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INTERPRETING SURFACE REPRESENTATION THROUGH COMPARATIVE ANALYSIS OF LIDAR-DERIVED TERRAIN AND SURFACE MODELS

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ABSTRACT

Accurate representation of the Earth's surface is fundamental for geospatial analysis and environmental studies. This research examines and compares the Digital Terrain Model (DTM) and Digital Surface Model (DSM), both generated from LiDAR data acquired over the ITERA campus, a region characterized by heterogeneous land cover, including built-up areas, vegetation, and open ground. Data were collected using a DJI M350 drone equipped with an APUS sensor at an altitude of 100 meters. The methodology involved preprocessing point cloud data, classifying ground and non-ground points, and generating elevation models using Triangulated Irregular Network (TIN) interpolation with a 0.5-meter grid. Vertical accuracy was evaluated through 12 reference checkpoints measured with Geodetic GPS technology. Results demonstrate that the DSM achieved higher vertical accuracy, with a root-mean-square error (RMSE) of 0.060 meters, compared to the DTM's RMSE of 0.342 meters. Analysis of the normalized DSM (nDSM) revealed elevation differences of up to ±38 meters between DSM and DTM, effectively identifying vertical structures such as dense vegetation and campus buildings. These findings confirm the DSM is more reliable for analyzing the absolute heights of surface objects, while the DTM remains essential for modeling natural landforms, even in areas with complex land cover and greater uncertainty.

Keywords:* *LiDAR, DSM, DTM, ITERA campus area, Accuracy

1. INTRODUCTION

Accurate representation of the Earth's surface is essential for geospatial analysis, as it influences landform interpretation, slope estimation, and the identification of morphological characteristics in topographic, hydrological, and environmental studies (Guth et al., 2021). To support these applications, LiDAR technology is widely used because it generates high-resolution and high-accuracy three-dimensional datasets through dense point clouds, enabling detailed representation of surface geometry and micro-topographic variations (Julian & Harintaka, 2019).

During elevation modeling, LiDAR data are commonly processed into two products: the Digital Surface Model (DSM) and the Digital Terrain Model (DTM). DSM represents the elevation of all surface features, including vegetation and buildings, whereas DTM represents the bare-earth surface after non-ground objects are removed, resulting in different elevation values and topographic characteristics (Hidayat & Sudarsono, 2024). In addition, LiDAR's multi-return capability improves ground detection beneath vegetation canopies, making it effective for generating accurate terrain models in vegetated areas (Mutiarasari et al., 2023).

The quality of DSM and DTM products depends on the accuracy of point cloud classification and filtering, as misclassification of ground and non-ground points can introduce elevation errors and reduce model reliability (Roberts et al., 2019). Therefore, model performance is typically assessed through vertical accuracy evaluation using field control points and statistical measures such as Root Mean Square Error (RMSE) and mean bias to identify discrepancies and systematic errors between modeled and observed elevations (Kucharczyk et al., 2018).

Previous studies have shown that differences between DSM and DTM affect not only elevation values but also derived parameters such as slope, curvature, roughness, and object-height estimation through normalized DSM (nDSM) (Maxwell & Shobe, 2022). However, most studies have focused on numerical accuracy, with limited discussion on the implications of these differences for landscape representation and spatial interpretation (Cahyono & Duantari, 2017). Therefore, this study integrates accuracy assessment, morphometric analysis, and spatial visualization to evaluate elevation differences and their impact on landscape interpretation in heterogeneous semi-urban environments, providing a more comprehensive basis for elevation model selection in topographic analysis and spatial planning applications (Orlof et al., 2024). This approach is expected to support more informed decision-making in spatial analysis and planning processes (Sudra et al., 2023).

2. METHODOLOGY

2.1 Study Area and Data Acquisition

The research was conducted in South Lampung, specifically on the campus of the Sumatra Institute of Technology (Itera), located at 5°21′29.9″ S and 105°18′52.9″ E. The Itera campus exhibited diverse surface characteristics, including built-up areas, dense vegetation, and heterogeneous ground surfaces. These features provided an appropriate setting for a comprehensive evaluation of surface representations generated by the Digital Terrain Model (DTM) and Digital Surface Model (DSM). (Hidayat et al., 2024).

The dataset utilized in this study consisted of a LiDAR point cloud acquired using a DJI M350 drone equipped with an APUS sensor. LiDAR technology functioned as an active remote sensing system that emitted laser pulses to measure distances from the sensor to the Earth's surface, thereby providing high-resolution coordinate data (Hayuningsih et al., 2023). Data acquisition was conducted in December 2025 at a flight altitude of 100 meters above ground level, with side and front overlaps of 65% and 70%, respectively, using the WGS 84/UTM Zone 48S coordinate system. Additionally, checkpoint data were collected using a CHC Geodetic GPS instrument. Twelve checkpoints were systematically distributed throughout the study area to assess the vertical accuracy of the LiDAR data, as shown in the figure below.

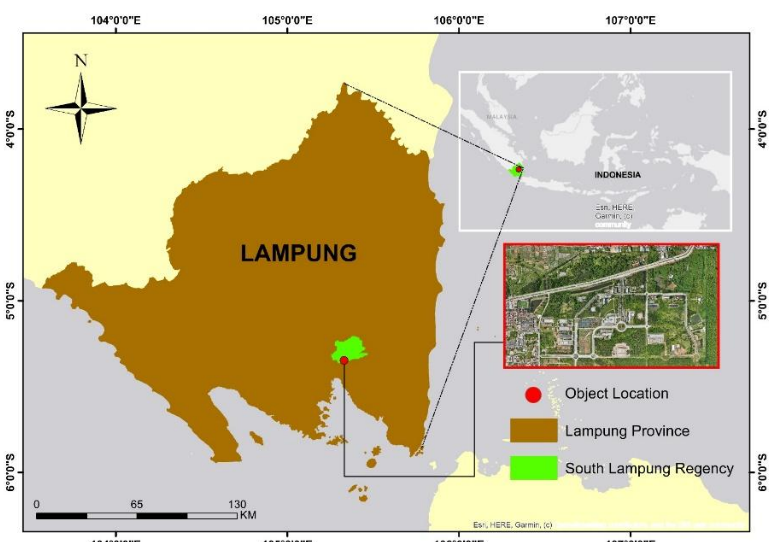


Figure 1. Research location map

2.2 LiDAR Point Cloud Preprocessing

The preprocessing stage was conducted to improve point cloud quality before surface modeling through data cleaning and separation, as LiDAR data contained ground surfaces, vegetation, buildings, and other features (Hayuningsih et al., 2023). Raw LiDAR data were processed in SATLAB for sensor integration and georeferencing, followed by optimization in Spatix through trajectory correction, strip adjustment, noise filtering, and ground/non-ground classification. This classification was essential because the DTM was generated from ground points only, whereas the DSM utilized all available points, thereby improving surface representation and reducing modeling errors (Mutiarasari et al., 2023).

2.3 Digital Terrain Model Generation

A Digital Terrain Model (DTM) was produced from a point cloud classified as ground and represented the bare-earth surface by excluding features such as vegetation and buildings, making it essential for topographic analysis and terrain modeling. The DTM was generated using the Triangulated Irregular Network (TIN) interpolation method, which converted discrete elevation points into a continuous surface that accurately represented the spatial distribution of topography. A grid resolution of 0.5 meters was selected based on the LiDAR point cloud density and analysis requirements to provide a detailed surface while maintaining computational efficiency. The resulting DTM was subsequently saved in raster format for further analysis, supporting various applications such as hydrological analysis, contour mapping, and topographic assessment (Science, 2023).

2.4 Digital Surface Model Generation

A Digital Surface Model (DSM) was generated using the entire point cloud, including both ground and non-ground points, to represent upper surface features such as vegetation and buildings (Liao et al., 2021). The DSM was created using the Triangulated Irregular Network (TIN) interpolation method with a 0.5-meter grid resolution, enabling the generation of a continuous surface that accurately captured above-ground features and supported comprehensive analysis of vertical structures. As a result, the DSM was widely utilized for three-dimensional modeling, vegetation analysis, and urban mapping due to its ability to represent surface conditions in detail (Firdaus et al., 2020).

2.5 Comparative Surface Representation Framework

An analytical framework compared DTMs and DSMs derived from identical LiDAR datasets. DTMs represented ground surfaces, while DSMs displayed the upper surface layer, including soil, buildings, and vegetation. Consequently, these models differed in both elevation values and surface representation.

The elevation difference between DSM and DTM was calculated as follows:

$$(\text{Height Difference} = \text{DSM} - \text{DTM}) \quad (1)$$

The model was employed to analyze the spatial distribution and patterns of building and vegetation heights. Topographic parameters, including slope, curvature, and roughness, were calculated separately from the Digital Terrain Model (DTM) and Digital Surface Model (DSM). The resulting parameter values were compared to assess the influence of above-ground objects on topographic analysis outcomes. Additionally, spatial analyses such as cross-sectional profiling and three-dimensional visualization were conducted to improve the visualization of surface shape differences. This methodology enabled the study to compare elevation differences and evaluate how each model generated distinct landscape representations.

2.6 Accuracy Assessment and Validation

An accuracy evaluation was performed to assess the quality of the resulting Digital Terrain Model (DTM) and Digital Surface Model (DSM). The vertical accuracy of each model was determined by comparing the model's elevation values to checkpoint reference points. Accuracy parameters included the Root Mean Square Error (RMSE) and the average bias value. Vertical accuracy was quantified using RMSE, calculated as follows:

$$\text{RMSE}= \sqrt{1/n} \sum(\text{Zmodel}-\text{Zreference})2 \quad (2)$$

Root Mean Square Error (RMSE) is a widely used metric for evaluating the accuracy of elevation models. Lower RMSE values correspond to higher model accuracy. RMSE calculations are performed separately for Digital Terrain Models (DTMs) and Digital Surface Models (DSMs) to detect potential systematic errors in each model. Previous studies have demonstrated that DTMs derived from LiDAR data can achieve a vertical accuracy of 0.195 meters, thereby meeting national mapping accuracy standards (Ananda & Handayani, 2023). Additionally, Unmanned Aerial Vehicle (UAV) LiDAR technology can generate high-accuracy elevation models that meet national standards, making it suitable for terrain analysis and surface modeling (Fakih, 2025).

2.7 Interpretation-Oriented Analysis

In the final stage, surface interpretation analyzed the differences between the Digital Terrain Model (DTM) and Digital Surface Model (DSM) to clarify how topographic features and surface objects were represented. The DTM represented the actual land surface and was more suitable for analyses of natural landforms, such as hydrological studies, geomorphological analysis, and soil volume estimation (Di et al., 2019). In contrast, the DSM represented all surface objects, including vegetation and buildings, making it more appropriate for applications involving above-ground features, such as urban planning, building height analysis, and vegetation studies (Yusuf & Setiaji, 2023). The comparison of these models enabled the identification of vertical structures and enhanced understanding of surface characteristics, thereby supporting the evaluation of their effectiveness in representing actual topographic conditions.

3. RESULTS AND DISCUSSION

The lower accuracy of the DTM is mainly related to the field conditions of several checkpoint locations. Some checkpoints were located near vegetation and areas with complex terrain, which made ground-point classification more difficult. As a result, errors in ground extraction and interpolation increased the elevation differences between the DTM and the checkpoint measurements. In contrast, the DSM retains all LiDAR returns and is less affected by ground classification errors, resulting in higher vertical accuracy.

3.1 LiDAR Point Cloud Characteristics

The LiDAR data utilized in this study generate a three-dimensional point cloud containing horizontal coordinates (X, Y) and elevation (Z), which enables detailed representation of terrain and surface features such as vegetation and buildings (Yulianto & Catur Aries Rokhmana, 2024). The high density and uniform distribution of points support accurate surface modeling by capturing subtle elevation variations, making LiDAR highly suitable for detailed mapping, urban planning, and environmental monitoring.

Figure 2. Point cloud distribution

The three-dimensional point cloud visualization highlights elevation variations and surface features through color differences, enabling the identification of terrain, vegetation, and built-up areas while demonstrating the high level of detail captured by LiDAR data.

3.2 DTM and DSM Surface Characteristics

The resulting DTM and DSM provide different surface representations, where the DTM depicts the bare-earth surface and the DSM includes vegetation and buildings (Safi'i & Hartanto, 2019). As shown in Figure 3, the DTM presents a smooth terrain surface that clearly reflects actual topographic variations.

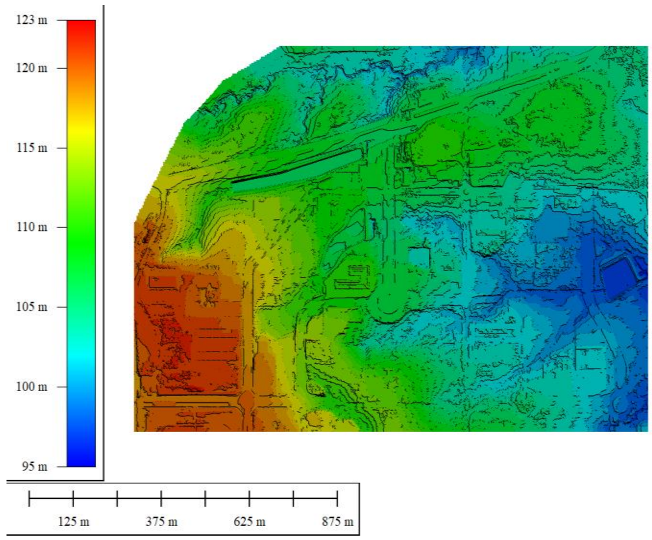


Figure 3. Visualization of DTM results

In contrast, the DSM shown in Figure 4 displays greater elevation variation because it includes surface objects such as vegetation and buildings. As a result, the DSM represents both terrain and above-ground features, producing a more heterogeneous surface than the DTM.

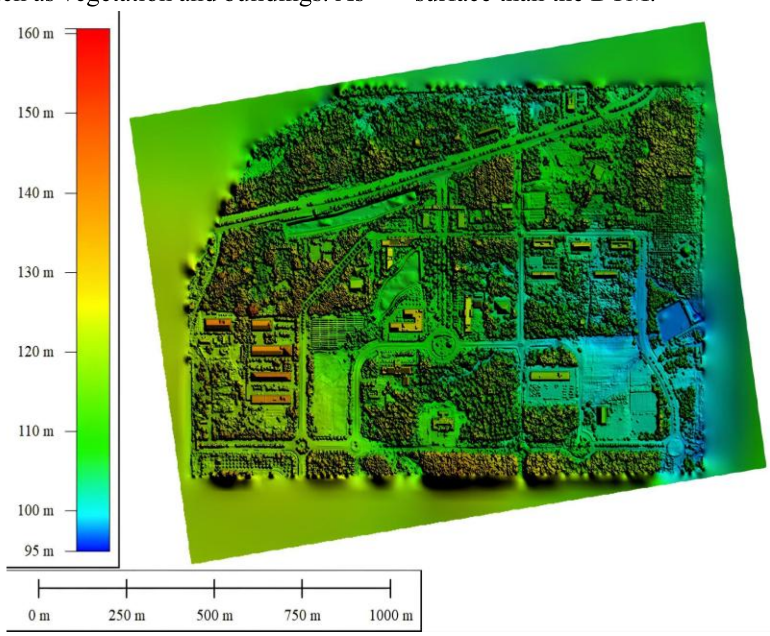


Figure 4. Visualization of DSM results

The differences between these two models extend beyond visual appearance and significantly affect the interpretation of surface features. Digital Terrain Models (DTM) are more suitable for topographic analysis, while Digital Surface Models (DSM) provide supplementary information about the location and elevation of surface features. To facilitate visual interpretation, the following figure displays hillshades generated from both DTM and DSM.

3.3 Elevation Difference Analysis

The elevation difference between the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) provides valuable insights. It reveals the distribution of objects on the ground surface, as shown in the following figure.

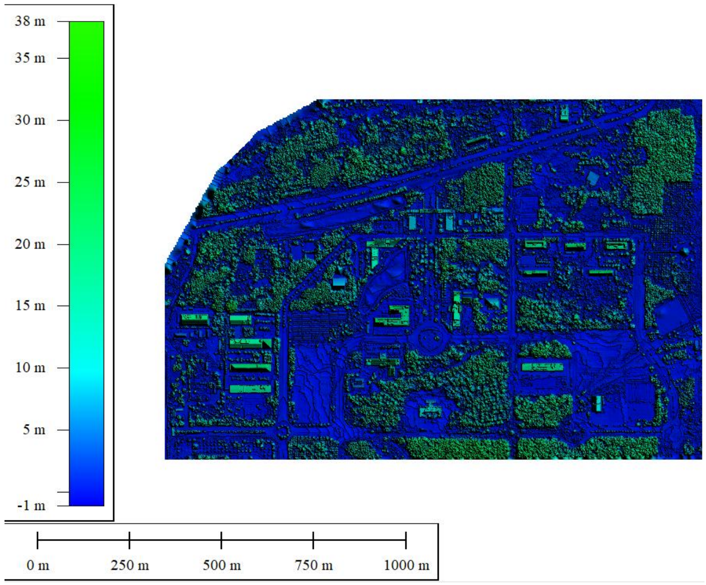


Figure 6. NDSM results visualization

The DSM–DTM elevation difference ranged from 0 m to approximately 38 m, indicating variations in the height of surface objects across the Itera campus. Low values generally corresponded to open areas, whereas high values represented vegetation and buildings. The spatial distribution of the normalized Digital Surface Model (nDSM) further highlighted this pattern, demonstrating its effectiveness in identifying vertical surface structures and distinguishing different land-cover features.

3.4 Accuracy Assessment Results

Accuracy testing was conducted to evaluate the precision of the resulting Digital Surface Model (DSM) and Digital Terrain Model (DTM) using reference data from checkpoints (Shen et al., 2022). Twelve test points, distributed across the study area, were selected as validation samples. The elevation at each checkpoint was compared with the corresponding model elevation to quantify the elevation difference. The root mean square error (RMSE) was used as the primary metric for assessing vertical accuracy, based on differences between model elevations and checkpoint data (see the following table).

Table 1. DSM accuracy test results with check point

Amount	0.044
Average	0.004
RMSE	0.060
Accuracy	0.100

Table 2. DTM accuracy test results with check point

Amount	1.404
Average	0.117
RMSE	0.342
Accuracy	0.564

on Geospatial Information Agency Regulation (Perka BIG) Number 18 of 2021, vertical accuracy was evaluated using the LE90 parameter derived from RMSE values. The results showed that the DSM achieved an LE90 of ±0.099 m, meeting Class 1 accuracy at a 1:1,000 scale, whereas the DTM recorded an LE90 of ±0.564 m, corresponding more closely to Class 3. These findings indicate that the DSM provided higher and more consistent vertical accuracy, while the DTM exhibited greater error variation, likely due to uncertainties introduced during ground classification and interpolation processes, particularly in areas with complex surface conditions. The accuracy assessment results are presented in the following table.

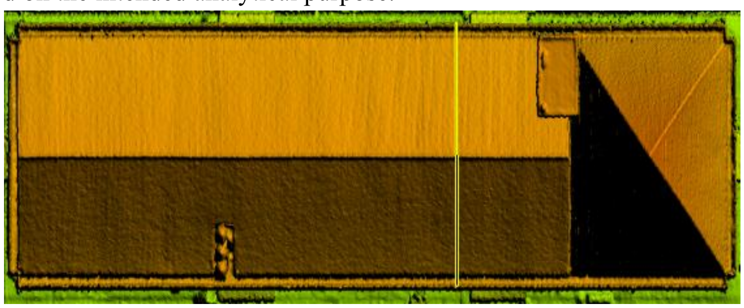
Table 3. DSM accuracy test with DTM

Amount	1.3632
Average	0.1136
RMSE	0.3370
Accuracy	0.5561

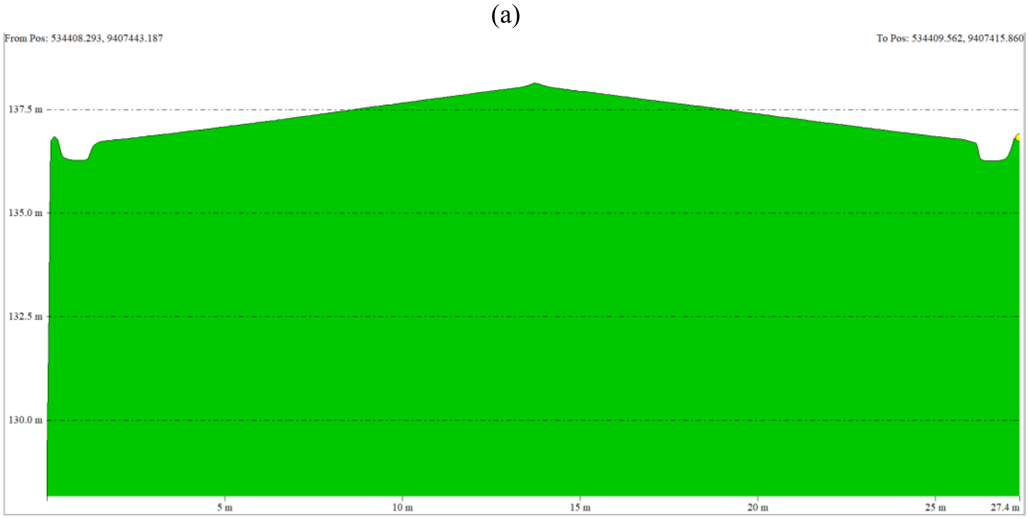
A direct comparison between the DSM and DTM yielded an RMSE of 0.337 m and an accuracy value of 0.5561, which were comparable to the DTM accuracy assessment results. These differences primarily reflected uncertainties associated with ground surface extraction in the DTM, while the elevation differences between the models also represented the height of above-ground objects such as vegetation and buildings (nDSM). Overall, the DSM retained complete surface-object information and demonstrated higher accuracy, whereas the DTM provided a more refined representation of terrain morphology despite exhibiting greater uncertainty. Therefore, the selection of either model should be based on the intended analytical purpose.

3.5 Terrain and Surface Feature Representation

Visual and spatial comparisons between the DTM and DSM demonstrated the ability of LiDAR data to distinguish ground surfaces from above-ground objects, such as buildings and vegetation. While the DSM preserved the three-dimensional characteristics of surface features, the DTM represented the underlying terrain by removing non-ground objects, thereby providing a clearer depiction of landform morphology and land-cover complexity within the study area (Idris et al., 2023).



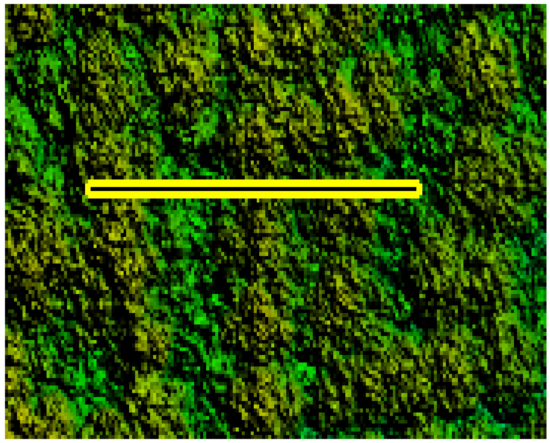
(a)



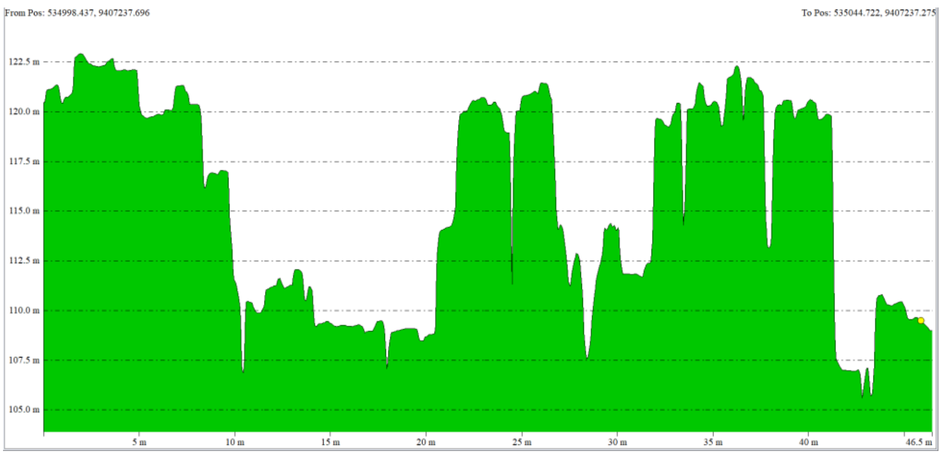
(b)

Figure 7. DSM results on GKU 1 ITERA (a), transverse profile on GKU 1 ITERA (b).

The analysis showed that LiDAR data effectively distinguished terrain from surface features, where the DSM accurately represented the height and geometry of buildings and vegetation, while the DTM depicted the underlying ground surface after removing non-ground objects. The integration of both models through the nDSM enabled detailed extraction of object heights and provided a more comprehensive understanding of topographic conditions and land-cover characteristics within the study area.



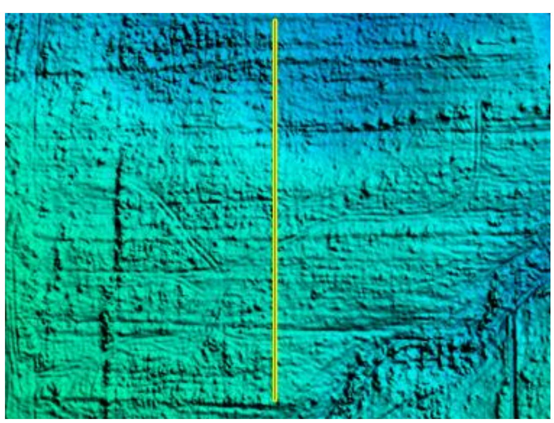
(a)



(b)

Figure 8. DSM results in the vegetation area (a), cross-profile in the vegetation area (b).

The DSM effectively represented vegetation distribution and canopy density around the ITERA dormitory, while the DTM maintained a continuous ground surface beneath vegetated areas through LiDAR ground-point detection. Furthermore, the nDSM enabled the identification of vegetation heights, which reached approximately 38 m in the tallest tree stands, providing valuable information on the vertical structure of vegetation within the study area.



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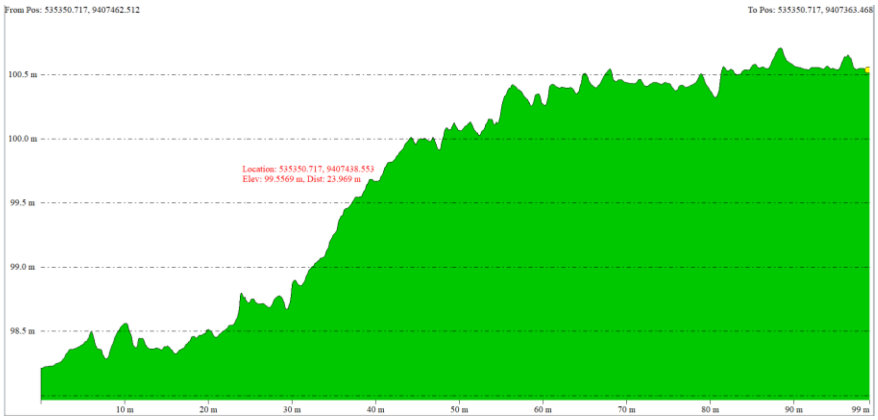
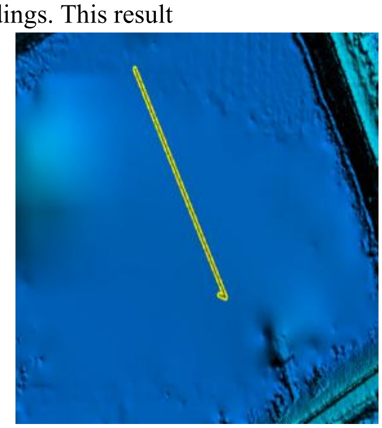


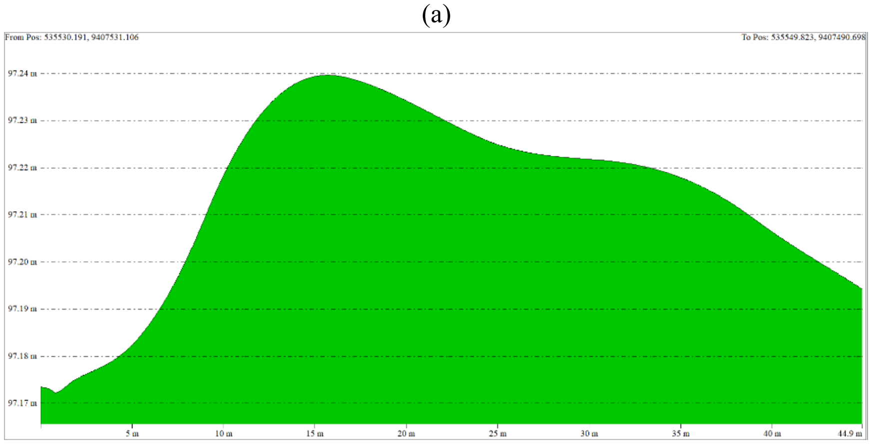
(b)

Figure 9. DTM results for open land (a) and corresponding cross-sectional profile (b).

Analysis of open land and road infrastructure showed that the DSM and DTM produced nearly identical elevation values, indicating that both models consistently represented the original terrain in areas free of vegetation and buildings. This result demonstrated the vertical accuracy and stability of LiDAR data, making it reliable for topographic mapping, hydrological analysis, and infrastructure planning.



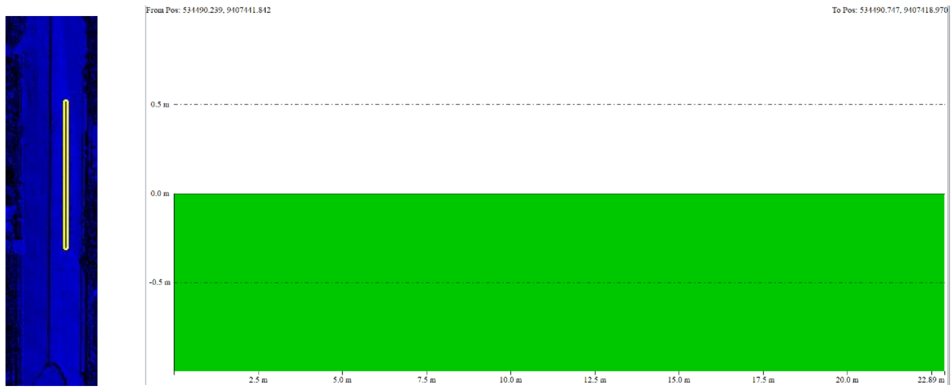
(a)



(b)

Figure 10. DTM results in aquatic environments (a), transverse profile within aquatic environments (b).

Analysis of the Embung ITERA area showed minimal differences between the DSM and DTM due to the absence of significant vertical objects. Both models accurately represented the embankment and surrounding terrain, demonstrating the reliability of LiDAR data for hydrological and geomorphological analysis



(a) (b)

Figure 11. DTM results for the road (a) and corresponding transverse profile (b).

The analysis of open land and the main road network showed minimal differences between the DTM and DSM, indicating that LiDAR accurately represented ground morphology and provided reliable data for topographic and infrastructure analysis.

3.6 Implications of DTM–DSM Differences on Surface Interpretation

The comparison between DTM and DSM revealed significant elevation differences, with the nDSM indicating object heights of up to 38 m. Low nDSM values represented open areas, while higher values corresponded to vegetation and buildings. The DTM was more suitable for terrain analysis, whereas the DSM better preserved above-ground features. Integrating both models through nDSM enabled effective object-height extraction and improved landscape interpretation (Chen et al., 2017).

3.7 Influence of Land Cover on Model Performance

The differences between the DTM and DSM were strongly influenced by land-cover characteristics, with high nDSM values occurring in vegetated and built-up areas, while values near zero were associated with open land and roads (Hidayat & Sudarsono, 2024). Dense vegetation reduced LiDAR penetration to the ground surface, increasing uncertainty in ground classification and contributing to the lower accuracy of the DTM. In contrast, the DSM remained more stable because it retained all surface points without requiring ground extraction. These findings demonstrate that integrating DTM and DSM through nDSM analysis provides a more comprehensive representation of surface conditions and land-cover variability.

3.8 Relevance for Practical Applications

The results demonstrate that the selection of an elevation model should be aligned with the objectives of geospatial analysis. The DSM achieved higher vertical accuracy (RMSE 0.060 m) and was more suitable for applications involving buildings, three-dimensional modeling, and object-height analysis, whereas the DTM (RMSE 0.342 m) provided a clearer representation of the ground surface for topographic, hydrological, and landform analyses. Furthermore, the nDSM effectively identified above-ground features, including vegetation heights of up to approximately 38 m, making it valuable for biomass estimation and green-space monitoring. Therefore, the combined use of DTM, DSM, and nDSM provides a comprehensive and reliable framework for extracting spatial information from LiDAR data while minimizing interpretation bias.

4. CONCLUSIONS AND SUGGESTIONS

A comparative analysis of LiDAR-based elevation models on the ITERA campus showed that the APUS sensor effectively distinguished terrain and surface features. The DSM achieved higher vertical accuracy (RMSE 0.060 m) than the DTM (RMSE 0.342 m), while nDSM analysis successfully identified object heights of up to approximately 38 m. In open areas, the DTM and DSM produced nearly identical elevations, indicating high sensor stability. Overall, the DSM was more suitable for three-dimensional object analysis, whereas the DTM provided a reliable representation of ground topography.

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