666,525.51 NGN for the terrestrial method. This substantial cost savings is primarily due to reduced personnel, transportation, and equipment expenses, as UAV surveys require fewer personnel and simplify logistical operations.

Beyond cost efficiency, the UAV method also demonstrated a significant reduction in survey time. While the terrestrial method required 11 days to complete, the UAV approach reduced the total time to just 6 days, representing 45.45% time savings. This improved efficiency allows for faster project delivery, making UAVs particularly suitable for large/medium scale surveys and time-sensitive projects.

The accuracy assessment indicates that UAV-derived coordinates exhibit high horizontal precision, with positional discrepancies mostly within a few millimetres. However, vertical accuracy variations were observed, particularly in vegetated areas, where terrain obstruction impacts the accuracy of elevation measurements. Despite these variations, the Pearson correlation coefficients for Easting (0.99999999), Northing (0.99999998), and Height (0.99999939) confirm a strong agreement between UAV and terrestrial GNSS measurements, establishing UAVs as a reliable and efficient alternative for large-scale topographic mapping.

Based on the findings of this study, UAV-based surveying is highly recommended for large-area mapping and projects requiring rapid data acquisition, especially in challenging terrain and remote locations with limited accessibility. However, for applications demanding high-precision vertical accuracy, incorporating ground control points (GCPs) from GNSS observations is essential, as demonstrated in this study, to improve the reliability of elevation models. To enhance the accuracy and effectiveness of the UAV method of mapping, advanced post-processing techniques such as point cloud classification, filtering, and digital terrain model (DTM) refinement should be utilized, particularly in areas with dense vegetation. Furthermore, future research should focus on integrating UAV LiDAR technology, which offers improved elevation accuracy and broader applicability in engineering, cadastral, and infrastructure development surveys.

References

Abd Rahman, Mohd Faizuddin. (2025). Technological Innovations in UAVs for Geospatial Data Collection: A Review of Current Trends. 10.13140/RG.2.2.29650.26565.

Quamar, M. M., Al-Ramadan, B., Khan, K., Shafiullah, M., & El Ferik, S. (2023). Advancements and Applications of Drone-Integrated Geographic Information System Technology—A Review. *Remote Sensing*, 15(20), 5039. https://doi.org/10.3390/rs15205039

Emmanuel O. K. (2025). Comparison of traditional survey methods and structure from motion (UAV drone) in topographical mapping. https://www.researchgate.net/publication/388177304_Traditional_Surveying_vs_UAV_Drone-Based_Structure-from-Motion_Advancements_in_Topographical_Mapping_Accuracy_and_Efficiency

Jiménez-Jiménez, S. I., Ojeda-Bustamante, W., Marcial-Pablo, M. d. J., & Enciso, J. (2021). Digital Terrain Models Generated with Low-Cost UAV Photogrammetry: Methodology and Accuracy. *ISPRS International Journal of Geo-Information*, 10(5), 285. https://doi.org/10.3390/ijgi10050285

Moravec, David & Komarek, Jan & Kumhálová, Jitka & Kroulik, M. & Prošek, Jiří & Klápště, Petr. (2017). Digital elevation models as predictors of yield: Comparison of an UAV and other elevation data sources. *Agronomy Research*, 15. 249-255.

Ajayi, Oluibukun & Salubi, Akporode & Angbas, Alu & Odigure, Mukwedeh. (2017). Generation of accurate digital elevation models from UAV acquired low percentage overlapping images. *International Journal of Remote Sensing*, 38. 1-22. 10.1080/01431161.2017.1285085.

Nieuwenhuis, B. O., Marchese, F., Casartelli, M., Sabino, A., van der Meij, S. E. T., & Benzoni, F. (2022). Integrating a UAV-Derived DEM in Object-Based Image Analysis Increases Habitat Classification Accuracy on Coral Reefs. *Remote Sensing*, 14(19), 5017. https://doi.org/10.3390/rs14195017

Olayinka-Dosunmu, Dupe Nihinlola & Omolaye, Kayode & Ilesanmi, Adewale & Okolie, Chukwuma & Arungwa, Ikenna. (2021). Application of UAV Surveys for evaluating the productivity levels of Traditional and Mechanised farmers in a Customary Land Tenure System. *ISPRS - International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences*, XLIII-B3-2021. 617-622. 10.5194/isprs-archives-XLIII-B3-2021-617-2021.

Aminobiren Joel, Abubakar Zakariyya Al-Hasan, and Suleiman Ibrahim Abubakar. (2022). Unmanned Aerial Vehicles for Geographic Data Capture in Edo North Nigeria. Direct Research Journal of Engineering and Information Technology, 9(4), 184-191 DOI: https://doi.org/10.26765/DRJEIT619732154

Muhmad Kamarulzaman, A. M., Wan Mohd Jaafar, W. S., Mohd Said, M. N., Saad, S. N. M., & Mohan, M. (2023). UAV Implementations in Urban Planning and Related Sectors of Rapidly Developing Nations: A Review and Future Perspectives for Malaysia. *Remote Sensing*, 15(11), 2845. https://doi.org/10.3390/rs15112845

Ukwueze, T. K., Nwafor, S. C., Ugwueze, K. O., Nnadozie, E. C., Odo, M., Ezechi, U., Chukwuma, C. K., Okafor, K. & Ani, A. O. (2024). Design and Implementation of an Unmanned Aerial Vehicle (UAV) for Image Capture in Enterprise Farming. *Nigerian Journal of Technology*, 43(1), 150 – 158; https://doi.org/10.4314/njt.v43i1.17

Akanbi, O., Adesope, O., Olayiwola, O., Famurewa, D. & Bankole, D. (2023). Physico-chemical and Coliform Bacteria characterization of Selected Shallow wells in Awe, South-western Nigeria. *LAUTECH Journal of Civil and Environmental Studies*, 11, 10.36108/laujoces/3202.11.0120.

Jatto, K., Adeoye, A., Abegunrin, O., Oke, O. & Smart, O. (2020). Analysis of Plantain Marketing in Afijio Local Government Area of Oyo State, Nigeria. 26-34.

Pırtı, A., Arslan, N., Deveci, B., Aydin, O., Erkaya, H. & Hoşbaş, R. (2009). Real-Time Kinematic GPS for Cadastral Surveying. *Survey Review*, 41, 339-351. 10.1179/003962609X451582.

Pırtı, A. (2007). Performance Analysis of the Real Time Kinematic GPS (RTK GPS) Technique in a Highway Project (Stake-Out). *Survey Review*. 39, 43-53. 10.1179/003962607X164989.

Mohd Zahirudin Bin Mohammed Na'aim, Marlina Binti Abdul Manaf. (2024). Establishment of control points using GNSSRTK technique. E3S Web of Conferences 479, 02001 (2024) https://doi.org/10.1051/e3sconf/202447902001 ISSAT 2023

Wang, F., Zou, Y., del Rey Castillo, E., Ding, Y., Xu, Z., Zhao, H-W. & Lim, J. (2022). Automated UAV path-planning for high-quality photogrammetric 3D bridge reconstruction. *Structure and Infrastructure Engineering*, 20, 1-20. 10.1080/15732479.2022.2152840.

Mohd Zahirudin Bin Mohammed Na'aim, Marlina Binti Abdul Manaf, Jabatan Kejuruteraan Awam, Politeknik Kuching Sarawak, Sarawak, Malaysia 2 Jabatan Teknologi Maklumat Dan Komunikasi, Politeknik Kuching Sarawak, Sarawak, Malaysia

Mian, O. & Lutes, J. & Lipa, G. & Hutton, Joe & Gavelle, Erwan & Borghini, Sebastien. (2015). Direct georeferencing on small unmanned aerial platforms for improved reliability and accuracy of mapping without the need for ground control points. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-1/W4. 397-402. 10.5194/isprsarchives-XL-1-W4-397-2015.

Gabrlik, Petr. (2015). The Use of Direct Georeferencing in Aerial Photogrammetry with Micro UAV. *IFAC-PapersOnLine*, 48, 380-385. 10.1016/j.ifacol.2015.07.064.

Benassi, F., Dall'Asta, E., Diotri, F., Forlani, G., Morra di Cella, U., Roncella, R., & Santise, M. (2017). Testing Accuracy and Repeatability of UAV Blocks Oriented with GNSS-Supported Aerial Triangulation. *Remote Sensing*, 9(2), 172. https://doi.org/10.3390/rs9020172

Munyati, C. & Sinthumule, Innocent. (2021). Comparative suitability of ordinary kriging and Inverse Distance Weighted interpolation for indicating intactness gradients on threatened savannah woodland and forest stands. *Environmental and Sustainability Indicators*, 12, 100151. 10.1016/j.indic.2021.100151.

Kim, S-N., Lee, W-K., Shin, K-I., Kafatos, M., Seo, D. & Kwak, H. (2010). Comparison of spatial interpolation techniques for predicting climate factors in Korea. *Forest Science and Technology*, 6, 97-109. 10.1080/21580103.2010.9671977.