Tropical Built Environment Journal. Volume 9, No. 2, 209-217, 2023 www.tbejournal.com
ISSN: 1118-1790

EVALUATION OF THE SPATIAL AND GEOMETRIC QUALITY OF UAV-DERIVED DEM PRODUCT IN NNAMDI AZIKIWE UNIVERSITY AWKA, NIGERIA

J. O. Ejikeme*, T. Ayuba, E. C. Igbokwe and K. E. Idhoko

Department of Surveying and Geoinformatics, Nnamdi Azikiwe Uuniversity, Awka, Nigeria
*Corresponding Author: ejikemejoseph2@yahoo.com

Abstract

With the rapid advancement of UAV technology, it becomes imperative to assess the accuracy of UAVs to ascertain their suitability for cadastral and geomatic applications. Therefore, the aim of this study is to evaluate the spatial and geometric quality of UAV-derived DEM in Nnamdi Azikiwe University Awka, Anambra State Nigeria, with the view to determining their suitability in mapping applications. The methodology encompassed an evaluation of the vertical and horizontal accuracy of the UAV-derived DEM, employing Root Mean Square Error (RMSE) as a measure of reliability in representing elevation data. The vertical accuracy of the UAV-derived DEM was determined to be 0.84 meters, indicating a slight deviation from the actual ground truth elevation. The horizontal accuracy, represented by the RMSEr, was found to be 0.007 meters, indicating close agreement between predicted and true values. These results establish the UAV-derived DEM as a reliable source for elevation and spatial data in various geospatial applications. Continuous improvement of data processing techniques and sensor calibration will also contribute to enhancing the accuracy of the UAV-derived DEM. The study recommends among others that stakeholders should consider both the vertical and horizontal accuracy results to determine the model's suitability for their intended applications. Moreover, further investigation into the sources of vertical errors and potential improvements in vertical accuracy could be valuable for enhancing the overall performance of the UAV-derived DEM.

Keywords: Accuracy, DEM, Horizontal, UAV, Vertical

Introduction

Unmanned Aerial Vehicles (UAV) refers to an aircraft without an on-board human pilot. UAVs can be remotely controlled aircraft which is flown by a pilot at a ground station or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems. UAV is often used in military however now UAV is used in civil purpose such as mapping, facility management, construction and industrial applications. UAV has low manufacturing and operational cost of the systems, the flexibility of the aircraft to adjust according to user requirements and the elimination of the risk of pilots in difficult missions.

In the past, the use of unmanned aerial vehicles (UAVs) or drones was primarily motivated by military goals and applications. Three decades ago, UAVs were first used in geomatics applications, but today they have become a commonly used tool for data acquisition. This technique provides a low-cost alternative to classical aerial photogrammetry of small areas and large-scale topographic mapping or detailed 3D surface information (Ansari, 2012). Images acquired by UAV offer useful information

for archaeological investigation, geological and geomorphological surveys, urban modeling, hazard assessment, and engineering and geomatic applications.

In recent years, the Unmanned Aerial Vehicle (UAV) has outgrown its status as a disruptor to become a standard part of the Surveyor's toolkit for capturing the environment (GIM, 2022). One thing that makes the UAV so beloved is its versatility in wide –ranging applications under various circumstances. UAV technology can overcome many of the challenges associated with traditional methods of Surveying which can be time-consuming, labour-intensive and costly. The flexibility and affordability of the UAVs make them very efficient bridge between more expensive and time-consuming traditional survey techniques and classical aerial photogrammetry.

Like all other surveying tools, UAVs will be highly suited to some applications, but not all. If the project scale is national or regional, then satellite imagery or conventional aerial imagery will probably be more appropriate. If the work involves only a few parcels and demands high accuracy, then ground-based survey methods, using GNSS, are likely still great options. Fixed-wing UAVs are highly suited to community, village, corridor or municipality-scale mapping task. Rotary-blade UAVs are generally suitable for smaller, more complex areas, having the ability to remain stationary in the air, and are therefore great for 3D modeling of cadastral volumes, buildings and infrastructures.

Recent UAV platforms collect both imagery and elevation data. Their combined evaluation potentially generates 3D point clouds at accuracies and resolutions of some millimeters, so far limited to terrestrial data capture. UAVs deliver tailored orthoimages from which spatial data- including visible parcel boundaries, building outlines and coordinates can be derived.

Considering the rapid development of UAV technology, it is necessary to evaluate the accuracy of UAV to determine if they are fit for cadastral and geomatic purposes. Many studies have evaluated the technology based on measured checkpoints on the ground.

Padró *et al.* (2019) evaluated the data of a farm and showed that the horizontal and vertical RMSE of direct georeferencing were no more than 0.256 and 0.238 m, respectively. Nolan *et al* (2015) obtained data with a GSD of 10–20 cm in an area over tens of square kilometers and verified that the accuracy and precision (repeatability) of direct georeferencing were better than _30and _8 cm, respectively, at 95% RMSE. Tomaštík *et al.* (2019) and Erenoglu *et al.* (2018) in their various studies obtained the vertical RMSE of 10 and 20 cm, respectively. Mian *et al.* (2016) obtained a vertical RMSE of 40 cm using an image of 0.7 cm GSD.

This study seeks to evaluate the spatial and geometric quality of DEM and orthophoto obtained from UAV using Nnamdi Azikiwe University, Awka Nigeria as a case study.

Study Area

The study area, Nnamdi Azikiwe University, Awka also known as UNIZIK, is located at the Amansea area of Awka in Anambra state. The Institution is about 2.2km to the boundary of Enugu State. The landmark of the Institution spans between Awka North and Awka South L.G.As. While the Administrative block, the hostels and some other parts are in Awka South. The entire university community has an approximate area of about 4.98872 square kilometers.

Nnamdi Azikiwe University Awka is located along Onitsha-Enugu express road in Awka. The institution (Nnamdi Azikiwe University) according to the Nigeria Traverse Mercator (NTM) is in the middle belt and is located approximately between latitude 06^0 14' 73''.8 N and 06^0 14' 97'' N and longitude 07^0 07' 02E and 07^0 07' 10.''4E (see Figure 1).

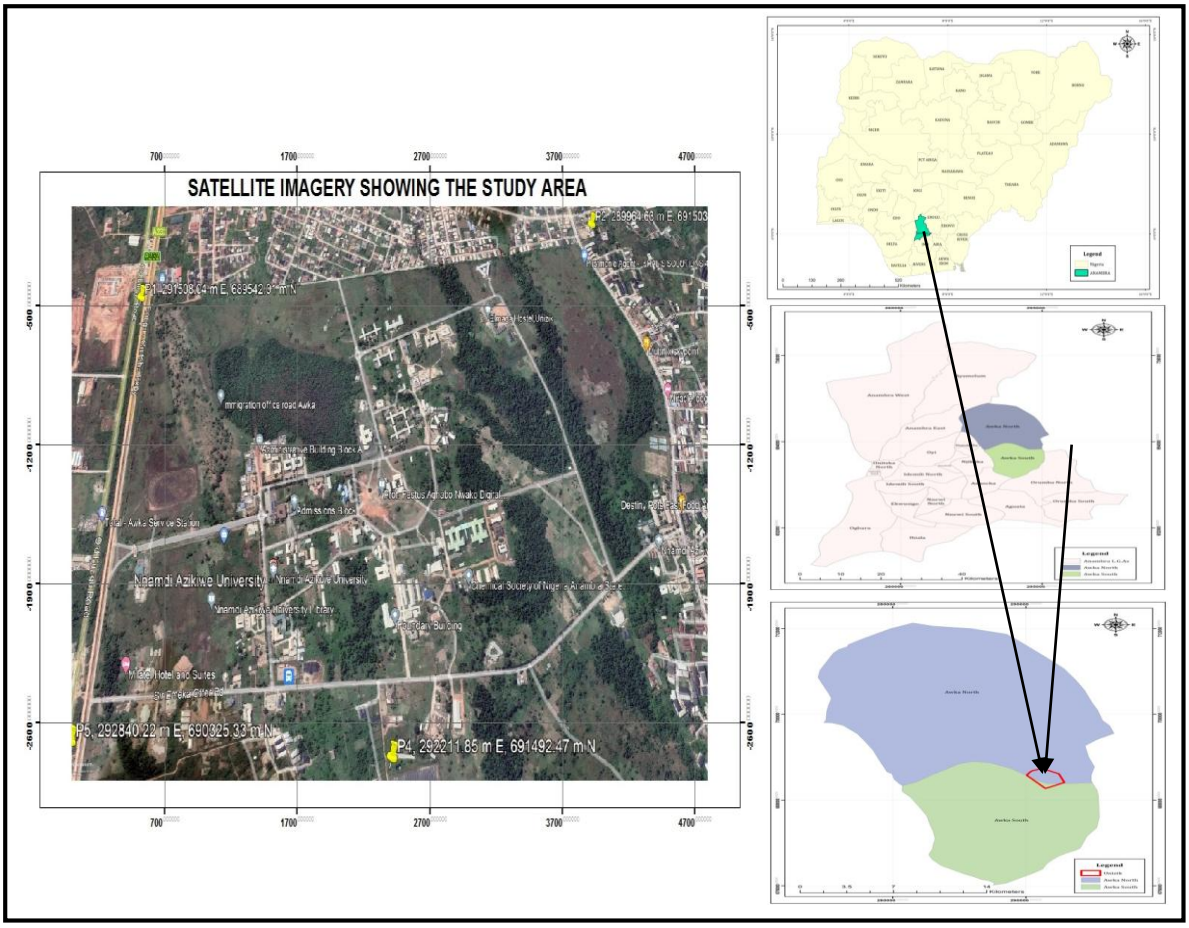


Figure 1: Map of the study area
Source: Author

Nnamdi Azikiwe University generally, is an academic institution. The people constituting its population therefore are the students, the staff of the institution and very few numbers of mini business men and women, who engage in mini business enterprises such as photocopying, restaurant, photography, Unizik internal transportation services and selling of stationeries mostly demanded by the students.

The area normally has greater population in the day time and almost zeros population in the night. Since it is an academic institution, the population is made up of heterogeneous group of people from diverse cultural backgrounds of Nigeria. Despite these ethnocentric cultural settings however, the Igbos and her culture still dominate.

Nnamdi Azikiwe University, Awka is Located in the tropical zone of Nigeria. The area experiences two major seasons brought about by the two predominant winds that rule the area. This includes the South Monsoon winds from the Atlantic Ocean and the North Eastern dry wind from across the Sahara Desert. The Monsoon winds from the Atlantic Ocean create seven months of heavy tropical rains which occur between April and October. This is followed by five months of dryness (November- March) with temperature of 27-30^{0}C between January and April brought about by the North Eastern dry wind. Few first order streams are found in the institution and in the rainy seasons, some locations are water logged which will dry up in the dry seasons. Thus, the soil texture is loose and can be muddy during the rainy seasons.

Awka is located in the Ecotom of the transition between the tropical rainforest and the wooden savanna grassland. Thus, the area is mostly dominated by grassland with some patches of gallery forests vegetation's along the stream valleys some of which may only contain water in the rainy seasons. However, this sort of grassland ecosystem might be the induced type, as a result of clearing the original vegetation for developmental purpose of the area.

Awka North which encompasses the study area experiences high temperatures in the range of

(27^0C to 28°C), which increases to a peak of about 35°C between February and April as the hottest period. The coolest periods occur from mid-July through December to early January, coinciding with middle of the rainy season and harmattan respectively. The area's high temperatures creating warm condition have great potentials for promoting outdoor recreational pursuits and tourism.

High humidity and rainfall characterize the Awka North region. These produce considerable discomfort. Between 1979 and 1989, the mean annual rainfall Recorded was 1,485.2 mm with mean monthly figure of 50mm. An absolute daily maximum of over 200mmn has been recorded between June and August in the area.

Methodology

The flowcharts for the methodology adopted is shown in Figure 2.

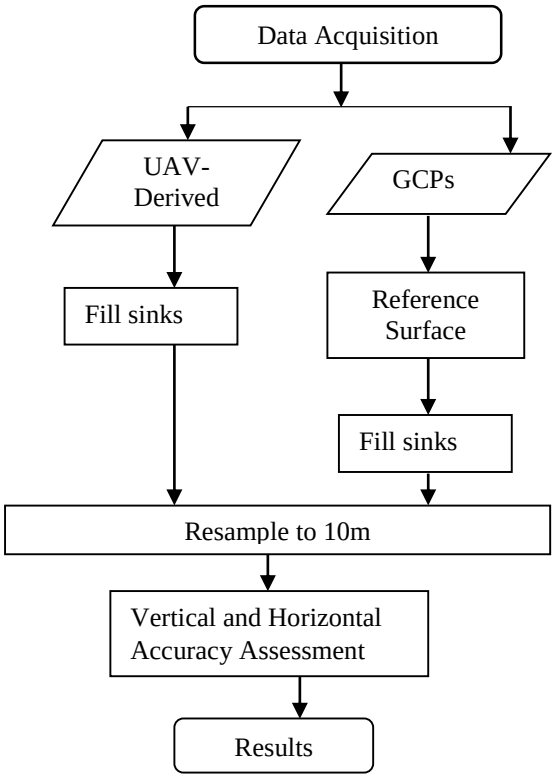


Figure 2: Flow chart of adopted Methodology

The root mean square error (RMSE) is the accepted and quantifiable measure of Digital Elevation Model (DEM) accuracy (Federal Geographic Data Committee, 1998). It serves as a comprehensive statistic that accounts for both random and systematic errors introduced during the data generation process, making it widely accepted and easy to use.

RMSE assesses how well the calculated solution of a DEM fits the original data by comparing it with elevation points that represent the "most probable" elevations at specific locations. To calculate the RMSE, the variation between each observation's actual value and its calculated value is computed, and then each variation is squared. The sum of these squared values is divided by the number of observations, and the square root is taken to obtain the RMSE value.

The RMSE value serves as a crucial indicator of the accuracy of DEM products, providing insight into the level of agreement between the generated elevation model and the actual ground truth. A lower RMSE value indicates a more accurate representation of elevation data, as the calculated values closely match the observed elevations.

By employing the RMSE as a quantitative measure of accuracy, this study ensures a robust evaluation of the UAV-derived DEM's performance and reliability. It allows for a precise assessment of the model's fit to the original data points, facilitating informed decision-making and enhancing confidence in the DEM's suitability for various geospatial applications.

RMSE for DEM vertical accuracy is defined by the USGS as:

$$RMSE = \sqrt{\frac{\sum (Z_i - Z_t)^2}{n}} \quad \text{… (1)}$$

Where Zi is the interpolated DEM elevation of a test point, Zt is the true elevation of a test point and n is the number of test points. RMSE quantifies the validity of a predictive model (USGS, 1998).

In this study, the extract sample tool of the spatial analyst tool within ArcGIS 10.7 software was utilized to identify common points in the UAV-derived DEM dataset. Specifically, the ground reference point was selected as the input point file, while the UAV-derived DEM dataset was chosen as the input raster data.

To ensure a representative sample, a random sampling technique was employed to extract 200 elevation common points from the dataset. These data points were subsequently exported to Excel for further analysis.

Next, the data underwent meticulous examination to identify and handle outliers. Outliers are data values that deviate significantly from the majority of the dataset and can have a considerable impact on statistical measures like the mean and standard deviation (Bluman, 2012). The removal of these outliers was essential to maintain the integrity and reliability of the analysis.

Following the outlier detection and removal process, the dataset was reduced to 172 points. By eliminating the outliers, the analysis could provide more accurate and representative insights into the underlying terrain.

This attention to detail and robust data processing approach strengthened the validity of the findings, making them more valuable for any further research or applications relying on this dataset.

The sample size for this study was determined using the Taro Yamane (1967) formula, which is a widely accepted method for calculating sample sizes with a 95% confidence level and a margin of error (P) set at 0.05.

By employing the Taro Yamane formula, a suitable sample size was determined to ensure a high level of confidence in the study's results. Careful consideration of the sample size is crucial in any research as it directly impacts the validity and generalizability of the findings. The chosen sample size strikes a balance between representing the population and managing data collection, thereby enhancing the overall quality and reliability of the study, the formula used is given as:

$$n = \frac{N}{1+N(e)^2} \quad \ldots (2)$$

Where n = sample size
N= population size, e= the level of precision (0.05) and1 = Theoretical constant

Therefore,

$n = \frac{172}{1+172(0.05)^2} = 120.07 = 120$ (To the nearest whole number)

As a result of applying the Taro Yamane (1967) formula for determining sample size with a 95% confidence level and a margin of error (P) set at 0.05, a total population size of 172 warranted a sample size of 120 points. These 120 sample points were meticulously selected to represent the broader population, ensuring that the study's findings would be statistically significant and robust.

The process of selecting the sample points involved randomization techniques to minimize bias and improve the overall representativeness of the sample. Each of these 120 points serves as a vital data point, contributing to the comprehensive analysis and insightful conclusions drawn from the study.

To assess the horizontal accuracy of the UAV-derived Digital Elevation Model (DEM) dataset, a rigorous horizontal ridgeline accuracy assessment was conducted, following the methodology proposed by Gameth (2010). This technique involves performing a linear accuracy test along well-defined topographic features, specifically focusing on ridgelines.

For the horizontal accuracy assessment, visible and well-defined ridgelines were carefully digitized from the reference DEM. These ridgelines represented portions of watershed boundaries. Similar river boundaries were then derived from the UAV-

derived DEM. By comparing the delineated river boundaries to the reference ridgelines, the accuracy of the UAV-derived DEM's delineations was calculated.

The assessment followed the guidelines provided by the Federal Geographic Data Committee (FGDC, 1998), which emphasize the importance of comparing planimetric coordinates of well-defined points in the dataset with coordinates obtained from an independent and higher accuracy source. To accomplish this, a control dataset consisting of 47 well-defined point locations was extracted from the reference DEM. These points served as references for comparison against similar points extracted from the UAV-derived DEM.

By utilizing the planimetric coordinates of these sample point features, the study was able to calculate the error offset between the control stream and the drainage networks delineated from each respective DEM, following the approach presented by Tveite and Langaas (1995).

The horizontal ridgeline accuracy assessment provided valuable insights into the UAV-derived DEM's horizontal accuracy, offering a comprehensive evaluation of its ability to accurately represent the terrain features, such as ridgelines and drainage networks. This assessment ensures a robust validation of the UAV-derived DEM's horizontal accuracy, supporting its suitability for geospatial applications that rely on precise and reliable horizontal data.

To determine the horizontal accuracy, the FGDC employs the Root Mean Square Error (RMSE) calculation, which provides a comprehensive measure of the differences between the reference data (X Ref, Y Ref) and the study data (X Study, Y Study). The formula for horizontal RMSE is given as follows:

Horizontal RMSE (RMSEr) = sqrt[Σ((X Ref – X Study) ² + (Y Ref – Y Study) ²) / n] ...(3)

Here, n represents the number of data points or features being compared. The horizontal RMSE can be further decomposed into RMSEx and RMSEy, which measure the error in the x and y directions separately:

RMSEx = sqrt [Σ ((X Ref - X Study) ² / n)]

…. (4)

RMSEy = sqrt [Σ ((Y Ref – Y Study) ² / n)]

…. (5)

RMSEx and RMSEy represent the errors in the horizontal position along the x and y axes, respectively.

Expanding on the calculation, the horizontal RMSE considers the squared differences between the reference and study coordinates for each data point, sums these differences, divides the sum by the total number of data points (n), and then takes the square root of the result. The RMSEx and RMSEy values are similarly computed by considering the squared differences for the x and y coordinates separately.

The horizontal RMSE value provides an essential measure of the overall positional accuracy of the dataset. A lower horizontal RMSE indicates a better agreement between the reference and study data, signifying higher accuracy in the horizontal positioning of the features. Conversely, a higher horizontal RMSE suggests greater discrepancies and lower positional accuracy.

Results and Discussion

Analysis of Vertical Accuracy of UAV-derived DEM dataset

The RMSE for DEM vertical accuracy was calculated using:

$$RMSE = \sqrt{\frac{\sum (Z_i - Z_t)^2}{n}} \quad \ldots (6)$$

where Z_i is the interpolated DEM elevation of a test point and Z_t is the true elevation of a test point and n is the number of test points.
Z_t = elevation points of UAV-derived DEM
Z_i = elevation points of Reference DEM

$\sum(Zi - Zt) = 85.471$

$$\frac{\sum(Z_i - Z_t)^2}{n} = \frac{85.471}{120} = 0.7122 RMSE$$
$$= \sqrt{\frac{\sum(Z_i - Z_t)^2}{n}} = \sqrt{0.7122}$$
$$= 0.84$$

The obtained vertical accuracy of 0.84 meters signifies that, on average, the elevations estimated by the UAV-derived DEM deviate from the actual ground truth by 0.84 meters. This metric allows us to quantify the degree of variation between the model's predictions and the real-world elevation values.

To illustrate this, consider a specific point on the ground with a measured elevation of 100 meters. According to the UAV-derived DEM, this point would be approximately estimated at 100.84 meters. The discrepancy between the estimated and actual values provides valuable insight into the precision of the model.

In assessing the accuracy of a model, a lower Root Mean Square Error (RMSE) value is indicative of higher accuracy. In this case, the RMSE of 0.84 meters suggests that the UAV-derived DEM's predicted values are relatively close to the true elevation values. This point to a favourable level of precision and reliability in the model's estimations.

Analysis of Horizontal Accuracy ofUAV-derived DEM dataset

For UAV-derived DEM dataset, the horizontal RMSE was calculated as follows:

RMSEr X = sqrt (Σ (XR -XS)^2/n)

= sqrt (0.000882/47)

= √0.00001877= 0.004m

N = the number of check points tested = 47

RMSEr Y = sqrt (Σ(YR-YS)^2/n)

= sqrt (0.00166/47)

= √0.00003531= 0.006m

Horizontal RMSEr = sqrt (RMSE x ² + RMSE y ²)

= sqrt ((0.004)^2 + (0.006)^2)

= √0.000052

= 0.007m

The RMSEx value of 0.004 meters indicates that, on average, the UAV-derived DEM's horizontal positioning along the x-axis differs from the reference data by 0.004 meters. Similarly, the RMSEy value of 0.006 meters signifies that the horizontal positioning along the y-axis differs by 0.006 meters. These low RMSE values demonstrate that the UAV-derived DEM's horizontal accuracy is quite high. The small discrepancies between the UAV-derived and reference data along both the x and y axes suggest that the model's horizontal predictions are generally very close to the true values.

The overall horizontal RMSEr value of 0.007 meters is the combined RMSE representing the overall horizontal accuracy of the UAV-derived DEM. Since this value is slightly higher than both RMSEx and RMSEy, it indicates that the overall horizontal accuracy considers the combined effects of both x and y-axis errors. The fact that the overall RMSEr is also relatively low reinforces the notion that the UAV-derived DEM performs well in accurately representing horizontal positions across the study area.

The significance of these results lies in the high level of horizontal accuracy achieved by the UAV-derived DEM. The low RMSE values (RMSEx = 0.004m, RMSEy = 0.006m, and overall RMSEr = 0.007m) indicate that the model's horizontal positioning is remarkably close to the reference data. This level of precision is especially important in various geospatial applications, such as cartography, land surveying, and infrastructure planning.

The small discrepancies in the horizontal positioning (measured in millimeters) highlight the reliability of the UAV-derived DEM for accurate spatial representation. Such high accuracy ensures that the model is suitable for applications requiring precise horizontal measurements, including engineering design, topographic mapping, and environmental monitoring.

The comparison between the vertical and horizontal accuracies of the UAV-derived DEM reveals interesting insights into the model's performance. In terms of vertical accuracy, the RMSE of 0.84 meters suggests that the UAV-derived DEM exhibits a moderate level of precision in estimating elevation values. While a deviation of 0.84 meters may be acceptable for certain applications such as topographic mapping or general terrain analysis, more precise tasks like engineering design might require higher vertical accuracy.

On the other hand, the horizontal accuracy of the UAV-derived DEM proves to be exceptionally high. With RMSEx and RMSEy values of 0.004 and 0.006 meters, respectively, and an overall horizontal RMSEr of 0.007 meters, the model demonstrates remarkable accuracy in representing horizontal positions along both the x and y axes. These low horizontal RMSE values indicate that the UAV-derived DEM provides precise spatial positioning, making it well-suited for tasks that demand accurate horizontal measurements, such as urban planning, infrastructure design, and navigation systems.

Conclusion and Recommendation

The study presents various findings from the analysis of vertical and horizontal accuracy of UAV-derived DEM accuracy. The findings suggest that the UAV-derived DEM provides reasonably accurate representations of elevation and spatial data, making it a reliable source for various geospatial applications. The UAV-derived DEM exhibits a mix of vertical and horizontal accuracies. The significance of these results hinges on the specific requirements of the project or study.

The UAV-derived DEM demonstrated promising accuracy in both vertical and horizontal dimensions, making it a reliable source for representing elevation and spatial data. Overall, the study provides valuable insights into the strengths and limitations of the UAV-derived DEM, contributing to informed decision-making in geospatial applications and landform-specific analyses. This broadens its utility for a wide range of applications, including urban development, environmental monitoring, and natural resource management.

Based on the findings of the study, several recommendations can be made to enhance the use and accuracy of the UAV-derived DEM in geospatial applications:

1. Terrain-specific Calibration: To improve accuracy, consider calibrating the UAV-derived DEM for specific terrain types. Different terrain configurations may have unique elevation characteristics that can influence the accuracy of the model. By fine-tuning the UAV-derived DEM based on terrain-specific characteristics, more accurate elevation representations can be achieved.
2. Implement Data Fusion Techniques: Integrating data from multiple sources, such as LiDAR, satellite imagery, or ground-based surveys, can lead to more accurate and detailed elevation models. Data fusion techniques can help combine the strengths of various data sources, mitigating the limitations of individual datasets and improving the overall accuracy of the UAV-derived DEM.
3. Continuous Quality Control: Establish a rigorous quality control process to identify and rectify errors or outliers in the UAV-derived DEM. Implementing robust data validation and outlier detection techniques during data processing and analysis will enhance the reliability and confidence in the elevation data.

4. Stakeholders must consider both the vertical and horizontal accuracy results to determine the model's suitability for their intended applications. Moreover, further investigation into the sources of vertical errors and potential improvements in vertical accuracy could be valuable for enhancing the overall performance of the UAV-derived DEM.

Reference

Ansari, A. (2012). Use of point cloud with a low-cost UAV system for 3D mapping. *International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM), IEEE*, Doi: 10.1109/ iceteeem.2012.6494471.

Bluman, A. G. (2009). *Elementary Statistics: A Step by Step Approach* (7th eds). New York: McGraw-Hill.

Erenoglu, R. C. and Erenoglu, O. (2018). A case study on the comparison of terrestrial methods and unmanned aerial vehicle technique in landslide surveys: Sarıcaeli landslide, Çanakkale, NW Turkey. *International Journal of Environment and Geoinf*ormatics, 5, 325–336.

FGDC**,** Federal Geographic Data Committee (1998). Geospatial Positioning Accuracy Standards. http://www.appliedgeoinformatics.org/ downloads/AGSE2012_2nd_edition_2 021_.pdf (Accessed August 17. 2021).

Gamett, B. J. (2010). An Accuracy Assessment of Digital Elevation Data and Subsequent Hydrologic Delineations in Low Relief Terrain: An Analysis for Idaho's Little Lost River Valley. *M.Sc Thesis*, Idaho State University.

Mian, O., Lutes, J., Lipa, G., Hutton, J. J.; Gavelle, E. and Borghini, S. (2016). Accuracy assessment of direct georeferencing for photogrammetric applications on small unmanned aerial platforms. *International Archives of the Photogrammetry Remote Sensing and Spatial Information Science*, XL-3/W4, 77–83. https://doi.org/10.5194/isprs-archives-XL-3-W4-77-2016.

Nolan, M., Larsen, C. and Sturm, M. (2015). Mapping snow depth from manned aircraft on landscape scales at centimeter resolution using structure-from-motion photogrammetry. *Cryosphere*, 9, 1445–1463.

Padró, J. C., Muñoz, F. J., Planas, J. and Pons, X. (2019). Comparison of four UAV georeferencing methods for environmental monitoring purposes focusing on the combined use with airborne and satellite remote sensing platforms. *International Journal of Applied Earth Observation and Geoinf*ormatics, 75, 130–140.

Tomaštík, J., Mokroš, M., Surový, P., Grznárová, A. and Merganič, J. (2019). UAV RTK/PPK method—An optimal solution for mapping inaccessible forested areas? *Remote Sensing*, 11, 721.

USGS. (2008). GLSDEM. Global Land Cover Facility. University of Maryland, College Park, Maryland.