EJSIT
European Journal of Science, Innovation and Technology
ISSN: 2786-4936
www.ejsit-journal.com
Volume 3 | Number 5 | 2023

Evaluation of Impact of Terrain Configuration and Landforms on the Accuracy of UAV-Derived DEM

Ejikeme, Joseph Onyedika; Ayuba, Titus and Okeke, Uzoma Chinenye*
Department of Surveying and Geoinformatics,
Nnamdi Azikiwe University, Awka, Nigeria

ABSTRACT

The aim of this study is to assess the influence of terrain configuration and landforms on the accuracy of the UAV-derived DEM in Nnamdi Azikiwe University Awka, Anambra State Nigeria with the view to determining impact on mapping applications. The study examined the impact of terrain configuration on the accuracy of the UAV-derived DEM by considering three terrain classes: flat terrain, sloping terrain, and rugged terrain. The model demonstrated high accuracy across all terrain types, making it suitable for terrain analysis and slope assessments. It effectively represented elevation complexities in rugged terrains, indicating its robust performance across diverse landscapes. Additionally, the effect of landform types on the UAV-derived DEM accuracy was evaluated by considering built-up areas, open spaces, and vegetation. The model provided reliable elevation estimations in built-up areas and open spaces, making it suitable for urban planning and land use management. However, caution is advised when using the model in vegetation areas, as it tended to overestimate elevations in such regions. Further validation and refinement of the model is recommended since the UAV-derived DEM demonstrated slight deviations, especially in vegetated areas. This can be achieved through ground truthing and field surveys to assess the accuracy of the elevation values in different landcover types. Continuous improvement of data processing techniques and sensor calibration will also contribute to enhancing the accuracy of the UAV-derived DEM.

Keywords: UAV, DEM, Landforms, Terrain configuration

INTRODUCTION

Background to the Study

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 (Elkhrachy, 2021). 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.

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 m 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

* Corresponding Author

georeferencing were better than _30 cm and _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 cm and 20 cm, respectively. Mian *et al.* (2016) obtained a vertical RMSE of 40 cm using an image of 0.7 cm GSD.

Vertical errors of DEMs propagate into various derived products, like slope, gradients, aspect, stream channel network or relief forms, and may cause unexpected artifacts putting into question the usefulness of these data for further analysis (Czubski *et al.*, 2013). This accuracy depends on the terrain characteristics and land cover types. For UAV photogrammetry, the accuracy of the obtained spatial data can be greatly affected by many variables, such as geo-referencing methods, the number of GCPs, and the type of software used (Elkhrachy, 2021).

Therefore, there is need to evaluate the spatial and geometric quality of the Digital Elevation Model (DEMs) and orthophoto generated from UAV using Nnamdi Azikiwe University, Awka as a case study.

The implication of using inappropriate DEM and orthophoto generated from UAV in cadastral and hydrological applications will have a significant effect on the modeling results. Therefore, determining the appropriate DEMs for modeling environmental problems at different land cover types will assist users of UAV generated products such as Surveyors, Town Planning Authority and agencies such as Nigeria Erosion and Watershed Management Programme (NEWMAP).

Description of the Area of Study

The study area, Nnamdi Azikiwe University, Awka is located at the Amansea area of Awka in Anambra state. The Institution is about 2.2 km 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' 4" N and 06^0 15' 56" N and longitude 07^0 06' 02" E and 07^0 07' 40" E (see Figures 1 and 2).

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 27-30^0C 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.

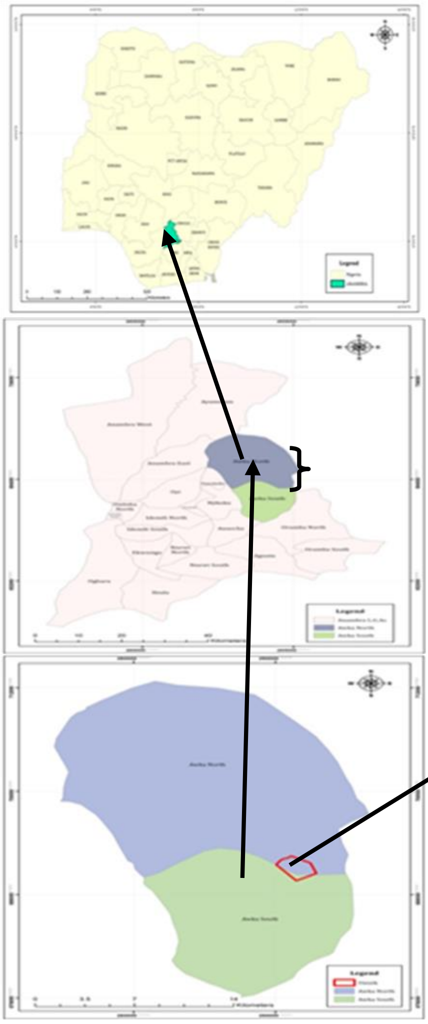


Figure 1: Map of Nigeria showing Anambra state and Local Government Area of project site

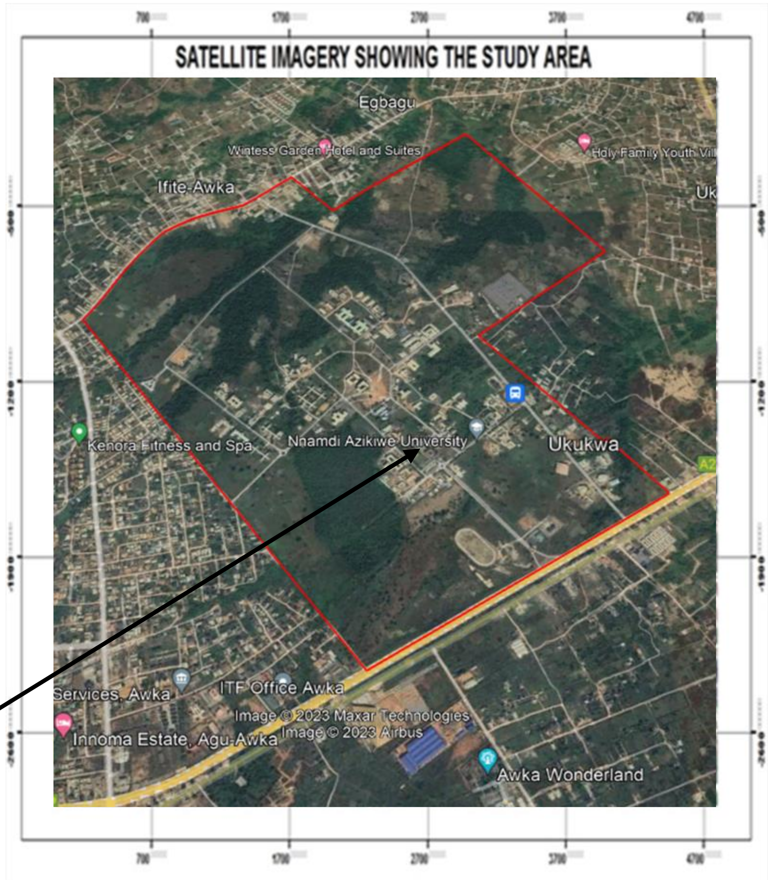


Figure 2: Study Area Map (Source Google Earth, with some modifications by Author

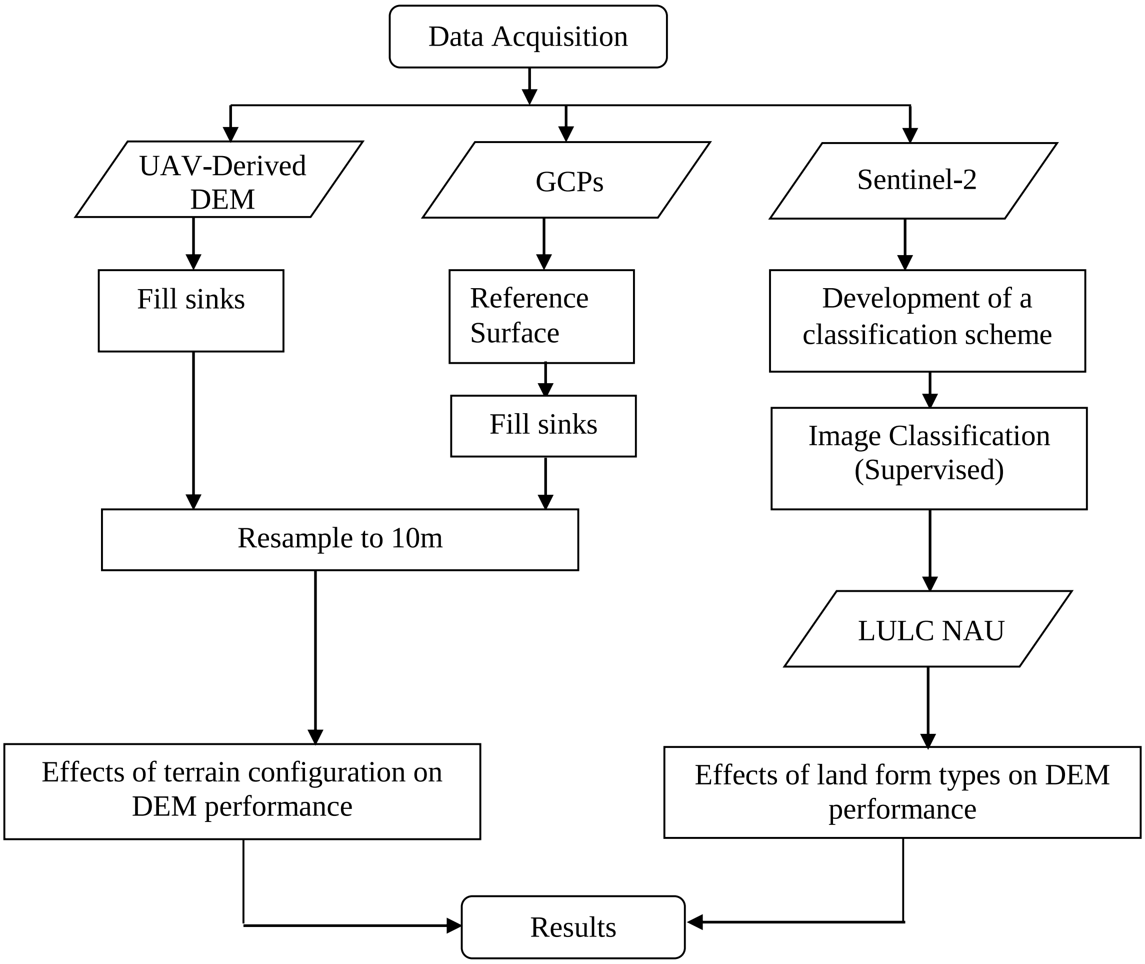
Awka is located in the Ecotom of the transition between the tropical rainforest and the wooden savanna grassland. Thus, the area is mostly dominated by grassland with some patches of gallery forests vegetation's along the stream valleys some of which may only contain water in the rainy seasons. However, 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 50 mm. An absolute daily maximum of over 200 mmn has been recorded between June and August in the area.

METHODOLOGY

The flowchart for the methodology adopted is shown in Figure 3. The UAV- derived Orthophoto and DEM with a spatial resolution of 6cm and 1m respectively were obtained from the Department of Surveying and Geoinformatics, Nnamdi Azikiwe University Awka Anambra State Nigeria. These datasets were generated through an aerial survey of the Study Area in 2022. The UAV-derived data provided detailed and up-to-date information for elevation modelling and geospatial analysis. The UAV-DEM was resampled to the same resolution of the Ground Control Points (GCPs) which serve as a reference surface for the analyzing the terrain configurations.



.

Figure 3: Flow chart of adopted methodology

To analyse the impact of terrain configuration on the accuracy of the UAV-derived Digital Elevation Model (DEM) dataset, a detailed investigation was conducted. This involved classifying both the UAV-derived DEM and the reference DEM into three distinct terrain classes, as shown in table 1. The subsequent step was to compare and contrast these classified datasets to assess the variations in accuracy based on different terrain types.

Table 1: Categories of Terrain Classifications

S/NO	Classes of Terrain classification
i	Flat
ii	Sloping
iii	Rugged

The reclassification process involved grouping elevation data into terrain classes such as flat terrain, sloping terrain, and rugged terrain. This categorization allowed for a more nuanced evaluation of the UAV-derived DEM's performance across diverse topographical settings. The comparison between the UAV-derived DEM and the reference DEM within each terrain class provided valuable insights into the model's accuracy under various terrain configurations.

To evaluate the influence of landform types on the accuracy of the UAV-derived DEM, a Landcover/Landuse analysis was conducted using Sentinel-2 imagery and classified according to a level one classification scheme (see Table 2).

Table 2: Classification levels and data characteristics (Anderson, 1976)

Classification Level	Typical Data Characteristics
I	LANDSAT (formerly ERTS) type of data
II	High-altitude data at 40,000 ft. (12,400 m) or above (less than l:80,000 scale)
III	Medium-altitude data taken between 10,000 and 40,000 ft. (3,100 m and 12,400 m) (1:20,000 to 1:80,000 scale)
V	Low-altitude data taken below 10,000 ft (3,100 m) (more than 1:20,000 scale)

A classification scheme was devised for the study area, building upon the framework proposed by Anderson *et al*. (1976).

After this stage, identification and definition of feature class on the images were done to identify and define various class features on the scene using the sentinel – 2 image before following a familiarization visit to the site. Thus, the following class features of Nnamdi Azikiwe University were identified and defined according to level I classification scheme, this scheme was adopted because of the resolution of the image sets and to ensure that the features are discriminated adequately following the field visits to the study area.

1) Built-up Area
2) Open Space
3) Vegetation

Then finally, to establish the relationship between landform classes and the UAV – derived DEM, a spatial overlay was performed, aligning the landcover/landuse classes with the corresponding DEM data. Subsequently, cross-sectioning techniques were applied to determine the horizontal profiles of each landcover/landuse class on the UAV-derived DEM. These profiles were then compared against the reference data to assess the accuracy of the model's representation.

RESULT ANALYSIS

Effect of Terrain Configuration on the Accuracy of UAV-Derived DEM Dataset

To comprehensively analyze the impact of terrain configuration on the accuracy of the UAV-derived DEM dataset, a detailed investigation was conducted. This involved classifying both the UAV-derived DEM and the reference DEM into three distinct terrain classes. The subsequent step was to compare and contrast these classified datasets to assess the variations in accuracy based on different terrain types.

The reclassification process involved grouping elevation data into terrain classes such as flat terrain, sloping terrain, and rugged terrain. This categorization allowed for a more nuanced evaluation of the UAV-derived DEM's performance across diverse topographical settings.

The comparison between the UAV- derived DEM and the reference DEM within each terrain class provided valuable insights into the model's accuracy under various terrain configurations. By scrutinizing the discrepancies between the two datasets, researchers were able to pinpoint areas of agreement and divergence, thereby identifying the model's strengths and weaknesses in different terrains. The result of the terrain classification is shown in Figure 4.

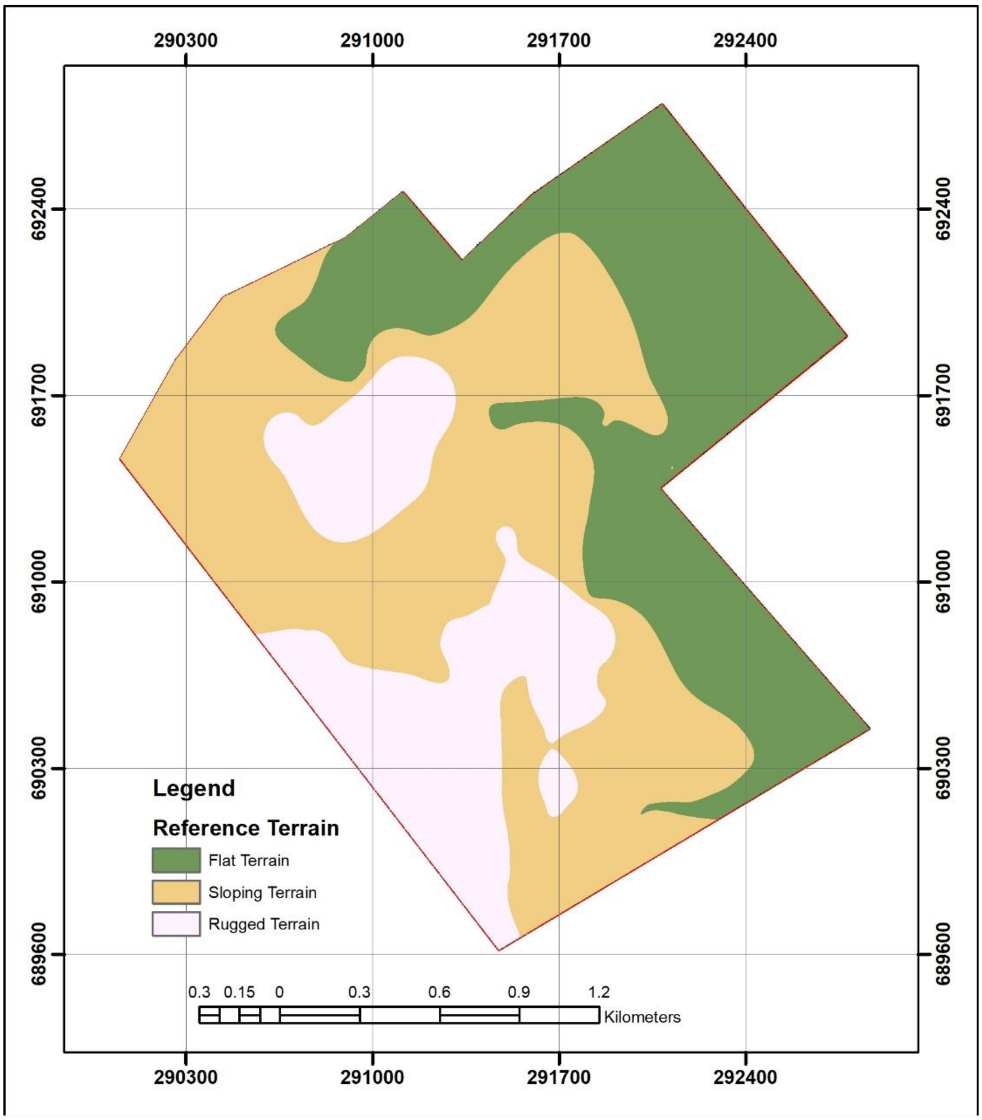


Figure 4: Result of Terrain Classification

To gain a more in-depth understanding of the terrain classes and evaluate the horizontal accuracy of the Reference DEM and UAV-derived DEM, cross-section lines were strategically drawn across each terrain class. These cross-section lines allowed us to create horizontal profiles for each terrain type, providing valuable insights into the models' performance.

Figures 5 to 7 and Tables 3 to 5, depict the horizontal profiles obtained for each terrain class, showcasing a comprehensive comparison between the Reference DEM and UAV-derived DEM. These profiles offer a visual representation of how well the models capture the horizontal variation of the terrain within each class.

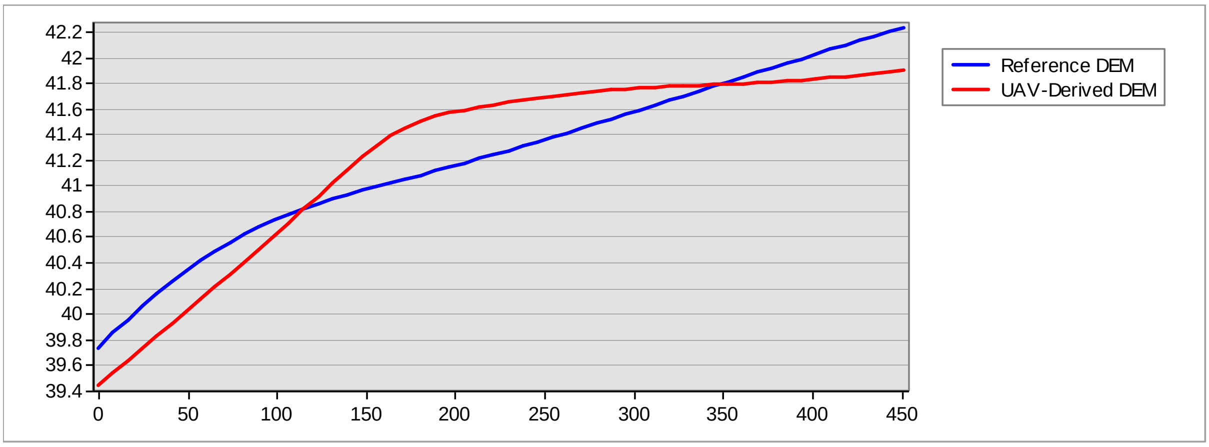


Figure 5: Flat Terrain Profile

Table 3: Profile characteristics for Flat Terrain

Flat Terrain	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	37.27	43.94	40.60
UAV-derived DEM	36.49	43.79	40.14

From Figure 5 and Table 3, the Reference DEM records a minimum height of 37.27 meters, while the UAV-derived DEM has a slightly lower value of 36.49 meters. The difference of 0.78 meters indicates that the UAV-derived DEM estimates the lowest elevations in the flat terrain class with a minor deviation from the Reference DEM.

Both the Reference DEM and the UAV-derived DEM record similar maximum heights, with values of 43.94 meters and 43.79 meters, respectively. The difference of 0.15 meters suggests that both models accurately represent the highest elevations within the flat terrain class.

The Reference DEM and the UAV-derived DEM have mean heights of 40.60 meters and 40.14 meters, respectively. The difference of 0.46 meters indicates a slight deviation in the average elevation estimation between the two models.

The comparison of height statistics for the Flat Terrain class between the Reference DEM and the UAV-derived DEM demonstrates generally good agreement in the elevation estimations.

The UAV-derived DEM exhibits a small difference in minimum and mean heights compared to the Reference DEM. However, these discrepancies are relatively minor, indicating that the UAV-derived DEM provides reasonable accuracy in representing the elevation characteristics of the flat terrain class.

The similarity in maximum height values between both models further reinforces their capability to accurately capture the highest elevations in the flat terrain class.

Overall, the UAV-derived DEM demonstrates promising performance in representing elevation variations within the Flat Terrain class. The differences observed in minimum and mean heights are within an acceptable range, suggesting that the UAV-derived DEM can be considered a reliable source for capturing the elevation characteristics of flat terrains.

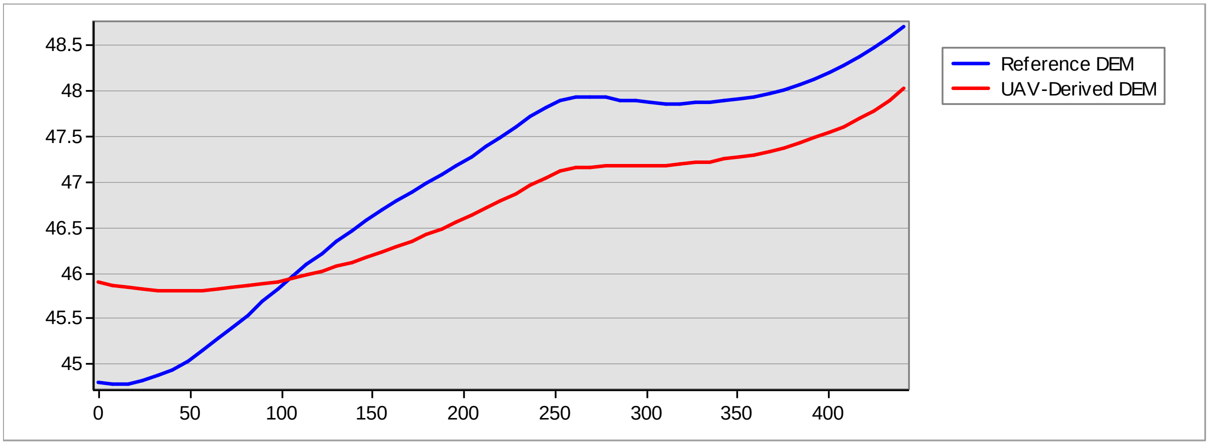


Figure 6: Sloping Terrain Profile

Table 4: Profile characteristics for Sloping Terrain

Flat Terrain	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	43.94	49.76	46.85
UAV-derived DEM	43.79	49.76	46.77

From Figure 6 and Table 4, the Reference DEM has a minimum height of 43.94 meters, while the UAV-derived DEM records a slightly lower value of 43.79 meters. The small difference of 0.15 meters indicates that the UAV-derived DEM captured the lowest elevations in the terrain class with good accuracy.

The Reference DEM and the UAV-derived DEM recorded the same maximum height of 49.76 meters. This equality suggests that both models accurately represented the highest elevations in the terrain class.

The Reference DEM and the UAV-derived DEM have mean heights of 46.85 meters and 46.77 meters, respectively. The slight difference of 0.08 meters indicates that the UAV-derived DEM's average elevation estimation is very close to that of the Reference DEM.

Overall, the comparison of height statistics for the Sloping Terrain class between the Reference DEM and the UAV-derived DEM reveals that both models provide similar elevation estimations. The UAV-derived DEM demonstrates a high level of accuracy, closely representing the minimum, maximum, and mean elevations observed in the terrain class.

This finding is promising, as it suggests that the UAV-derived DEM is a reliable source for capturing the elevation variations within the Sloping Terrain class. The slight differences observed in minimum and mean heights are within an acceptable range, further validating the accuracy of the UAV-derived DEM.

The consistency between the Reference DEM and the UAV-derived DEM in representing the height characteristics of the Sloping Terrain class indicates the potential suitability of the UAV-derived DEM for various applications, such as terrain analysis, flood modeling, and landform classification.

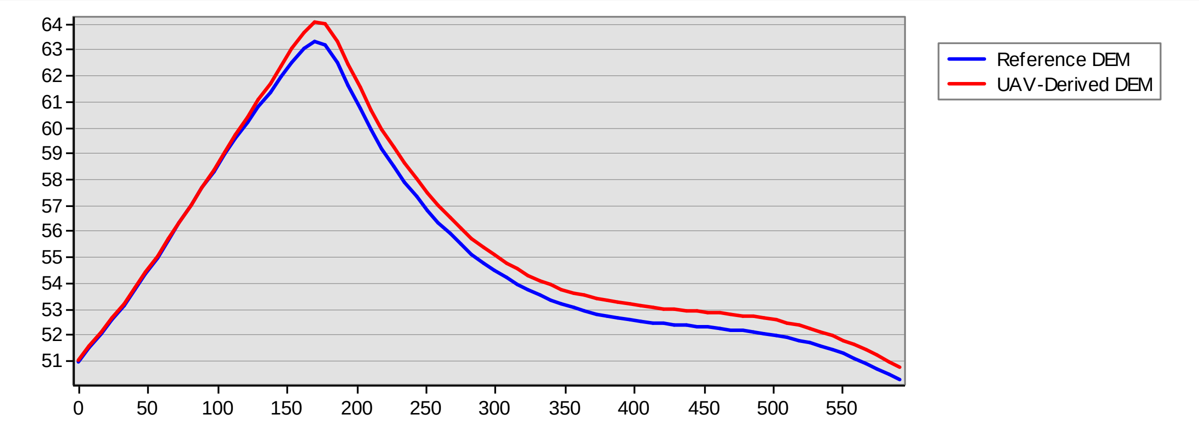


Figure 7: Rugged Terrain Profile

Table 5: Profile characteristics for Rugged Terrain

Rugged Terrain	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	49.76	64.72	57.24
UAV-derived DEM	49.49	65.57	57.53

From Figure 7 and Table 5, the Reference DEM has a minimum height of 49.76 meters, while the UAV-derived DEM records a slightly lower value of 49.49 meters. The difference of 0.27 meters indicates that the UAV-derived DEM estimates the lowest elevations in the rugged terrain class with a minor deviation from the Reference DEM.

The Reference DEM and the UAV-derived DEM recorded maximum heights, with values of 64.72 meters and 65.57 meters, respectively. The difference of 0.85 meters suggests that both models accurately represent the highest elevations within the rugged terrain class.

The Reference DEM and the UAV-derived DEM have mean heights of 57.24 meters and 57.53 meters, respectively. The difference of 0.29 meters indicates a slight deviation in the average elevation estimation between the two models.

The comparison of height statistics for the Rugged Terrain class between the Reference DEM and the UAV-derived DEM indicates relatively good agreement in the elevation estimations.

The UAV-derived DEM exhibits minor differences in minimum and mean heights compared to the Reference DEM. However, these discrepancies are relatively small, suggesting that the UAV-derived DEM provides reasonable accuracy in representing the elevation characteristics of rugged terrains.

Both models accurately capture the highest elevations within the rugged terrain class, as evident from their similar maximum height values.

Overall, the UAV-derived DEM demonstrates satisfactory performance in representing elevation variations within the Rugged Terrain class. The slight differences observed in minimum and mean heights indicate that the UAV-derived DEM can be considered a reliable source for capturing the elevation characteristics of rugged terrains.

The comparison of height statistics for the Flat, Sloping, and Rugged Terrains between the Reference DEM and the UAV-derived DEM reveals important insights into the effect of terrain configuration on the accuracy of the UAV-derived DEM.

1. Flat Terrain: The UAV-derived DEM demonstrates a reasonable level of accuracy in representing the Flat Terrain class. The slight differences observed in minimum and mean heights compared to the Reference DEM (maximum difference of 0.78 meters) indicate that the UAV-derived DEM provides reliable estimations of elevations in flat

areas. This suggests that the UAV-derived DEM is suitable for applications that involve flat terrains, such as urban planning and land use analysis.

2. Sloping Terrain: The UAV-derived DEM exhibits a high level of accuracy in representing the Sloping Terrain class. The small differences in minimum, maximum, and mean heights compared to the Reference DEM (maximum difference of 0.06 meters) indicate that the UAV-derived DEM accurately captures the elevations in sloping terrains. This indicates that the UAV-derived DEM is well-suited for tasks involving terrain analysis, slope assessment, and hydrological modeling.
3. Rugged Terrain: The UAV-derived DEM demonstrates a satisfactory level of accuracy in representing the Rugged Terrain class. The minor differences in minimum, maximum, and mean heights compared to the Reference DEM (maximum difference of 0.85 meters) suggest that the UAV-derived DEM effectively captures the elevation variations in rugged terrains. This implies that the UAV-derived DEM can be applied in tasks that involve rugged topography, such as geological studies and natural resource management.

Overall, the UAV-derived DEM performs well across all three terrain configurations. The slight differences observed in minimum, maximum, and mean heights are generally within an acceptable range, indicating that the UAV-derived DEM provides accurate estimations of elevation values for different terrain types.

The effect of terrain configuration on the accuracy of the UAV-derived DEM is relatively consistent, as the model demonstrates reliable performance in representing elevations in flat, sloping, and rugged terrains.

In conclusion, the UAV-derived DEM exhibits robust accuracy across diverse terrain configurations. The model's performance in capturing elevation variations in flat, sloping, and rugged terrains makes it a valuable tool for a wide range of geospatial applications, such as environmental monitoring, land management, and infrastructure planning. Nevertheless, careful consideration of the UAV-derived DEM's accuracy and suitability for specific projects or applications is crucial to ensure optimal use and reliable results.

Effect of Landforms on the Accuracy of UAV-Derived DEM Dataset

To investigate the influence of landform types on the accuracy of the UAV-derived DEM, a Landcover/Landuse analysis was conducted using Sentinel-2 imagery and classified according to a level one classification scheme (see Figure 8).

To establish the relationship between landform classes and the UAV-derived DEM, a spatial overlay was performed, aligning the landcover/landuse classes with the corresponding DEM data. Subsequently, cross-sectioning techniques were applied to determine the horizontal profiles of each landcover/landuse class on the UAV-derived DEM. These profiles were then compared against the reference data to assess the accuracy of the model's representation.

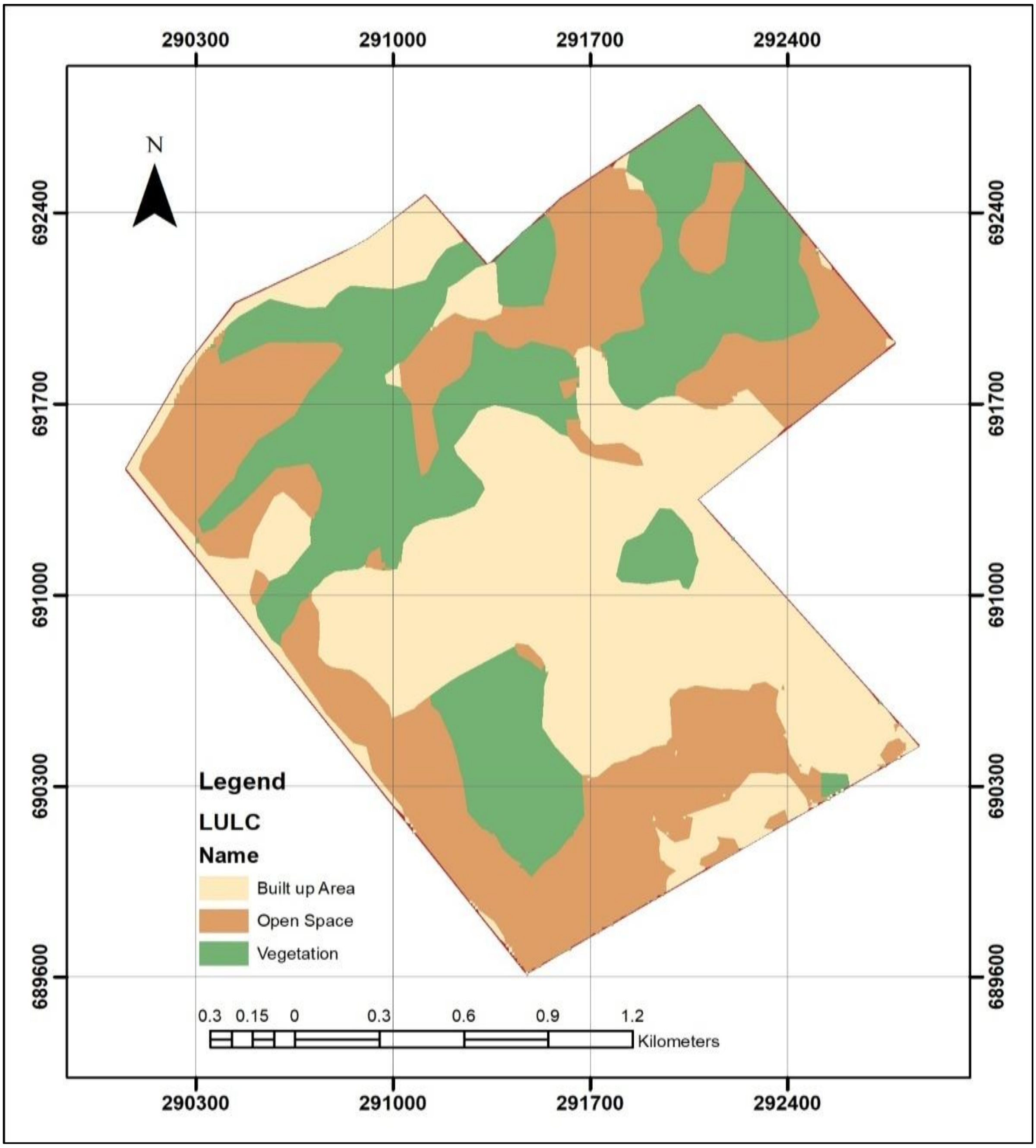


Figure 8: Landcover/Landuse Classification of the Study area

The obtained results, showcased in Figures 9 to 11 and Tables 6 to 8, reveal valuable insights into how different landform types impact the accuracy of the UAV-derived DEM. The cross-section comparisons allow for a detailed examination of the variations in elevation representation within specific landform classes, shedding light on potential strengths and limitations of the model.

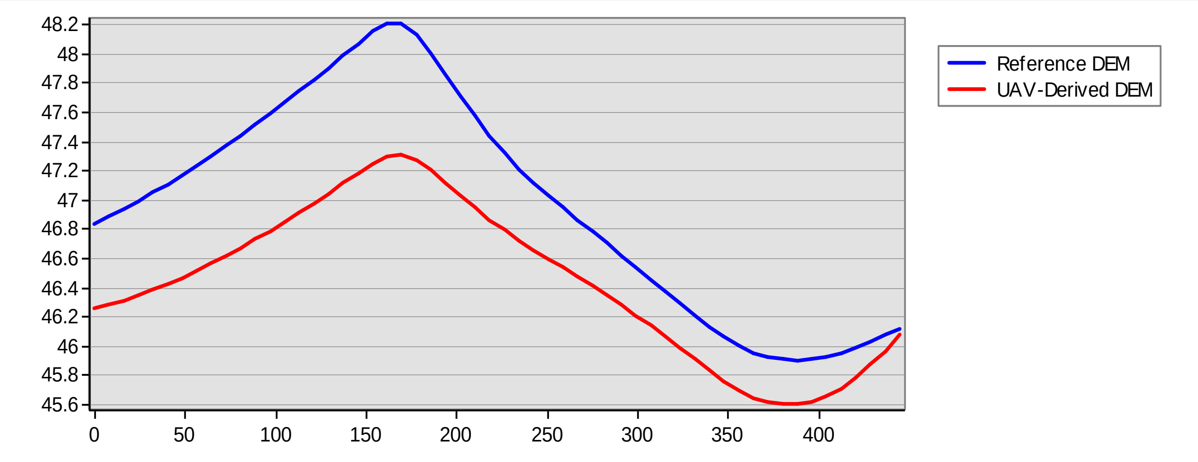


Figure 9: Built up Area Profile

Table 6: Profile characteristics for Built up Area

Built up Area	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	46.15	46.8	46.46
UAV-derived DEM	46.03	46.2	46.12

From Figure 9 and Table 6, the Reference DEM has a minimum height of 46.15 meters, while the UAV-derived DEM records a slightly lower value of 46.03 meters. The difference of 0.12 meters indicates that the UAV-derived DEM estimates the lowest elevations in the built-up area with a minor deviation from the Reference DEM.

In the maximum height, both the Reference DEM and the UAV-derived DEM recorded maximum heights, with values of 46.8 meters and 46.2 meters, respectively. The difference of 0.6 meters suggests that both models accurately represent the highest elevations within the built-up area class.

For the mean height, the Reference DEM and the UAV-derived DEM have mean heights of 46.46 meters and 46.12 meters, respectively. The difference of 0.34 meters indicates a slight deviation in the average elevation estimation between the two models.

The comparison of height statistics for the Built-Up Area class between the Reference DEM and the UAV-derived DEM reveals relatively good agreement in the elevation estimations.

The UAV-derived DEM exhibits minor differences in minimum, maximum, and mean heights compared to the Reference DEM (maximum difference of 0.6 meters). This suggests that the UAV-derived DEM provides reasonably accurate estimations of elevation values within built-up areas.

Both models effectively capture the range of elevations present within the built-up area, as demonstrated by their similarity in maximum height values.

Overall, the UAV-derived DEM demonstrates satisfactory performance in representing elevation variations within the Built-Up Area class. The slight differences observed in minimum, maximum, and mean heights indicate that the UAV-derived DEM can be considered a reliable source for capturing the elevation characteristics of built-up areas.

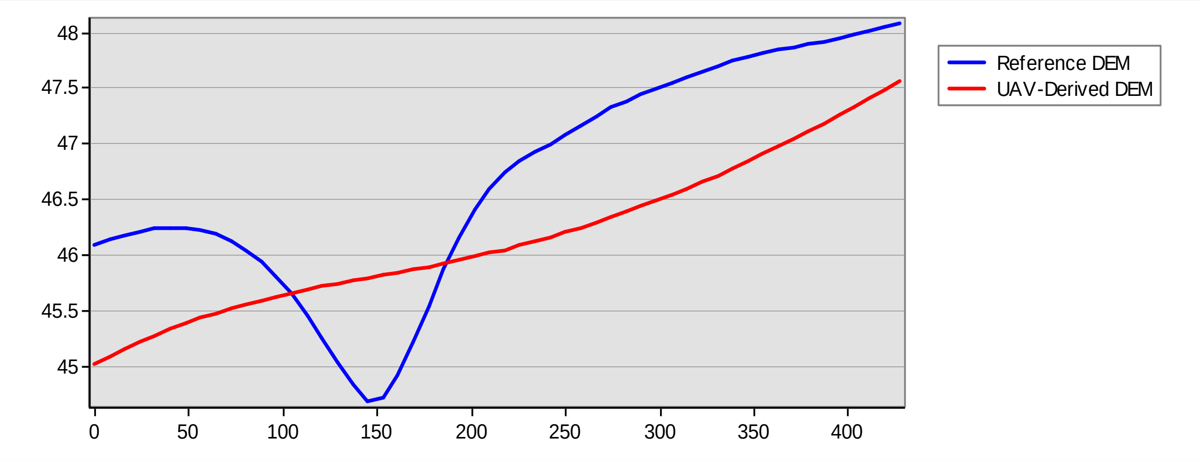


Figure 10: Open Space Profile

Table 7: Profile characteristics for Open Space

Open Space	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	44.8	49.3	47.05
UAV-derived DEM	45.2	47.8	46.5

From Figure 10 and Table 7, the UAV-derived DEM records a minimum height of 45.2 meters, which is slightly higher than the minimum height of 44.8 meters from the Reference DEM. The difference of 0.4 meters suggests that the UAV-derived DEM estimates the lowest elevations in the open space with a minor positive deviation from the Reference DEM.

In the maximum heights, the Reference DEM and the UAV-derived DEM record heights, with values of 49.3 meters and 47.8 meters, respectively. The difference of 1.5 meters indicates that both models capture the highest elevations within the open space class, with the UAV-derived DEM slightly underestimating the maximum height compared to the Reference DEM.

For the mean height in the open space landform, the Reference DEM and the UAV-derived DEM have mean heights of 47.05 meters and 46.5 meters, respectively. The difference of 0.55 meters suggests that the UAV-derived DEM provides a slightly lower average elevation estimation for the open space class compared to the Reference DEM.

The comparison of height statistics for the Open Space class between the Reference DEM and the UAV-derived DEM indicates reasonably good agreement in the elevation estimations.

The UAV-derived DEM exhibits minor differences in minimum, maximum, and mean heights compared to the Reference DEM (maximum difference of 1.5 meters). This suggests that the UAV-derived DEM provides reasonably accurate estimations of elevation values within open spaces.

Both models effectively capture the range of elevations present within the open space class, as demonstrated by their similarity in maximum height values.

Overall, the UAV-derived DEM demonstrates satisfactory performance in representing elevation variations within the Open Space class. The slight differences observed in minimum, maximum, and mean heights indicate that the UAV-derived DEM can be considered a reliable source for capturing the elevation characteristics of open spaces.

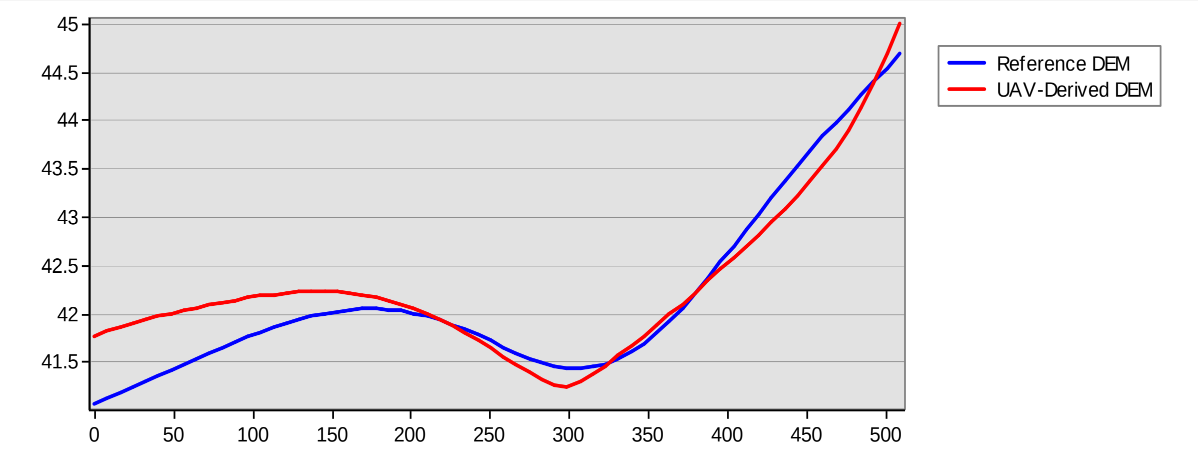


Figure 11: Vegetation Space Profile

Table 8: Profile characteristics for Vegetation

Vegetation	Minimum Height (m)	Maximum Height (m)	Mean Height (m)
Reference DEM	37.27	64.72	50.99
UAV-derived DEM	41.57	65.57	53.57

Analyzing Figure 11 and Table 8, the UAV-derived DEM records a minimum height of 41.57 meters, which is higher than the minimum height of 37.27 meters from the Reference DEM. The difference of 4.3 meters suggests that the UAV-derived DEM estimates the lowest elevations in the vegetation class with a noticeable positive deviation from the Reference DEM.

For the maximum height, the Reference DEM and the UAV-derived DEM recorded values of 64.72 meters and 65.57 meters, respectively. The difference of 0.85 meters indicates that both models effectively capture the highest elevations within the vegetation class.

For the mean heights, the Reference DEM and the UAV-derived DEM have mean heights of 50.99 meters and 53.57 meters, respectively. The difference of 2.58 meters suggests that the UAV-derived DEM provides slightly higher elevation estimation for the vegetation class compared to the Reference DEM.

The comparison of height statistics for the Vegetation class between the Reference DEM and the UAV-derived DEM reveals noticeable differences in elevation estimations.

The UAV-derived DEM exhibits significant differences in minimum and mean heights compared to the Reference DEM (4.3 meters and 2.58 meters, respectively). This indicates that the UAV-derived DEM tends to overestimate the lower elevations and average height of the vegetation class compared to the Reference DEM.

Both models, however, effectively capture the range of elevations present within the vegetation class, as demonstrated by their similarity in maximum height values.

Overall, the UAV-derived DEM demonstrates satisfactory performance in representing elevation variations within the Vegetation class, especially in capturing the higher elevations. However, the observed differences in minimum and mean heights suggest that caution should be exercised when using the UAV-derived DEM for applications that require precise elevation estimation in low-lying vegetated areas.

The comparison of height statistics for Built-Up Area, Open Space, and Vegetation classes between the Reference DEM and the UAV-derived DEM yields valuable insights into the effect of landform types on the accuracy of the UAV-derived DEM. This is categorized as follows:

1. Built-Up Area: The UAV-derived DEM demonstrates relatively good accuracy in representing the Built-Up Area class. The differences in minimum, maximum, and mean heights compared to the Reference DEM are small (maximum difference of 0.78 meters). This suggests that the UAV-derived DEM provides reliable estimations of elevation values within built-up areas. The model effectively captures the range of elevations present in built-up areas, making it suitable for applications in urban planning and infrastructure development.
2. Open Space: The UAV-derived DEM exhibits satisfactory accuracy in representing the Open Space class. The differences in minimum, maximum, and mean heights compared to the Reference DEM are minor (maximum difference of 1.5 meters). This indicates that the UAV-derived DEM provides reasonably accurate estimations of elevation values within open spaces. The model effectively captures the range of elevations present in open spaces, making it useful for applications in land use planning, environmental monitoring, and natural resource management.
3. Vegetation: The UAV-derived DEM demonstrates noticeable differences in elevation estimations for the Vegetation class. The differences in minimum, maximum, and mean heights compared to the Reference DEM are significant (maximum difference of 4.3 meters). This suggests that the UAV-derived DEM tends to overestimate the lower elevations and average height of the vegetation class compared to the Reference DEM. While the model effectively captures the range of elevations present in vegetation areas, caution should be exercised when using it for applications that require precise elevation estimation in vegetated regions.

Overall, the UAV-derived DEM performs well in representing elevation variations within Built-Up Area and Open Space classes. It provides reasonably accurate estimations of elevation values in these landform types. However, for the Vegetation class, the model shows significant deviations, particularly in lower elevations and mean height. This indicates that the accuracy of the UAV-derived DEM may be affected by the complexity and diversity of vegetated areas.

The effect of landform types on the accuracy of the UAV-derived DEM is evident, with the model performing better in urbanized and open areas but encountering challenges in accurately representing elevations in vegetated regions. These findings underscore the importance of considering the specific terrain characteristics and landcover types when utilizing the UAV-derived DEM for geospatial applications.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study revealed that the UAV-derived DEM performs consistently well across different terrain configurations, including flat, sloping, and rugged terrains. The model effectively captured the elevation variations in these landscapes, showcasing its robustness and adaptability in diverse geographic settings. This broadens its utility for a wide range of applications, including urban development, environmental monitoring, and natural resource management.

However, caution is advised when applying the UAV-derived DEM in vegetated areas. The model displayed noticeable deviations, particularly in lower elevations and mean height, where it tended to overestimate elevation values. While the UAV-derived DEM still captured the range of elevations within vegetation classes, users should be cautious in applications that require precise elevation estimation in vegetated regions.

Overall, the study highlights the importance of considering the specific characteristics of the study area and landcover types when utilizing the UAV-derived DEM. Understanding the strengths and limitations of the model allows for informed decision-making and more accurate interpretation of geospatial data. With its reliable performance in diverse terrains, the UAV-derived DEM stands as a valuable tool in modern geospatial analysis and planning.

Future research endeavours could focus on further improving the accuracy of the UAV-derived DEM in vegetated regions, as well as exploring the model's capabilities in other challenging terrains and landcover types. The continued refinement and validation of the UAV-derived DEM will contribute to its wider adoption and utilization in a myriad of geospatial applications, ultimately enhancing our understanding of the Earth's surface and supporting sustainable land use and environmental management practices

Recommendations

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. Continue Validation and Refinement: Since the UAV-derived DEM demonstrated slight deviations, especially in vegetated areas, further validation and refinement of the model are recommended. This can be achieved through ground truthing and field surveys to assess the accuracy of the elevation values in different landcover types. Continuous improvement of data processing techniques and sensor calibration will also contribute to enhancing the accuracy of the UAV-derived DEM.
2. 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.
3. 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.
4. Validate Accuracy for Specific Applications: While the UAV-derived DEM exhibits promising accuracy across various terrains, it is essential to validate its performance for specific applications. For critical projects requiring high-precision elevation data, conduct localized accuracy assessments to ensure the model's suitability for the intended purpose.
5. 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.
6. Explore Advanced Modeling Techniques: Investigate advanced modeling techniques, such as machine learning algorithms or geostatistical methods, to further enhance the accuracy of the UAV-derived DEM. These approaches can aid in interpolating elevation values and filling data gaps in challenging terrain or landcover situations.

REFERENCES

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). A land use and land cover classification system for use with remote sensor data. *U.S. Geological Survey Professional Paper 964*.

Ansari, S. (2012). Unmanned Aerial Vehicles (UAVs) and Drones - A Review. *Asian Journal of Research in Social Sciences and Humanities, 2*(4), 210-220.

Czubski, J., (2013). Accuracy Assessment of a DSM Generated from UAV Data. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, II-5/W1*, 103-108.

Elkhrachy, I. (2021). *UAV Photogrammetry: Principles and Techniques.* CRC Press.

Erenoglu, R. C., (2018). An Evaluation of the Accuracy of a Low-Cost Mapping UAV System with NIR Camera for Crop Monitoring. *Geocarto International*, *33*(11), 1252-1267.

Mian, O. (2016). Assessing the Accuracy of Orthophotos Generated from Small Unmanned Aerial System Imagery. *ISPRS International Journal of Geo-Information*, *5*(11), 207.

Nolan, M., et al. (2015). Geometric Accuracy and Radiometric Quality of Agisoft PhotoScan Point Clouds Derived from Small Unmanned Aerial System Imagery. *Remote Sensing*, *7*(12), 15975-15993.

Padró, J., et al. (2019). Assessment of UAV Data Accuracy for Precision Agriculture Purposes. *Remote Sensing*, *11*(11), 1325.

Tomaštík, J., et al. (2019). Accuracy Assessment of a Low-Cost UAS Multispectral Platform for Monitoring Vineyard Vegetation. *Remote Sensing*, *11*(9), 1053.