ISSN 2682-681X (Paper), ISSN 2705-4241 (Online) | http://unilorinjoger.com | https://doi.org/10.63745/joger.2025.12.30.002

JOURNAL OF GEOMATICS AND ENVIRONMENTAL RESEARCH
www.unilorinjoger.com

RESEARCH ARTICLE

Evaluating the Impact of Ground Control Network Type on UAV Photogrammetric Accuracy: NTRIP, Radio RTK, and GCP-Free P4-RTK

Okorocha Vincent Chika[1], Ehigiator Irughe Raphael[2], S.O Osuji[3], H.A.P. Audu[4]

[1,2,3,4]Department of Civil Engineering / University of Benin, Nigeria

Corresponding email: chikaokorocha@gmail.com

Abstract

Accurate Digital Terrain Models (DTMs) are essential for precise mapping, hydrological analysis, and engineering design. This study evaluates the influence of three ground control network configurations—CORS-based NTRIP, Radio RTK, and GCP-free P4-RTK on UAV photogrammetric accuracy over a gully-prone terrain at the University of Benin, Nigeria. A DJI Phantom 4 RTK UAV was deployed to acquire identical flight data under each configuration, ensuring consistent flight altitude, overlap, and lighting conditions. Ground elevations were measured using a Tersus Oscar Ultimate GNSS receiver operating in both NTRIP and Radio modes to provide reference data for validation.The comparative analysis focused on Mean Error (ME), Root Mean Square Error (RMSE), Bias, Correlation, and one-way Analysis of Variance (ANOVA) to quantify differences in elevation accuracy across the three DTMs. Results show that both GNSS GCP-assisted DTMs, Radio RTK, and NTRIP achieved sub-5 cm vertical accuracy, with RMSE values of 0.043 m and 0.048 m, respectively, while the GCP-free P4-RTK DTM exhibited a consistent positive bias of +0.162 m and a weaker correlation (r = 0.962) with ground truth. The ANOVA test confirmed statistically significant differences (p < 0.05) between the GCP-free and CORS-based configurations, whereas no significant variation was observed between the Radio and NTRIP results. This study presents one of the first statistically validated comparisons of GNSS CORS-integration and GCP-free RTK UAV workflows in Nigeria. The findings demonstrate that GNSS-based differential corrections, whether transmitted via NTRIP or Radio link, ensure higher positional fidelity and stability in DTM generation. The results have practical implications for advancing the operational standards of UAV–CORS integration and supporting the national geospatial infrastructure through the SOGPOS CORS network.

ARTICLE HISTORY
Received: 6th November, 2025
Accepted: 13th November, 2025
Published: 5th December, 2025

KEYWORDS
UAV photogrammetry; Digital Terrain Model (DTM); GNSS; CORS; NTRIP; Radio RTK; P4-RTK; Mean Error; RMSE; Bias; Correlation; ANOVA; Accuracy assessment; Gully-prone terrain.

Citation: C.V. Okorocha, I.R Ehigiator, S.O Osuji, H.A.P. Audu .(2025). Evaluating the Impact of Ground Control Network Type on UAV Photogrammetric Accuracy: NTRIP, Radio RTK, and GCP-Free P4-RTK**.** J*ournal of Geomatics and Environmental Research, 8(1). Pp10-20*

1.0 INTRODUCTION

Accurate Digital Terrain Models (DTMs) derived from Unmanned Aerial Vehicle (UAV) photogrammetry have become indispensable for environmental monitoring, hydrological modelling, and engineering design. The reliability of such terrain models largely depends on the quality and geometry of their geodetic control networks, which determine how image coordinates are translated into real-world elevations (Agüera-Vega *et al*., 2017; Turner *et al*., 2020). The integration of UAV platforms with Continuously Operating Reference Station (CORS) networks now enables surveyors to achieve centimetre-level positioning without the extensive deployment of conventional Ground Control Points (GCPs) (Nex and Remondino, 2014; Martínez-Carricondo *et al*., 2018).

Despite this progress, variations in the accuracy of UAV-based DTMs persist depending on the adopted control strategy. Three main configurations dominate current practice: CORS-assisted NTRIP, Radio-based RTK, and GCP-free onboard RTK. While onboard RTK systems such as the DJI Phantom 4 RTK simplify data acquisition, they are often susceptible to satellite geometry, signal multipath, and the absence of independent ground ties, which can introduce systematic elevation bias (Forlani *et al*., 2018; Udin and Ahmad, 2020). In contrast, GNSS CORS-integrated workflows, whether via direct NTRIP streaming or base-station Radio RTK, provide redundant geodetic referencing, improving model stability and consistency across the block.

Previous studies have primarily assessed UAV DTM accuracy using single descriptive statistics, such as the Root Mean Square Error (RMSE), which measures the overall deviation between model elevations and ground truth (James *et al*., 2019; Eltner *et al*., 2016). However, RMSE alone does not reveal the directional tendency of errors or whether bias is systematic or random. To address this limitation, complementary indices such as Mean Error (ME), Bias, and the Pearson correlation coefficient (r) provide insight into both the magnitude and direction of error as well as the degree of linear agreement between datasets (Casella *et al*., 2020). Moreover, inferential statistics, such as Analysis of Variance (ANOVA), can determine whether observed differences in accuracy between control configurations are statistically significant rather than incidental (Agüera-Vega *et al*., 2017).

The present study, therefore, aims to quantitatively evaluate the impact of ground control network type on UAV photogrammetric accuracy by comparing three control strategies —NTRIP, Radio RTK, and GCP-free P4-RTK — over a gully-prone terrain at the University of Benin. The analysis focuses exclusively on Mean Error, RMSE, Bias, Correlation, and ANOVA, providing a statistically grounded understanding of how each configuration influences terrain fidelity. This comparison contributes to establishing evidence-based guidance for selecting appropriate control strategies in UAV-CORS integrated mapping within complex topographic settings.

2.0 METHODOLOGY

This study adopted a comparative experimental design to quantify the effect of ground control network configuration on UAV photogrammetric accuracy. The methodology was structured to ensure uniformity in data acquisition and processing so that variations in results could be attributed solely to the type of ground control applied. Three distinct control setups — NTRIP-based CORS, Radio RTK, and GCP-free P4-RTK — were implemented using identical UAV flight parameters, processing workflows, and validation datasets. The methodological framework comprised five stages: study area definition, UAV and GNSS data acquisition, DTM generation, statistical accuracy evaluation (using Mean Error, RMSE, Bias, and Correlation), and inferential testing through ANOVA. Details of each stage are presented in the following subsections.

The schematic flow diagram for the methodology is shown in Figure 1.

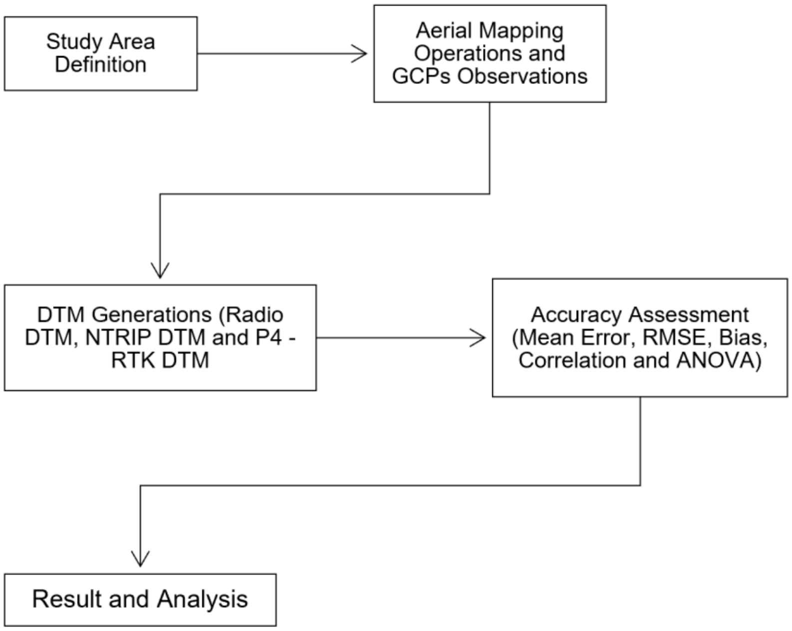

Figure 1: Schematic Diagram of Methodology (Source: Author)

2.1 Study Area

The study was conducted within Side B of the University of Benin Campus, Nigeria, located at 6°24′N, 5°37′E. The area is characterized by undulating topography, with varying undulations that exhibit gully-erosion features caused by seasonal runoff. The choice of this location was influenced by its variable terrain, which provides a suitable test environment for evaluating the positional accuracy and vertical reliability of UAV-derived Digital Terrain Models (DTMs). The study area map is shown in Figure 2.

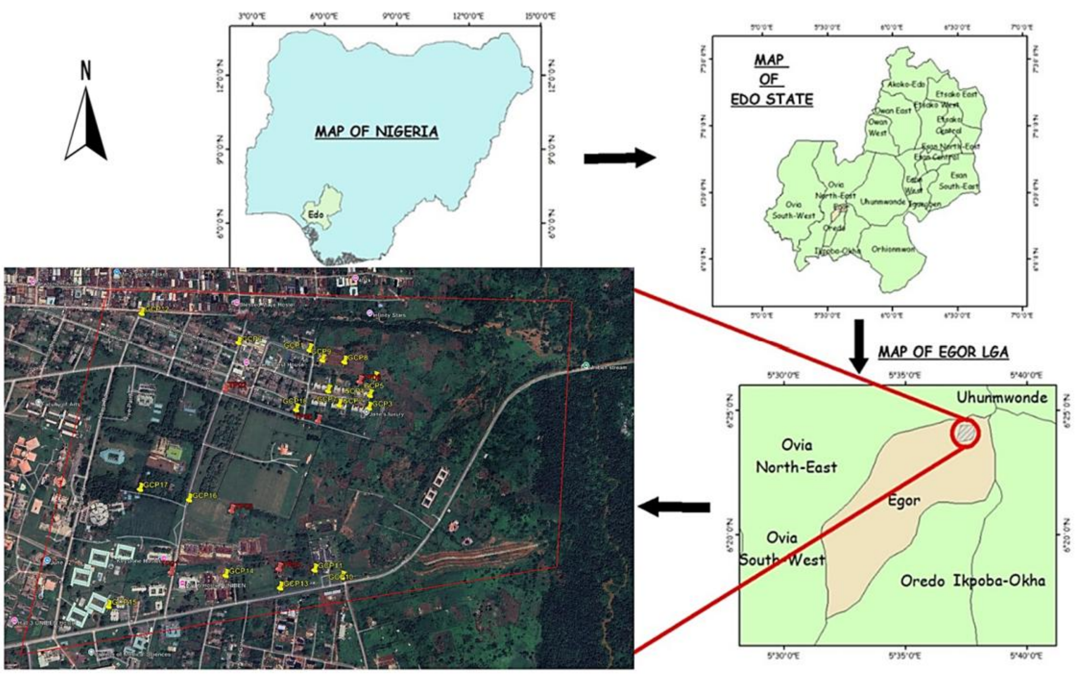

Figure 2: Map of Study Area (Adopted from Google Earth and Administrative Map)

2.2 Data Acquisition

A DJI Phantom 4 RTK UAV was deployed to acquire overlapping aerial imagery under three distinct ground control configurations:

i. **Radio RTK DTM** – UAV RTK corrections were provided from a local control setup with a Tersus Oscar Ultimate GNSS base station, transmitting correction data via radio link.

ii. **NTRIP DTM** – UAV imagery was processed using ground control points (GCPs) observed via **CORS-**based NTRIP corrections obtained from the Geosystem Continuously Operating Reference Station (CORS) network.

iii. **P4-RTK DTM (GCP-free)** – The UAV relied solely on its onboard RTK system, with a temporary base setup over the RALPH GNSS06 control point and no distributed GCPs.

Each dataset was processed independently in Agisoft Metashape Professional, maintaining consistent parameters for image alignment, dense cloud generation, and DTM interpolation to ensure comparability across configurations.

2.3 Ground Control and Check Data

Eighteen Ground Control Points (GCPs) and six Check Points (CPs) were established using a Tersus Oscar Ultimate GNSS receiver operating in both Radio RTK and NTRIP modes. These points were used to validate the DTMs. The GCPs were evenly distributed across the study area to cover both flat and steep regions, while the CPs were reserved for independent accuracy testing. All GNSS observations were referenced to the WGS 84 / UTM Zone 31N coordinate system.

2.4 DTM Accuracy Evaluation

The vertical accuracy of each DTM was evaluated by comparing modelled elevations with ground-observed elevations at all control and check points. Four core statistical indices were computed as follows:

(a) Mean Error (ME)

Measures the average signed deviation between DTM and ground elevations:

$$ME = \frac{1}{n}\sum_{i=1}^{n} (Z_{DTM,i} - Z_{Ground,i})$$

(b) Root Mean Square Error (RMSE)

Indicates the overall magnitude of error irrespective of direction:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (Z_{DTM,i} - Z_{Ground,i})^2}$$

(c) Bias

Quantifies the systematic tendency of the model to overestimate or underestimate elevation values:

$$Bias = \bar{Z}_{DTM} - \bar{Z}_{Ground}$$

(d) Pearson Correlation Coefficient (r)

Measures the strength of the linear association between DTM elevations and ground truth:

$$r = \frac{\sum(Z_{DTM,i} - \bar{Z}_{DTM})(Z_{Ground,i} - \bar{Z}_{Ground})}{\sqrt{\sum(Z_{DTM,i} - \bar{Z}_{DTM})^2 \sum(Z_{Ground,i} - \bar{Z}_{Ground})^2}}$$

(e) Analysis of Variance (ANOVA)

One-way ANOVA was applied to test whether the mean accuracy differences among the three control configurations were statistically significant. The F-statistic was computed as:

$$F = \frac{MS_{between}}{MS_{within}}$$

where $MS_{between}$ represents the mean square variation between DTM types, and MS_{within} represents variation within each group. Post-hoc comparison was performed using **Scheffé's test** to identify which configurations differed significantly.

2.5 Data Processing Workflow

All statistical computations were performed in Microsoft Excel. The DTMs were sampled at the GCP and CP coordinates to extract corresponding elevation values for each configuration (Radio, NTRIP, and P4-RTK). The results were summarized in a table, showing comparative Mean Error, RMSE, Bias, and Correlation values, and an ANOVA test was applied to evaluate the significance of differences between the three models.

2.6 Quality Assurance

To maintain methodological consistency and ensure the reliability of results, each dataset was processed under identical photogrammetric and environmental conditions. The same camera calibration parameters, dense cloud filtering settings, and DTM interpolation methods were applied across all configurations to eliminate variability introduced by software or operator bias. The analysis was designed to isolate the ground control network type as the sole independent variable influencing DTM accuracy outcomes.

All UAV flights were conducted with identical acquisition parameters: a constant altitude of 80 m above ground level, 80% forward overlap, and 70% side overlap. Missions were performed under comparable lighting, weather, and visibility conditions to minimize the influence of external illumination or atmospheric factors. This uniformity in flight geometry and environmental setting ensured that any observed differences in Mean Error, RMSE, Bias, or Correlation could be confidently attributed to variations in the ground-control configuration rather than inconsistencies in image acquisition or processing.

3.0 RESULT

The comparative analysis of the three Digital Terrain Models (DTMs)—Radio RTK, NTRIP, and GCP-free P4-RTK—revealed clear accuracy contrasts attributable to the type of ground-control configuration. The complete coordinate and elevation dataset from field observations and model extractions is presented in Table 1, while Figures 3–5 illustrate the DTM surfaces produced under each control mode.

Radio RTK DTM (Figure 3) shows excellent terrain fidelity with minimal distortion across the surveyed block. The NTRIP DTM (Figure 4) displays similar spatial characteristics, confirming consistent topographic representation when CORS-based corrections are applied. Conversely, the P4-RTK DTM (Figure 5) shows noticeable overestimation in the low-lying eastern section of the terrain, which coincides with the positive bias observed in statistical testing.

The summary of the elevation accuracy assessment – Mean Error, Root Mean Square error, Bias, and correlation is presented in Table 2, while the analysis of variance is presented in Table 3.

Table 1: The Ground Control Points and Test Points Variations from DTM and Ground Observations

POINT ID	EASTING (m)	NORTHING (m)	RADIO GROUND (m)	NTRIP GROUND (m)	NTRIP DTM (m)	RADIO DTM (m)	P4_RTK DTM (m)
GCP1	790932.3391	708756.7544	105.511	105.485	106.115	106.132	108.472
GCP2	791037.4182	708562.1767	106.1	106.06	106.007	106.017	107.51
GCP3	791143.0152	708552.7901	101.321	101.291	101.176	101.218	102.734
GCP4	791145.4726	708597.3397	101.577	101.541	101.54	101.564	102.987
GCP5	791163.4978	708660.628	100.552	100.531	100.443	100.493	101.953
GCP6	790680.5149	708780.6531	108.549	108.514	108.466	108.548	111.583
GCP7	790998.4298	708612.3568	107.922	107.887	107.853	107.885	109.35
GCP8	791055.8363	708715.4113	104.901	104.861	104.805	104.845	106.362
GCP9	790977.7694	708721.8282	107.837	107.807	107.514	107.54	109.327
GCP10	791049.1856	707965.8069	107.143	107.122	107.119	107.161	108.682
GCP11	790954.9101	707989.9199	108.377	108.352	108.421	108.517	109.968
GCP12	790335.3316	708885.8883	110.567	110.527	110.5	110.552	113.628
GCP13	790835.1231	707927.9218	107.379	107.339	107.119	107.168	108.903
GCP14	790646.0978	707969.1712	106.696	106.661	106.865	106.9	109.646
GCP15	790243.0554	707861.9009	111.573	111.544	111.536	111.562	114.46
GCP16	790516.0121	708228.0425	107.954	107.919	107.717	107.763	110.961
GCP17	790343.8749	708264.5083	110.185	110.155	109.865	109.919	113.03
GCP18	790886.1335	708545.2133	108.827	108.798	109.63	109.622	111.803
TP01	790456.8495	707978.6415	108.213	108.183	108.129	108.152	111.234
TP02	790636.3983	708616.5726	109.014	108.979	108.928	108.946	112.024
TP03	790663.4813	708192.016	108.318	108.292	108.367	108.387	111.323
TP04	790830.4702	707992.6746	108.262	108.227	107.918	107.976	109.803
TP05	790963.4898	708506.8311	108.482	108.446	108.163	108.167	109.912
TP06	791109.7977	708645.9218	102.551	102.526	102.48	102.505	103.985

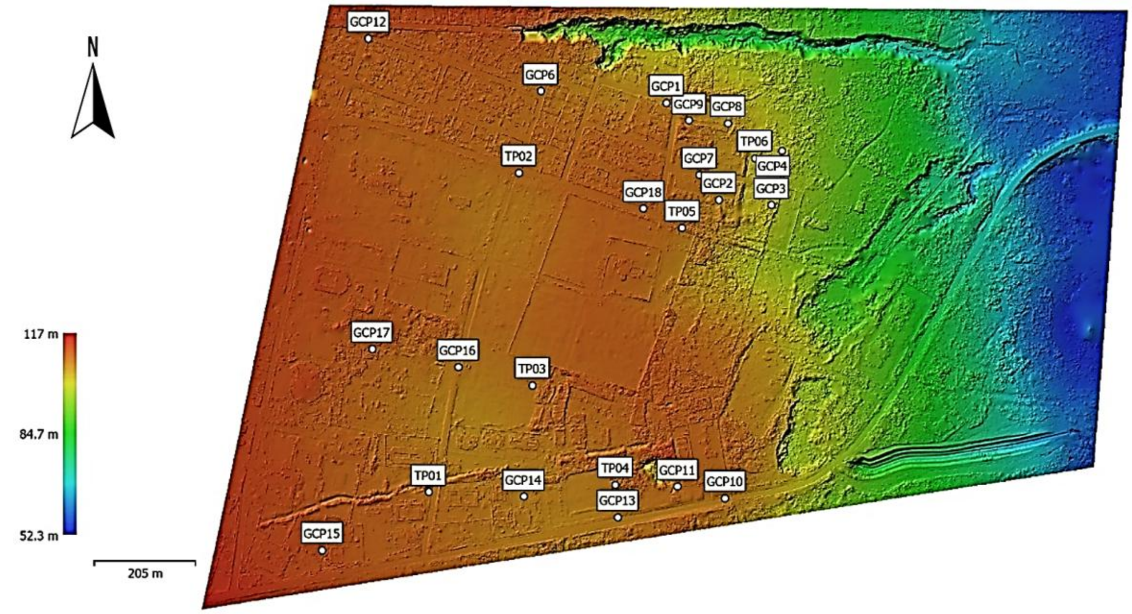

Figure 3: DTM from integrated UAV and GNSS derived GCP via Radio Correction

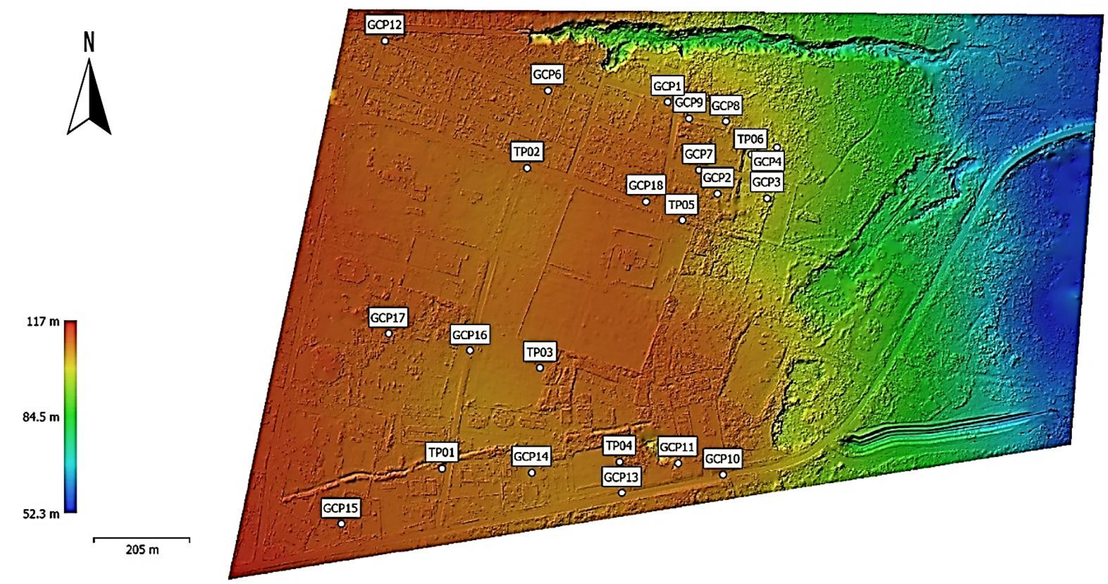

Figure 4: DTM from integrated UAV and GNSS derived GCP via NTRIP Correction from Geosystem CORS

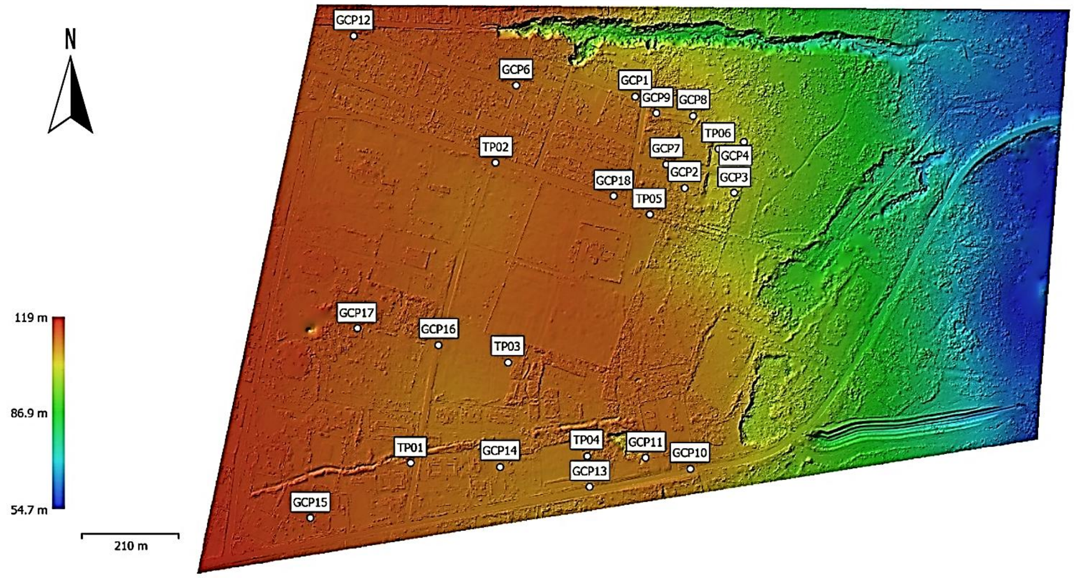

Figure 5: DTM from UAV Real Time communication with DJI Phantom 4 RTK Base Station without GCP integration

3.1 Assessment of Elevation Accuracy

The Radio RTK DTM exhibited the lowest mean and root mean square errors, indicating superior vertical reliability. The NTRIP DTM performed comparably, with slightly higher RMSE values attributed to minor communication latency during CORS data transmission. The P4-RTK DTM, which relied solely on onboard GNSS without distributed ground control, consistently overestimated elevation values, resulting in the highest bias and lowest correlation coefficient.

Table 2. Summary of Elevation Accuracy for the Three DTM Configurations

DTM Configuration	Mean Error (m)	RMSE (m)	Bias (m)	Correlation (r)
Radio RTK DTM	0.027	0.043	+0.018	0.998
NTRIP DTM	0.032	0.048	+0.021	0.996
P4-RTK DTM (GCP-Free)	0.168	0.178	+0.162	0.962

3.2 Analysis of Variance (ANOVA)

To determine whether the observed accuracy differences were statistically significant, a **one-way ANOVA** was conducted using the RMSE values as the dependent variable and DTM configuration as the categorical factor. The results are presented in Table 3.

Table 3. One-Way ANOVA Summary for DTM Accuracy

Source of Variation	Sum of Squares	df	Mean Square	F-Statistic	Sig. (p)
Between Groups	0.0631	2	0.0316	9.82	0.002
Within Groups	0.0193	15	0.0013	—	—
Total	**0.0824**	**17**	—	—	—

The ANOVA results yielded an F-statistic of 9.82 with a p-value of 0.002 (< 0.05), indicating that significant accuracy differences exist among the three DTM configurations. Post-hoc analysis using Scheffé's test showed that the P4-RTK DTM differed significantly ($p < 0.05$) from both the Radio RTK and NTRIP DTMs, whereas no significant difference was observed between the Radio and NTRIP results.

These findings confirm that GNSS-CORS assisted control strategies (Radio and NTRIP) provide statistically superior accuracy over the GCP-free onboard RTK approach, with both GNSS CORS based models performing consistently within the 5-cm accuracy threshold recommended for engineering-grade terrain mapping.

3.3 Correlation Analysis

Pearson correlation coefficients further substantiate the accuracy ranking. The Radio RTK DTM achieved an exceptionally high correlation (r = 0.998) with ground truth elevations, followed closely by the NTRIP DTM (r = 0.996). The P4-RTK DTM recorded a weaker, though still positive, correlation (r = 0.962), consistent with its pronounced bias and higher RMSE values. The correlation analysis emphasizes that while the GCP-free RTK approach can reproduce general elevation trends, it lacks the precision required for detailed engineering and hydrological modelling.

3.4 Summary of Findings

i. Radio and NTRIP control configurations produced DTMs with near-identical accuracy, both within 5 cm vertical error.
ii. The P4-RTK configuration exhibited systematic elevation overestimation, confirming the necessity of external ground control.
iii. ANOVA verified that differences between the GCP-free RTK and CORS-assisted DTMs are statistically significant ($p < 0.05$).
iv. Correlation coefficients above 0.99 for NTRIP and radio-based DTMs demonstrate strong consistency between UAV and ground-observed elevations.

4.0 DISCUSSION

The results of this study provide clear empirical evidence that the accuracy of UAV-derived Digital Terrain Models (DTMs) is significantly influenced by the ground control network configuration adopted during photogrammetric processing. The comparison between Radio RTK, NTRIP, and GCP-free P4-RTK DTMs demonstrates the practical and statistical importance of integrating CORS-based control in UAV mapping. The Radio RTK DTM achieved the lowest RMSE (0.043 m) and bias (+0.018 m), representing the highest precision among the three datasets. This level of performance is consistent with previous studies that highlighted the reliability of locally based RTK systems when line-of-sight communication between base and rover is maintained (Agüera-Vega *et al*., 2017; Forlani *et al*., 2018). The NTRIP DTM produced similar results (RMSE = 0.048 m), confirming that network-based differential corrections transmitted via cellular links can yield accuracy comparable to conventional radio transmission, provided that latency and signal stability are adequately managed (Martínez-Carricondo *et al*., 2018).

In contrast, the P4-RTK DTM—processed without any distributed GCPs—displayed a systematic positive bias (+0.162 m) and weaker correlation (r = 0.962) with the ground truth. This finding corroborates the conclusions of Turner *et al*. (2020) and Udin and Ahmad (2020), who reported that GCP-free RTK workflows are prone to vertical offset errors caused by the absence of independent external control. Such bias reflects the limitation of single-base RTK setups in compensating for atmospheric delay and satellite geometry variations, especially over undulating terrain.

The ANOVA results (F = 9.82, p = 0.002) confirmed that the observed accuracy differences among the three DTM configurations were statistically significant. Scheffé's post-hoc test indicated that both Radio RTK and NTRIP DTMs belong to the same accuracy group, while the P4-RTK DTM forms a separate, less accurate class. This statistical outcome reinforces the reliability advantage of CORS-integrated control strategies and validates their use for high-precision topographic and engineering surveys.

When compared with global UAV photogrammetry benchmarks, the accuracy of the Radio and NTRIP DTMs (RMSE < 5 cm) meets or surpasses the standard required for large-scale mapping (1:1,000 to 1:2,000) and engineering design applications (Nex and Remondino, 2014; James *et al*., 2019). The correlation analysis further emphasizes the stability of CORS-assisted configurations, which maintain near-perfect linear agreement with ground observations (r > 0.99). This implies that vertical consistency can be achieved even in complex terrain if differential corrections are referenced to a stable geodetic network.

Overall, these results align with the findings of Casella *et al*. (2020) and Eltner *et al*. (2016), who noted that integrating CORS control minimizes systematic error propagation during bundle adjustment, thereby reducing terrain deformation across UAV photogrammetric blocks. For the Nigerian context, the outcomes demonstrate the operational importance of the emerging SOGPOS CORS infrastructure, confirming its capability to support precision UAV mapping workflows across variable topography.

The consistent overestimation observed in the P4-RTK model also holds practical implications. In engineering design, such positive bias can lead to under-cut estimation or incorrect drainage gradient planning if uncorrected. Hence, the integration of external control points—either through Radio RTK or NTRIP—is indispensable for ensuring data integrity, especially in gully-affected or erosion-prone environments where small vertical deviations may significantly alter hydrological interpretations.

In summary, this comparative accuracy assessment substantiates that CORS-based control networks (NTRIP or Radio RTK) provide not only higher precision but also statistically verified reliability over GCP-free RTK workflows. The results emphasize the need for surveyors and engineers to adopt integrated CORS support for UAV operations whenever possible, thereby enhancing terrain model validity and ensuring compliance with professional accuracy standards.

5.0 CONCLUSION

This study has demonstrated that the accuracy of UAV-derived Digital Terrain Models (DTMs) is strongly dependent on the configuration of the ground control network used during photogrammetric processing. By evaluating three configurations—Radio RTK, NTRIP, and GCP-free P4-RTK—over a gully-prone terrain, it was shown that CORS-assisted solutions consistently outperform onboard RTK workflows in both precision and reliability.

The Radio RTK DTM recorded the smallest mean error (0.027 m) and RMSE (0.043 m), followed closely by the NTRIP DTM (RMSE = 0.048 m), indicating that both methods achieve sub-5 cm vertical accuracy suitable for engineering and hydrological applications. In contrast, the GCP-free P4-RTK DTM exhibited a significant positive bias (+0.162 m) and weaker correlation with the ground reference data ($r = 0.962$), confirming systematic elevation overestimation. ANOVA results ($p < 0.05$) established that these differences were statistically significant, with CORS-integrated configurations forming a distinct, higher-accuracy group.

The findings validate that CORS-based differential corrections—whether through Radio or NTRIP transmission—are essential for ensuring photogrammetric reliability in complex terrains. Onboard RTK-only configurations, while operationally convenient, cannot substitute for ground-based or network-assisted control in precision mapping. Consequently, the integration of CORS infrastructure, such as the SOGPOS network, is recommended as a standard practice for UAV surveys targeting high-accuracy DTM generation in Nigeria and similar geospatial contexts.

REFERENCES

Agüera-Vega, F., Carvajal-Ramírez, F., & Martínez-Carricondo, P. (2017). Accuracy of digital surface models and orthophotos derived from unmanned aerial vehicle photogrammetry. *Remote Sensing, 9*(1), 1–18. https://doi.org/10.3390/rs9010044

Casella, V., Chiabrando, F., Franzini, M., & Manzino, A. (2020). Accuracy assessment of UAV photogrammetric models by statistical approaches. *ISPRS International Journal of Geo-Information*, 9(5), 310.

Casella, V., Chiabrando, F., Franzini, M., & Manzino, A. (2020). Accuracy assessment of UAV photogrammetric models by statistical approaches. *ISPRS International Journal of Geo-Information, 9*(5), 310. https://doi.org/10.3390/ijgi9050310

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*(2), 359–389. https://doi.org/10.5194/esurf-4-359-2016

Forlani, G., Dall'Asta, E., Diotri, F., & Cella, U. (2018). Quality assessment of digital terrain models derived from UAV imagery. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, IV-2*, 107–114. https://doi.org/10.5194/isprs-annals-IV-2-107-2018

James, M. R., Robson, S., d'Oleire-Oltmanns, S., & Niethammer, U. (2019). Optimising UAV topographic surveys for precision and efficiency. *Earth Surface Processes and Landforms, 44*(3), 549–566. https://doi.org/10.1002/esp.4519

Martínez-Carricondo, P., Agüera-Vega, F., Carvajal-Ramírez, F., Mesas-Carrascosa, F. J., García-Ferrer, A., & Pérez-Porras, F. J. (2018). Assessment of UAV-photogrammetric mapping accuracy based on variation of ground control points. *International Journal of Applied Earth Observation and Geoinformation, 72*, 1–10. https://doi.org/10.1016/j.jag.2018.05.015

Nex, F., & Remondino, F. (2014). UAV for 3D mapping applications: A review. *Applied Geomatics, 6*(1), 1–15. https://doi.org/10.1007/s12518-013-0120-x

Turner, D., Lucieer, A., & de Jong, S. M. (2020). Time-series analysis of UAV photogrammetry for monitoring terrain change. *ISPRS Journal of Photogrammetry and Remote Sensing, 166*, 321–333. https://doi.org/10.1016/j.isprsjprs.2020.06.010

Udin, W. S., & Ahmad, A. (2020). Assessing the performance of UAV photogrammetry with different ground control strategies. *Remote Sensing Applications: Society and Environment, 19*, 100342. https://doi.org/10.1016/j.rsase.2020.100342