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# A Generalized Guideline for Airborne LiDAR Data Quality Assessment: An Indian Perspective

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**Keywords:** Airborne LiDAR, Accuracy assessment, Ground control points (GCPs), Nominal pulse spacing (NPS), Nominal point density (NPD).

**Abstract**

Airborne LiDAR is a widely adopted remote sensing technology for generating high-resolution three-dimensional (3D) geospatial data. However, ensuring the application-specific reliability and usability of LiDAR datasets requires precise quality assessment. Internationally, the airborne LiDAR data quality assessment guidelines and standard are very few and none of them from India. Thus, it is crucial to address the distinctive challenges and requirements that arise from India's geographical and climatic conditions. This study presents a structured framework and suggested guidelines for evaluating the quality of airborne LiDAR data that align with India's specific characteristics. The methodology begins with the selection of representative test sites across different land cover types, including both vegetated and non-vegetated areas. High-precision Ground Control Points (GCPs) and independent checkpoints are collected using a range of surveying techniques, including RTK, RTN, static GNSS, and total station surveys. The vertical, horizontal, and 3D positional accuracy of the LiDAR data are statistically evaluated using RMSE metrics. In cases where the LiDAR returns do not coincide directly with checkpoints, interpolation techniques such as Triangulated Irregular Networks (TIN), Inverse Distance Weighting (IDW), and Kriging are applied to estimate elevation values. Beyond absolute accuracy, internal dataset consistency is evaluated by analyzing Nominal Pulse Spacing (NPS), Nominal Pulse Density (NPD), swath overlaps, point spacing uniformity, and identifying data voids. The study presents practical and comprehensive guidelines for data quality reporting, offering clarity to both data producers and end-users.

## 1. Introduction

The accuracy assessment of LiDAR data is a critical quality control step that safeguards against financial losses and enhances the overall efficiency of geospatial projects. By verifying that the data meets the required quality for specific applications such as city mapping, forestry, it ensures the reliability and usability of the dataset. Without this step, there is a significant risk of decision-making errors, project delays, or costly data reprocessing. Thus, quality assessment not only ensures data compliance with client specifications but also maximizes the economic value of geospatial investments. However, the accuracy and reliability of LiDAR data can vary significantly based on factors such as terrain, vegetation, and sensor configuration (Habib & Rens, 2008). While international standards exist for LiDAR data quality assessment, they are not tailored to the diverse geographical and climatic conditions of India. This lack of region-specific guidelines creates challenges in ensuring consistent and reliable data quality for Indian projects. Motivated by this gap, the present study proposes a structured framework for assessing airborne LiDAR data quality suited to Indian conditions (Lohani & Ghosh, 2017). The approach includes evaluating absolute accuracy using Root Mean Square Error (RMSE) metrics from ground control and checkpoint comparisons, along with internal consistency checks such as pulse spacing, density, overlap, spatial distribution, and data voids. The study also offers practical guidelines to help standardize data quality validation and reporting for both providers and users (Abdullah, 2023).

The proposed framework in this study integrates BIS (2023) requirements with adaptations aimed at handling diverse Indian terrains and operational constraints. In mountainous and high-altitude regions, the methodology emphasizes increased swath overlaps and a denser distribution of ground control and checkpoints than generic international practices, to counter GNSS signal obstruction and elevation variation within short distances. In coastal and deltaic zones such as mangrove areas, the framework applies stricter nominal pulse spacing and pulse density checks to ensure adequate ground point capture through vegetation. In complex urban environments, where irregular building footprints and narrow streets cause occlusions, the method encourages cross-track flight planning and applies internal consistency checks like NPS, NPD, and spatial distribution at smaller spatial units. These scenario-driven steps are embedded in the BIS-based procedures described in the methodology, ensuring the assessment process is responsive to the specific operational and environmental challenges encountered in India.

## 2. Related Work

Abdullah et al., 2023 presented the updated ASPRS Positional Accuracy Standards, Edition 2, which are independent of sensor type and data-driven, addressing modern airborne mapping technologies such as LiDAR, UAV, and photogrammetry. The standards adopt RMSE as the only accuracy metric, introduce 3D positional accuracy, refine checkpoint requirements to a minimum of 30 and a maximum of 120, and remove VVA as a

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requirement for determining compliance. For airborne LiDAR, guidelines include nominal pulse density, nominal pulse spacing, swath-to-swath precision, and within-swath smoothness. Additional guidance documents link required product accuracy to process specifications such as aerial triangulation, GNSS/IMU performance, and ground control precision, offering a comprehensive framework for airborne data quality assessment (Abdullah, 2023). This aligns with our study's adoption of RMSE-based evaluation and provides an international benchmark against which our proposed framework can be positioned.

Fu et al., 2025 developed a comprehensive airborne LiDAR point cloud quality evaluation method tailored for forest resource surveys. The framework assesses horizontal accuracy, vertical accuracy, point density, and classification precision, integrating field-measured GNSS checkpoints with automated point cloud analysis. A case study in China's forested regions showed that dense vegetation reduces vertical accuracy, while slope and canopy closure affect point density distribution. The proposed evaluation method enables identification of problematic areas in airborne LiDAR datasets and supports targeted improvements in acquisition planning and processing workflows for forestry applications (Fu et al., 2025).

Liu and Zhang, investigated LiDAR data reduction techniques for efficient and high-quality DEM generation in the Corangamite Catchment Management Authority region, Australia. Using high-density airborne LiDAR data with 2.2 m average spacing, the study tested the impact of reducing point density on DEM accuracy. Results showed that a 50% reduction-maintained accuracy comparable to the full dataset while halving processing time. The authors emphasized preserving critical terrain features such as breaklines during reduction to maintain morphological correctness and hydrological integrity, recommending data optimization to balance storage, processing efficiency, and accuracy (Liu & Zhang, 2008).

BIS proposed the Indian national standard for airborne LiDAR data acquisition, specifying requirements for mission planning, data collection, quality control, and reporting. The guidelines define parameters such as nominal pulse density, nominal pulse spacing, swath overlap, and allowable data voids, along with procedures for ground control and checkpoint collection. Accuracy evaluation is based on RMSE metrics for horizontal, vertical, and 3D positional accuracy, referencing ASPRS standards but adapting them to India's diverse terrain and climatic conditions. The standard also includes specifications for internal consistency checks, interpolation methods, and uniform spatial distribution to ensure reliable, high-quality airborne LiDAR datasets for Indian projects (BIS, 2023). These national standards form a key compliance reference for our proposed methodology, ensuring its applicability to Indian airborne LiDAR projects.

Jin et al., 2025, addressed the challenge of systematic and random errors in airborne laser scanning (ALS) data caused by multi-sensor integration and variable acquisition conditions. They proposed two quality enhancement methods: rigorous system calibration and robust strip adjustment. The calibration process simultaneously estimates external and internal parameters using a rigorous observation model and robust nonlinear least squares, integrating ground truth through an interactive user interface. The strip adjustment leverages spatial-temporal segmentation, robust ICP registration, and trajectory optimization to improve point cloud fusion and georeferencing accuracy. Experimental results showed that calibration reduced offsets from meters to centimeters and improved RMSE by 2–3 times, while also enhancing efficiency through parallel processing and an automated workflow. The methods demonstrated scalability across platforms and applications, with potential uses in urban planning, infrastructure management, and disaster response (Jin et al., 2025).Their dual focus on systematic and random error mitigation complements our framework's objective to address both types of errors in airborne LiDAR datasets.

Liu, proposed a novel framework for accuracy assessment of LiDAR-derived DEMs that evaluates both vertical accuracy and the preservation of elevation order (isomorphism). Using approximation theory, the approach separates total error into sensor, ground, and interpolation components, enabling spatial mapping of error distribution. For elevation order assessment, Kendall's rank correlation coefficient is applied to quantify how well a DEM maintains the true rank of terrain points. A case study on a tidal salt marsh in California demonstrated that, while vertical accuracy was moderate, preservation of elevation order was poor, highlighting the importance of integrating isomorphism in DEM quality evaluation (Liu, 2022).

Ahokas et al., 2003, conducted a quality assessment of airborne laser scanner data using Toposys-1 and TopEye systems over various terrains in Finland, evaluating the effects of flying altitude, surface material, and observation angle on DEM accuracy. Ground truth was collected with RTK GPS and tachymeter, and comparisons were made using mean height, nearest point, and interpolated values. Results showed higher altitudes produced larger height errors, observation angle changes caused systematic errors of ~10 cm, and surface type influenced standard deviation, with asphalt showing the lowest variability. Flight line differences significantly impacted accuracy, highlighting the need for strip adjustment and distributed control points for reliable airborne LiDAR products (Ahokas et al., 2003).

## 3. Methodology

The quality assessment of airborne LiDAR data begins with the selection of representative test sites encompassing varied terrain and land cover types, such as flat plains, urban areas, and vegetated zones. Ground Control Points (GCPs)**,** surveyed using high-precision global navigation satellite system (GNSS) or total stations, and are established within these sites for calibration and georeferencing of the LiDAR data.

Airborne LiDAR data is then acquired over the test areas, producing a dense point cloud representing surface elevations. From this, a Digital Elevation Model (DEM) is generated to visualize and analyze elevation variations across the terrain. The DEM derived from the LiDAR point cloud is classified as a Digital Terrain Model (DTM), representing the bare-earth surface by excluding vegetation and man-made structures. DTM is typically used in vertical accuracy assessments where ground elevation is the reference. If a Digital Surface Model (DSM) is used instead, the canopy and buildings would affect the interpretation of vertical errors and must be considered when validating against Ground Control Points. Independent checkpoints surveyed but not used in calibration are employed for validation to ensure unbiased assessment (Elaksher et al., 2023). Interpolation techniques are applied to estimate LiDAR elevations at checkpoint locations when direct point coincidence is absent in the point cloud or the derived DEM. The selection of the interpolation method is determined by terrain characteristics and data density. Triangulated Irregular Networks (TIN) are generally preferred in non-vegetated areas with abrupt elevation changes, as break-lines and sharp features are preserved. Inverse Distance Weighting (IDW), a simpler deterministic approach, is considered appropriate for moderately varied terrain where stronger influence is exerted by nearby points on the estimated values. In contrast, Kriging, a geostatistical method is recommended for vegetated or spatially autocorrelated


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environments, as it incorporates spatial trends and provides error estimates alongside its predictions.

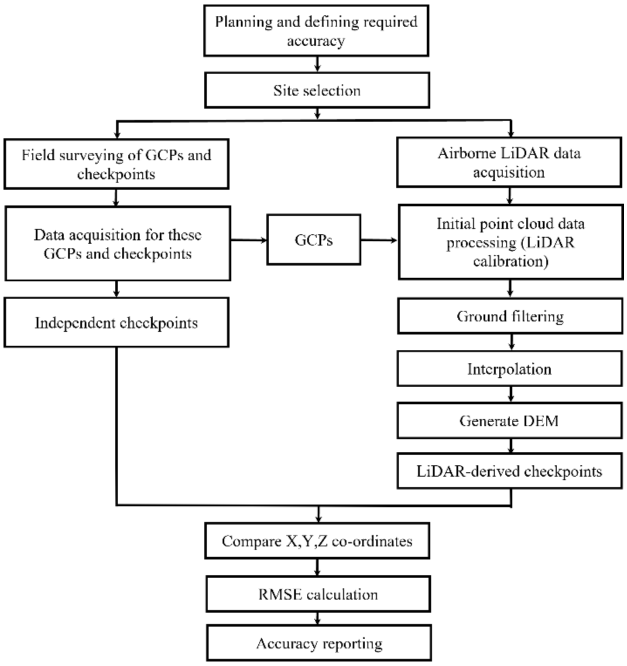


Figure 1. Proposed framework for airborne LiDAR data accuracy assessment.

Once interpolated elevation values at checkpoint locations are obtained, the RMSE is calculated to quantify vertical accuracy. RMSE is defined as the square root of the mean of the squared elevation differences between LiDAR-derived and ground-truth checkpoint values. RMSE serves as a statistical indicator of the average magnitude of vertical errors in the dataset (Xiaoye Liu, 2011). This metric is used to evaluate how accurately the LiDAR surface is represented with respect to the true terrain and is benchmarked against standards such as ASPRS and NSSDA, so that accuracy levels appropriate for mapping and engineering applications are classified. The complete workflow for airborne LiDAR vertical accuracy assessment from site selection to RMSE computation is shown in Figure 1.

## 3.1 Selection of a Test Site

Test sites should be evenly distributed across the Area of Interest, with at least one site per 50 km² (e.g., 20 sites for a 1000 km² project). Locations must be flat, at low elevation, and representative of various land cover types and terrain conditions such as bare earth, vegetation, urban areas, and wetlands (BIS, 2023). This ensures comprehensive testing of the airborne LiDAR system under diverse landscape scenarios and accounts for spatial biases like GNSS or ranging errors.

## 3.2 Selection of GCPs and Checkpoints

### 3.2.1 Ground Control Points (GCPs)

GCPs are accurately surveyed locations with known X, Y, and Z coordinates, typically measured using GNSS or total stations. These points are essential during airborne LiDAR data processing, as they help correct positional errors and improve the geometric accuracy of the dataset. In contrast, checkpoints are independently surveyed points used solely for accuracy validation and are not involved in the calibration process. They are classified into two types: non-vegetated checkpoints, placed in open or bare-ground areas, and vegetated checkpoints, located in regions with tree cover or dense vegetation.

GCPs should be evenly distributed across the project area, covering both central and outer zones to ensure balanced correction and minimize bias. Non-vegetated checkpoints should be placed on hard, flat surfaces such as paved roads or compacted soil, with slopes not exceeding 10%, and must be free from sudden elevation changes, curbs, or markings that could distort results. To ensure accurate GNSS measurements, the points should be placed at least 10 meters away from tall objects and located in open-sky areas, with an unobstructed cone-shaped view of the sky ranging from 30° to 45° in elevation around the receiver (Abdullah, 2023).

#### 3.2.1.1 Different methodologies for field surveying of GCPs and checkpoints

This section lists the best methods for the field surveying of GCPs and checkpoints, which are preferred while assessing the accuracy of airborne LiDAR data (Abdullah, 2023).

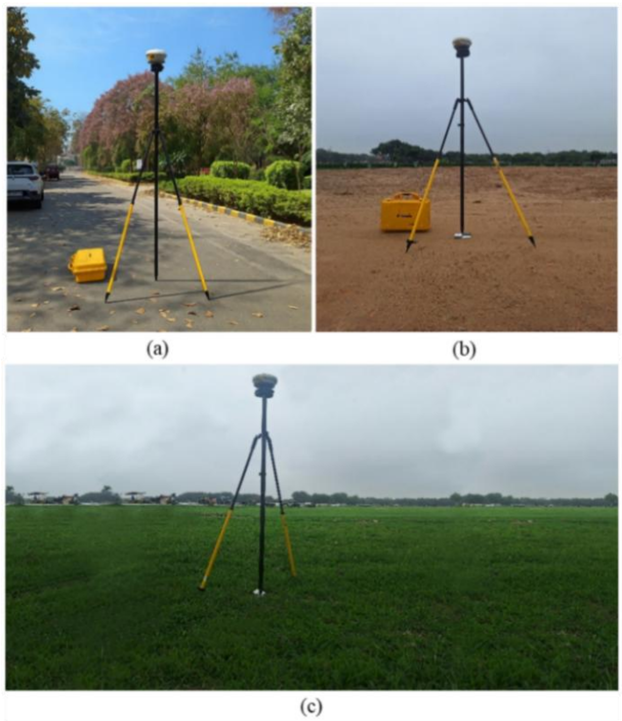


Figure 2. Preferred ground surface conditions for GCPs and non-vegetated checkpoints, (a) on unobstructed road (b) on flat compact ground surface (c) on non-vegetated and unobstructed grass field.

Any of the following five methodologies can be used to establish GCPs and checkpoints.

a) Static control and RTK surveying.
b) GNSS real-time networks (RTN).
c) GNSS real-time precise point positioning (RT-PPP) in areas with clear, unobstructed sky views.
d) Conventional surveying for vegetated checkpoints under tree canopies.
e) TLS and MLS for GCPs and non-vegetated checkpoints.

Figure 2 (a) illustrates the GNSS setup deployed for GCP collection on a flat, paved, and unobstructed road surface. This environment offers both physical stability and optimal satellite visibility, ensuring high positional accuracy. Figure 2 (b) shows a GNSS station set up on open, bare ground with a gentle slope (less than 10%), offering a stable and flat surface that helps in getting accurate GNSS measurements. Figure 2 (c) shows GCP collection in a vegetated grassy field with a gentle slope (also <10%) and no overhead obstructions. Despite the presence of low vegetation, the absence of canopy ensures minimal signal degradation, thereby preserving GNSS signal integrity and positioning accuracy.

(a) (b) (c)

Figure 3. Ground surface not recommended for GCPs/ Checkpoints collection, (a) uneven surface, (b) location near buildings, (c) on curb edge.

Figure 3 illustrates examples of ground surfaces that are not recommended for GCP or checkpoint collection due to their potential to compromise GNSS accuracy and positional stability. Figure 3a, shows an uneven terrain, which can introduce instability in tripod setup and result in measurement errors due to tilt or movement during data acquisition. Figure 3b, captures a location adjacent to a building structure, where signal obstruction and multipath effects caused by reflections from nearby walls can significantly degrade GNSS accuracy. Figure 3c, shows a GNSS setup positioned on the edge of a curb, a location that is both physically unstable to obstruction from passing vehicles or pedestrians, causing safety concerns. These scenarios highlight the importance of selecting stable, open, and obstruction-free surfaces for reliable GCP collection.

#### 3.2.2 Checkpoints

In areas with vegetation, placing checkpoints needs extra care because tree canopies can block the GNSS signal. These checkpoints should not be located in heavily shaded zones or under dense foliage, as LiDAR pulses may not reach the ground. Instead, they should be placed on smooth, open terrain, away from tree trunks, building edges, or any features causing sudden elevation changes(Abdullah, 2023). Maintaining GNSS visibility through a clear conical space around the point is equally important here. Using high-density LiDAR in these areas is important because it helps capture more ground points, reduces errors when filling gaps, and gives more accurate elevation models.

As per the standard guidelines, the accuracy of checkpoints must be at least two times better than the specified accuracy of the LiDAR dataset being assessed. Adequate number of checkpoints are required to assess the both horizontal and vertical accuracy. Table 1 provides recommended Number of Checkpoints according to ASPRS (2024). For the purpose of Vegetated Vertical Accuracy (VVA) assessment, it is recommended that an additional set of at least 30 checkpoints be collected beyond those listed in Table 1.

| Project area (square kilometer) | Total number of checkpoints |
|---|---|
| <1000[1] | 30 |
| 1001-2000 | 40 |
| 2001-3000 | 50 |
| 3001-4000 | 60 |
| 4001-5000 | 70 |
| 5001-6000 | 80 |
| 6001-7000 | 90 |
| 7001-8000 | 100 |
| 8001-9000 | 110 |
| 9001-10000 | 120 |
| >10000 | 120 |

Table1. Recommended Number of Checkpoints for Horizontal Accuracy and NVA Testing Based on Project Area (Source: ASPRS, 2024).

### 3.3 Quality Assessment of Airborne LiDAR Data

#### 3.3.1 Absolute Accuracy: RMSE

To evaluate the quality of airborne LiDAR data, both absolute accuracy and internal consistency must be assessed using specific parameters. The RMSE is the primary metric for measuring absolute vertical and horizontal accuracy by comparing LiDAR elevations to ground truth data, such as GCPs or checkpoints. To evaluate the accuracy of airborne LiDAR data, surveyed checkpoints are evenly distributed across the project area. For each checkpoint, the LiDAR-derived coordinates are compared with field-surveyed ground truth. The differences (errors) in X, Y, and Z directions are used to compute the RMSE for each dimension (Abdullah, 2023).

$$RMSE_X = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(x_{i(L)} - x_{i(G)}\right)^2} \tag{1}$$

$$RMSE_Y = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_{i(L)} - y_{i(G)}\right)^2} \tag{2}$$

$$RMSE_Z = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(z_{i(L)} - z_{i(G)}\right)^2} \tag{3}$$

Where,

$x_{i(L)}$, $y_{i(L)}$, $z_{i(L)}$ = X, Y, Z components of airborne LiDAR points, $x_{i(G)}$, $y_{i(G)}$, $z_{i(G)}$ = X, Y, Z components of Higher accuracy checkpoints, and n= number of points

The accuracy of airborne LiDAR data is typically assessed by comparing LiDAR-derived coordinates with precisely surveyed ground checkpoints. This assessment is divided into three key components: vertical, horizontal, and three-dimensional accuracy.

#### 3.3.2 Vertical Accuracy

Vertical accuracy refers to how well the LiDAR data represents true elevation values and is evaluated along the Z-axis. It is calculated using the Root Mean Square Error in the vertical direction ($RMSE_Z$), which measures the average difference between the LiDAR elevation and the actual ground elevation at

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each checkpoint. The LiDAR data elevation fit to checkpoints is represented by the first component of error $RMSE_{V1}$.

$$RMSE_{V1} = RMSE_Z ;$$

The second component of vertical error is the error of the survey of the control points and checkpoints. The second component of vertical error is represented as $RMSE_{V2}$ (Abdullah, 2023).

$$\text{Vertical accuracy } (\text{RMSE}_\text{V}) = \sqrt[2]{\left(RMSE_{V_1}\right)^2 + \left(RMSE_{V_2}\right)^2} \quad (4)$$

$$\text{RMSE}_\text{V} = \sqrt[2]{(RMSE_z)^2 + \left(RMSE_{V_2}\right)^2} \quad (5)$$

### 3.3.3 Horizontal Accuracy

Horizontal accuracy addresses the positional accuracy in the X and Y directions. It is computed using $RMSE_X$ and $RMSE_Y$ representing the average planimetric errors in the east-west and north-south directions, respectively. These values are especially important for applications requiring high precision in ground positioning (Abdullah, 2023).
Horizontal accuracy can be calculated by the following formula:

$$\text{Horizontal accuracy } (\text{RMSE}_\text{H}) = \sqrt[2]{(RMSE_X)^2 + (RMSE_Y)^2} \quad (6)$$

### 3.3.4 Three-dimensional Accuracy

For a complete spatial accuracy assessment, three-dimensional (3D) accuracy is calculated by combining the individual RMSE values in all three directions. The overall 3D RMSE provides a single metric that reflects the total positional error in space, offering a comprehensive measure of airborne LiDAR dataset accuracy. Together, these metrics help determine whether the LiDAR data meets the required quality standards and is suitable for further analysis or application (Abdullah, 2023).
Overall 3D Root Mean Square Error ($RMSE_{3D}$) is calculated using both the horizontal and vertical error components, as defined by a standard formula.

$$\text{RMSE}_\text{3D} = \sqrt[2]{(RMSE_X)^2 + (RMSE_Y)^2 + (RMSE_Z)^2} \quad (7)$$

Or

$$\text{RMSE}_\text{3D} = \sqrt[2]{(RMSE_H)^2 + (RMSE_V)^2} \quad (8)$$

### 3.3.5 Relative Accuracy

Relative or internal accuracy refers to the geometric consistency of LiDAR data within itself, independent of external controls. It helps detect issues like sensor misalignment or GNSS drift (Abdullah, 2023). This is evaluated through within-swath precision, which checks elevation consistency over flat surfaces within a single swath, and swath-to-swath precision, which measures agreement in overlapping flight lines. At least 30 tests areas should be selected and evenly distributed throughout the project extent to ensure meaningful evaluation.
Assessment of data internal precision includes two aspects of data quality:

1. within-swath (smooth-surface) precision, and
2. Swath-to-swath precision (Abdullah, 2023).

Within-swath precision evaluation as shown in Figure 4, involves analyzing the smoothness of elevation values over flat, continuous surfaces within a single swath. This is done by rasterizing the point cloud and comparing minimum and maximum elevations within each raster cell, or by examining systematic variations in elevation across scan directions. The resulting distribution highlights potential sensor misalignments or systematic drift.

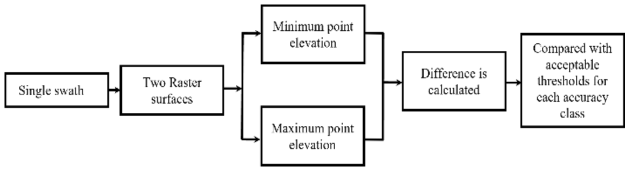


Figure 4. Flowchart for evaluating relative accuracy within-swath.

Swath-to-swath precision evaluation as shown in Figure 5, focuses on overlapping regions between adjacent flight lines. Here, elevation surfaces are generated for each swath, and sampled control areas are used to compute vertical differences between overlapping zones. The $RMSE_Z$ from these differences quantifies the consistency between swaths. Systematic deviations indicate temporal GNSS drift, IMU calibration errors, or trajectory mismatches. The flowcharts in Figures 4 and 5 illustrate these assessment workflows and serve as a guide for implementing consistent relative accuracy validation procedures.

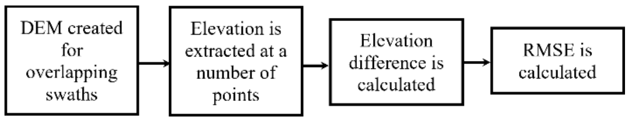


Figure 5. Flowchart for evaluating relative accuracy swath-to-swath.

## 3.4 Internal Consistency of Airborne LiDAR Data

For assessing internal data quality and consistency across the dataset, several additional parameters are considered. These include Nominal pulse spacing (NPS), which reflects the average distance between individual LiDAR points, and Nominal Pulse Density (NPD), indicating the number of pulses per square meter. Swath overlap is also critical, ensuring consistent data coverage between adjacent flight lines. The presence of data voids, or gaps where LiDAR returns are missing, must be minimized for reliable surface modeling. Finally, Spatial distribution evaluates how uniformly LiDAR points are spread across the area of interest (BIS, 2023), which directly impacts the representativeness and usability of the dataset. Together, these parameters provide a comprehensive understanding of LiDAR data quality, guiding both data validation and processing workflows.

### 3.4.1 Nominal Pulse Spacing (NPS)

NPS is the average horizontal distance between adjacent laser pulses on the ground in a LiDAR dataset as shown in Figure 6.
To evaluate NPS, a Delaunay triangulation is first constructed using the (X, Y) coordinates of the LiDAR points. This forms a mesh of non-overlapping triangles connecting neighboring points. The horizontal distances of the edges in the triangulation are then computed, and for each point, the average length of edges connected to it is taken as its individual spacing value. After obtaining these spacing values for all N points, the 95th percentile (denoted as $S_V$) is calculated. If 95% of the spacing values are less than or equal to $S_V$, the dataset is considered to meet the NPS requirement outlined in the proposed BIS guidelines (BIS, 2023). Figure 7, explains this process in a flowchart format. It begins with point extraction and triangulation, proceeds

to edge distance measurement, and then computes the average spacing values.

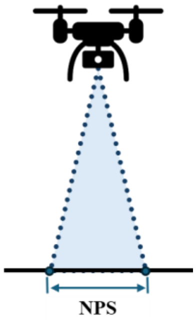


Figure 6. Visualization of Nominal Pulse Spacing computation.

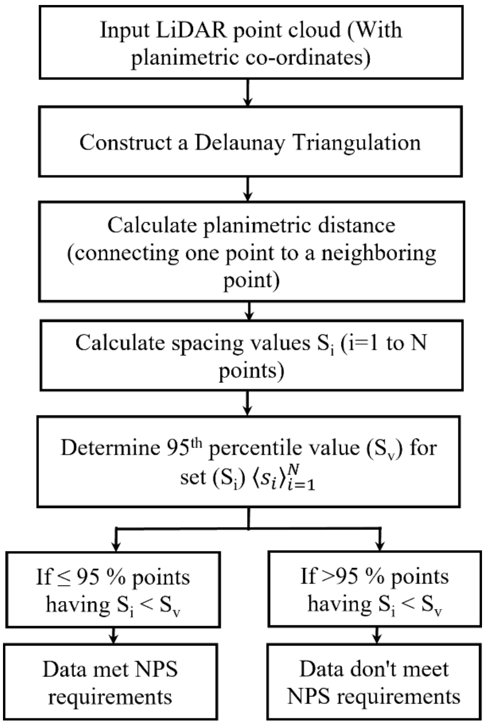


Figure 7. Flowchart of Nominal Pulse Spacing methodology to check internal consistency of Airborne LiDAR data.

These are statistically filtered to calculate the 95th percentile, which is then compared against predefined spacing thresholds to validate whether the dataset satisfies NPS requirements. This method ensures that the points are spread evenly and closely across the survey area, which is important for checking the quality of LiDAR data.

### 3.4.2 Nominal Pulse Density (NPD)

NPD is defined as the average number of LiDAR pulses (or points) per unit area as shown in figure 8, typically expressed in points per square meter (points/m²), representing how densely the laser pulses cover the ground. To estimate local point density, a Voronoï diagram is created using the (X, Y) coordinates of all LiDAR points.

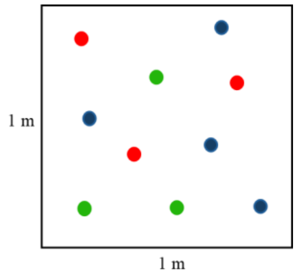


Figure 8. Figure showing Nominal pulse density in LiDAR dataset.

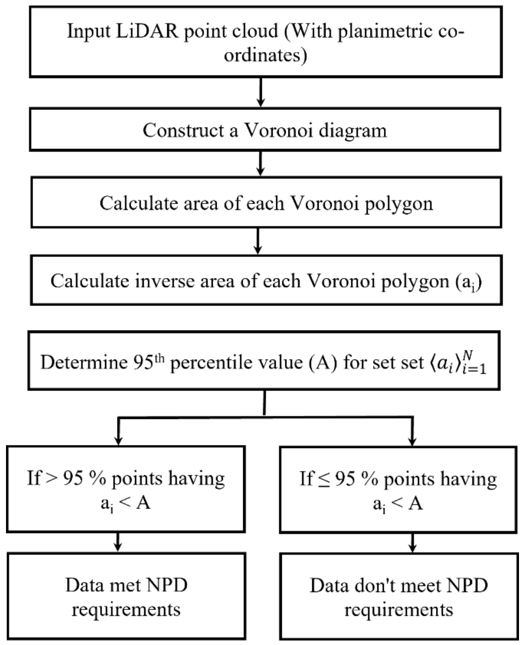


Figure 9. Flowchart showing Nominal Pulse Density methodology to check internal consistency of Airborne LiDAR data.

Each polygon in the diagram represents the area closest to a specific point. The area of each polygon is calculated, and its inverse is taken to determine the local point density. For a dataset with N points, the 95th percentile of these density values, denoted as A, is computed. If at least 95% of the points have densities equal to or greater than A, the dataset satisfies the NPD requirement as per proposed BIS guidelines (BIS, 2023).Figure 9, shows a step-by-step flowchart of this process. This method ensures the data has enough points that are evenly spaced, which helps create accurate elevation models and detect features, especially in areas with trees or complex terrain.

### 3.4.3 Overlap

Airborne LiDAR data is captured in overlapping swaths to ensure full surface coverage and data consistency (Figure 10). Overlap is verified by visually inspecting adjacent swaths in tools like LAStools or ArcGIS and measuring the shared width against the project's minimum overlap requirement (BIS, 2023).

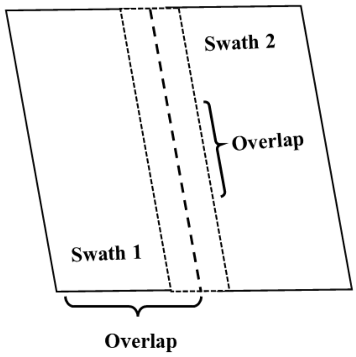


Figure 10. Figure showing overlap in airborne LiDAR dataset.

### 3.4.4 Data Voids

Data voids (Figure 11) are gaps in the LiDAR dataset where the area exceeds 4 × ANPS². They are found using mapping tools that measure their size, how often they occur, and where they are located. Data voids are then compared with land cover maps to explain causes such as water bodies or dense vegetation (BIS, 2023).

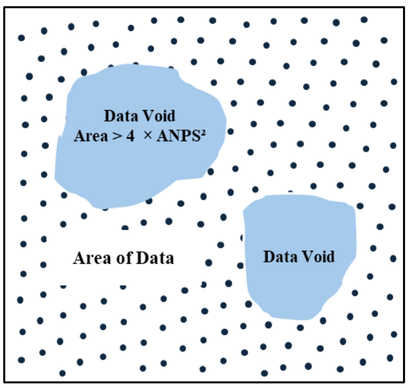


Figure 11. Figure showing data voids in airborne LiDAR dataset (source: USGS, 2025).

### 3.4.5 Spatial Distribution

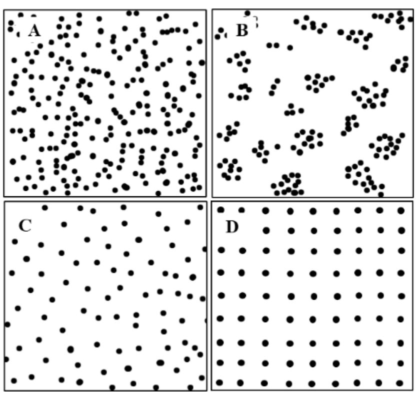


Figure 12. Figure showing spatial distribution of points in airborne LiDAR dataset A: Complete randomness, B: clustered, C: weak random/semi-regular D: uniform distribution (source: USGS, 2025).

Spatial distribution (Figure 12) is assessed by overlaying a regular grid (cell size = 2 × ANPS) on a single swath's central area and checking that at least 90% of the cells contain one or more first-return points. Known valid voids are excluded to confirm even point coverage (BIS, 2023).

### 3.4.6 Reporting of Accuracy

This section outlines how both the data user and the data producer should formally report the positional accuracy of LiDAR products, including horizontal, vertical, and three-dimensional accuracy. Each accuracy type must be reported in accordance with its appropriate classification, based on established standards and project requirements.
All accuracies (Vertical accuracy, Horizontal accuracy, three-dimensional accuracy) are reported in a specified format as given below (Abdullah, 2023). For example: Horizontal accuracy -

"This dataset was evaluated according to [Name of the published guidelines and year]. It was tested under the __ (cm) $RMSE_H$ Horizontal Positional Accuracy Class, as defined in the standard/guideline. Based on the results, the measured horizontal positional accuracy was found to be $RMSE_H$ = __ (cm)."

## 4. Conclusion

This study provides a clear and well-structured method for checking the quality of airborne LiDAR data, specifically designed to suit India's varied geography and climate. By using precise ground survey tools like RTK GNSS and total stations, along with simple statistics like RMSE, this guideline helps to check how accurate the data is both overall and within the dataset itself. It also includes important checks like NPS, NPD, swath overlap, and how evenly the points are spread across the area.The suggested way of selecting test sites and checkpoints ensures that diverse land cover types are adequately represented. Interpolation methods are used when airborne LiDAR data points do not exactly match with the ground checkpoints. This framework follows well-known international standards like those by ASPRS, while also addressing the unique challenges found in Indian conditions. The guidelines mandate evenly distributed test sites with explicit coverage of varied Indian land cover types (e.g., wetlands, high-altitude terrain, dense vegetation), ensuring a more representative accuracy assessment than generic site selection rules. The recommended checkpoint counts are scaled to the project area and adjusted for vegetated vertical accuracy (VVA), addressing error patterns more prevalent in Indian forested and agricultural zones. The proposed method specifies terrain-based interpolation, using TIN, IDW, or Kriging based on land cover and slope to reduce elevation estimation errors in complex environments. The guidelines require not only nominal pulse spacing (NPS) and nominal pulse density (NPD) checks, but also swath overlap verification, spatial distribution uniformity, and explicit data void thresholds. Overall, this study addresses an important gap in checking the quality of airborne LiDAR data in India. It offers practical and standardized guidelines that can be useful for government departments, private survey companies, and researchers. By following these recommendations, the concerned stakeholders can improve the reliability of their airborne LiDAR data, avoid costly errors or rework, and build more trust in LiDAR-specific geospatial applications across the country.

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**References**

Abdullah, Q. (2023). The ASPRS Positional Accuracy Standards, Edition 2: The Geospatial Mapping Industry Guide to Best Practices. *Photogrammetric Engineering and Remote Sensing*, *89*(10), 581–588. https://doi.org/10.14358/PERS.89.10.581.

Ahokas, E., Kaartinen, H., & Hyyppä, J. (2003). A quality assessment of airborne laser scanner data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV(3/W13), 1–6. Available at: https://www.researchgate.net/publication/313721004_A_quality_assessment_of_airborne_laser_scanner_data

Bureau of Indian Standards. (2023*). Airborne LiDAR data acquisition – Part 1: Requirements (Draft Indian Standard, Doc No. LITD 22 (23096) P Draft V01, Aug 2023)*. Bureau of Indian Standards.

Elaksher, A., Ali, T., & Alharthy, A. (2023). A Quantitative Assessment of LIDAR Data Accuracy. *Remote Sensing*, *15*(2). https://doi.org/10.3390/rs15020442.

Fu, L., Shu, Q., Yang, Z., Xia, C., Zhang, X., Zhang, Y., Li, Z., & Li, S. (2025). Accuracy assessment of topography and forest canopy height in complex terrain conditions of Southern China using ICESat-2 and GEDI data. *Frontiers in Plant Science*, *16*. https://doi.org/10.3389/fpls.2025.1547688.

Habib, A., & Rens, J. Van. (2008). *Quality Assurance and Quality Control of LiDAR Systems and Derived Data*.

Jin, Q., Hu, Q., Duan, X., Zhao, P., Li, Z., Li, J., & Mao, Q. (2025). Airborne laser scanning data quality enhancement via rigorous calibration and comprehensive strip adjustment techniques. *Geo-Spatial Information Science*. https://doi.org/10.1080/10095020.2025.2514174.

Liu, X. (2022). A new framework for accuracy assessment of LiDAR-derived digital elevation models. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *5*(4), 67–73. https://doi.org/10.5194/isprs-Annals-V-4-2022-67-2022.

Liu, X., & Zhang, Z**.** (2008). LiDAR data reduction for efficient and high quality DEM generation. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVII(B3b), 275–280.

Lohani, B., & Ghosh, S. (2017). Airborne LiDAR Technology: A Review of Data Collection and Processing Systems. In *Proceedings of the National Academy of Sciences India Section A - Physical Sciences* (Vol. 87, Issue 4, pp. 567–579). Springer India. https://doi.org/10.1007/s40010-017-0435-9.

Liu, X. (2011). Accuracy assessment of LiDAR elevation data using survey marks. *Survey Review, 43*(323), 80–91. https://doi.org/10.1179/003962611X12894696204704