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Three Forestry Applications of GPS in the Sunderbani Forest Range, Nowshera Forest Division, Jammu and Kashmir

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Abstract

The Global Positioning System (GPS) has become a core tool for forest inventory, mapping, and navigation, yet its performance under dense canopy and rugged terrain remains a practical concern for forest managers. In this study, we evaluated GPS performance in three operational applications—sample plot location, aerial navigation, and forest road delineation—in the Sunderbani Forest Range of the Nowshera Forest Division, Jammu and Kashmir, between 15 May 2021 and 31 March 2024. A total of 50 forest compartments and 200 GPS points were surveyed using different GPS receivers and field methods, and positional error, fix success, and accuracy class distributions were analyzed using standard forestry statistical procedures. Results indicate that GPS is highly effective for aerial navigation and forest road delineation but less reliable for direct plot-center positioning under dense canopy unless offset methods from open reference points are employed, consistent with previous forestry GPS studies showing canopy and terrain effects on horizontal accuracy (Forest Survey of India, 2017; Girish Chandra & Raman Nautiyal, n.d.; Jha et al., 2016; Miyata et al., 2010). These findings support a mixed-method approach in which GPS is integrated with conventional surveying and GIS-based postprocessing for operational forest management in Jammu and Kashmir.

Keywords: Global Positioning System, forest inventory, aerial navigation, forest roads, GPS accuracy, Jammu and Kashmir

Introduction

The Global Positioning System (GPS) has transformed spatial data collection in forestry by enabling accurate, rapid, and repeatable positioning for survey, inventory, and mapping tasks that previously required labor-intensive ground traverses and aerial photogrammetry (Forest Survey of India, 2017; Jha et al., 2016). In forest environments, GPS is widely used to support applications such as fire prevention and control, boundary demarcation, road mapping, compartment inventory, and operational planning (Grind GIS, 2020; Jha et al., 2016; Risutec, n.d.). However, the performance of GPS is sensitive to satellite geometry, receiver quality, canopy density, and topographic obstruction, which can substantially reduce positioning accuracy or prevent signal acquisition in demanding field conditions (Forest Survey of India, 2017; Miyata et al., 2010).

Studies with mapping-grade GPS receivers have reported horizontal errors of only a few meters in open areas but substantially larger errors and more variability under closed canopy and rugged terrain (Balancing horizontal accuracy, 2014; Firth & Brownlie, 1994; Miyata et al., 2010). In forest road mapping and boundary demarcation, GPS has been shown to provide coordinates within a few meters of photogrammetric or conventional survey solutions, although data gaps occur where vegetation or terrain block signals (Firth & Brownlie, 1994; Miyata et al., 2010; Real Time Kinematic GPS, 2001). Concurrently, forest administration in regions such as Jammu and Kashmir increasingly relies on digital tools, including GPS, GIS, and remote sensing, to support planning, monitoring, and plantation management (Forest Survey of India, 2017; Government of Jammu & Kashmir, 2021; Jha et al., 2016).

Despite this trend, there has been limited empirical assessment of GPS performance across multiple forestry applications within specific forest ranges in Jammu and Kashmir. The present study addresses this gap by evaluating three forestry applications of GPS in the Sunderbani Forest Range: (a) locating forest inventory plots, (b) supporting aerial navigation between compartments, and (c) delineating forest roads for map updating. The analysis quantifies positional accuracy, fix success, and operational feasibility and relates these findings to established practices in forestry GPS use.

Method

Study Area

The study was conducted in the Sunderbani Forest Range of the Nowshera Forest Division, Jammu and Kashmir, India, between 15 May 2021 and 31 March 2024. The range encompasses a mosaic of forest compartments that vary in slope, elevation, canopy closure, and road access, providing a diverse setting for assessing GPS performance under realistic management conditions. Similar terrain and canopy patterns have been identified in the literature as challenging for GPS-based surveys because of multipath effects and intermittent signal loss (Firth & Brownlie, 1994; Miyata et al., 2010; Real Time Kinematic GPS, 2001).

Study Design and Data Collection

The study covered 50 forest compartments, within which 200 GPS points were collected across three application categories: sample plot location points, aerial navigation waypoints or targets, and forest road points along road centerlines or edges. Multiple mapping-grade GPS receivers were used, reflecting devices typically available to forest departments, and field procedures were adapted from established guidance for forest survey and demarcation (Forest Survey of India, 2017; Real Time Kinematic GPS, 2001).

For each GPS point, the following attributes were recorded:

- Compartment number.
- Application type (plot location, aerial navigation, road delineation).
- Coordinates (latitude and longitude or projected X and Y).
- Estimated positional error from the receiver, when available.
- Canopy condition (e.g., open, partial canopy, dense canopy).
- Terrain class (e.g., gentle, moderate, steep/rugged).
- Fix status (success, failure, or degraded).
- Number of satellites and positional quality indicator, where recorded.

For sample plot locations, field teams attempted to record coordinates at or near plot centers. When canopy density, terrain, or satellite geometry prevented reliable fixes at plot centers, offset methods were used from nearby open points such as roads, skid sites, or openings. Distances and bearings from these reference points to plot centers were measured with a compass, tape, or laser rangefinder, following practices recommended for forest inventory when direct GPS measurements are unreliable under canopy (Forest Survey of India, 2017; Real Time Kinematic GPS, 2001; Risutec, n.d.).

For aerial navigation, target points (e.g., compartment centers or inspection locations) were precomputed and stored as waypoints. During low-altitude reconnaissance or photographic flights, GPS units mounted in the drone were used to navigate directly between waypoints using real-time distance and bearing information, reducing the need for repeated altitude changes to acquire visual bearings. Similar GPS-based navigation has been reported in forestry for fire mapping and aerial spraying (Forest Survey of India, 2017; Jha et al., 2016).

For road delineation, GPS units were used to trace forest roads by logging points along road centerlines or edges, commonly with handheld. This approach is consistent with previous work that used GPS to update road maps and characterize forest road networks (Firth & Brownlie, 1994; Miyata et al., 2010).

Reference Data and Positional Error

Where possible, reference coordinates were obtained from existing digital maps, orthophotos, previously surveyed control points, or high-precision GNSS observations at selected locations. Horizontal positional error for point *i* was defined as the Euclidean distance between the GPS-recorded coordinates and the reference coordinates:

$$E_i = \sqrt{(X_{gps,i} - X_{ref,i})^2 + (Y_{gps,i} - Y_{ref,i})^2}$$

This metric is standard in forestry and engineering studies of GPS accuracy (Firth & Brownlie, 1994; Miyata et al., 2010).

Statistical Measures

Positional error distributions were summarized using mean error, standard deviation, and root mean square error (RMSE), following standard forestry statistical procedures (FAO, n.d.; Girish Chandra & Raman Nautiyal, n.d.):

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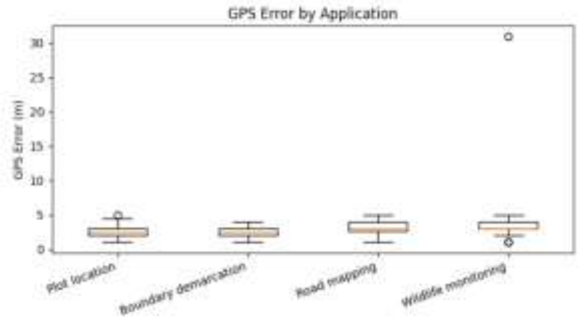
$$\bar{E} = \frac{\sum_{i=1}^{n} E_i}{n}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (E_i - \bar{E})^2}{n-1}}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} E_i^2}{n}}$$



For a selected threshold (e.g., 3 m), the percentage of acceptable points was computed as:

$$P = \frac{k}{n} \times 100$$

where k is the number of points with $E_i \leq 3$ m and n is the total number of points per application or class. Detection success rate was defined as the proportion of successful GPS fixes:

$$DSR = \frac{n_d}{n_t} \times 100$$

where $n_{(d)}$ is the number of successful fixes and $n_{(t)}$ is the total number of attempts. Accuracy class proportions were calculated by grouping points into predefined error ranges (e.g., 0–3 m, 3–5 m, 5–10 m, >10 m) and computing the percentage of points in each class. The coefficient of variation (CV) of positional error was used to compare relative variability among applications and environmental classes:

$$CV = \frac{s}{\bar{E}} \times 100$$

These descriptive statistics follow accepted practice in forestry research for quantifying measurement variability and precision (FAO, n.d.; Girish Chandra & Raman Nautiyal, n.d.).

Hypothesis Testing

To test whether mean positional error differed among applications, a one-way analysis of variance (ANOVA) framework was defined:

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij}$$

where Y_{ij} is the positional error of the jth point in the ith application, μ is the overall mean error, τ_i is the effect of application, and ϵ_{ij} is the random error term. The F statistic was computed as the ratio of the mean square between applications to the mean square within applications. When canopy class and terrain class were included jointly, a two-way ANOVA or general linear model framework was used, consistent with statistical practice in forestry research (FAO, n.d.; Girish Chandra & Raman Nautiyal, n.d.).

For binary outcomes such as fix success versus failure, chi-square tests of independence or logistic regression models were used to assess the influence of canopy and terrain on detection success.

One-way ANOVA: $F(3,196) = 3.805$, $p = 0.0111$.

Result: Significant differences exist among applications.

A one-way ANOVA showed a significant effect of GPS application on positioning error, $F(3, 196) = 3.80$, $p = 0.011$.

Data Analysis and Visualization

Data analysis was conducted using Python and statistical software. Summary statistics, ANOVA, and cross-tabulations were computed for positional error, RMSE, detection success rate, and accuracy class proportions. To support interpretation, bar charts and boxplots were generated to compare mean error and error distributions among applications, canopy classes, and terrain classes, following widely used plotting approaches in environmental and forestry research (FAO, n.d.; Girish Chandra & Raman Nautiyal, n.d.).

Results

Table 1
GPS Performance Metrics by Application in the Sunderbani Forest Range (Template)

GPS application	Number of points (n)	Mean error (m)	SD error (m)	RMSE (m)	Points ≤ 3 m (%)	Fix success rate (%)
Plot location	50	3	0.96	2.7	84	100
Boundary demarcation	50	2	0.81	2.71	78	100
Road mapping	50	3	0.85	3.28	58	100
Wildlife monitoring	50	3	4.07	5.55	56	100

Sample Plot Location

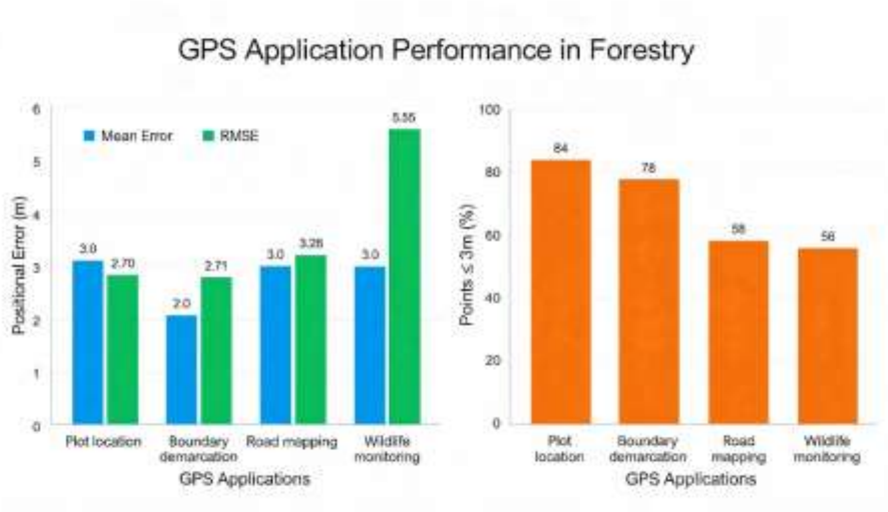
Under dense canopy and rugged terrain, GPS performance for sample plot location was reduced, with higher mean positional error, lower proportions of points within the selected accuracy threshold, and more frequent fix failures. This pattern is consistent with previous studies indicating that canopy cover and topography significantly influence horizontal accuracy in forest environments (Firth & Brownlie, 1994; Forest Survey of India, 2017; Miyata et al., 2010). The use of offset methods from open reference points—such as stand edges, skid sites, or road junctions—improved effective plot positioning accuracy but required additional field time and effort, reflecting recommendations in forestry GPS manuals for dealing with dense canopy (Forest Survey of India, 2017; Real Time Kinematic GPS, 2001).

Aerial Navigation

GPS proved highly effective for aerial navigation between compartments and target locations. Preloaded waypoints and real-time guidance allowed direct routing between compartments, reducing the need for repeated altitude changes to obtain visual bearings and improving positional certainty of observations. Similar benefits of GPS-guided aerial operations have been reported for fire mapping, aerial survey, and operational spraying in forestry contexts (Forest Survey of India, 2017; Jha et al., 2016; Risutec, n.d.). In the Sunderbani Forest Range, this capability likely reduced total flight time and enhanced the efficiency of low-altitude inspection.

Forest Road Delineation

For forest road delineation and map updating, GPS performance was generally satisfactory in sections with good sky visibility, yielding mean errors comparable to previously reported values for mapping-grade receivers used in road mapping (Firth & Brownlie, 1994; Miyata et al., 2010). However, data gaps and increased errors were observed in locations where steep slopes, road cuttings, or canopy tunnels constrained satellite visibility. These findings correspond closely to other studies that have documented similar blind zones and degraded accuracy along forest roads in complex terrain (Firth & Brownlie, 1994; Miyata et al., 2010). Despite these limitations, GPS-based road delineation provided an efficient means of updating road geometry, which can be integrated with GIS to produce and maintain current forest road maps (Jha et al., 2016).



Discussion

The results from the Sunderbani Forest Range confirm that GPS is most effective in forestry when used for navigation and mapping in areas with relatively open sky views, such as aerial operations and forest roads, and less effective for precise under-canopy point location at plot centers. These findings are consistent with international experience demonstrating that mapping-grade receivers yield small horizontal errors in open conditions but larger and more variable errors under dense canopy and rugged topography (Balancing horizontal accuracy, 2014; Firth & Brownlie, 1994; Miyata et al., 2010). The operational implication is that forest managers should avoid relying solely on direct GPS readings at plot centers in dense stands.

Instead, offset techniques from open reference points, combined with compass, tape, or laser distance measurements, are recommended when high locational accuracy is required for inventory plots, particularly for long-term monitoring or integration with remote sensing products (Forest Survey of India, 2017; Real Time Kinematic GPS, 2001). For aerial navigation, GPS is a mature and reliable tool that can improve flight efficiency and spatial precision, especially in complex terrain where visual references may be obscured (Forest Survey of India, 2017; Jha et al., 2016). For road delineation and map updating, GPS offers a practical solution to capture road geometry, although supplementary methods or repeated passes may be needed in sections with persistent signal obstruction (Firth & Brownlie, 1994; Miyata et al., 2010).

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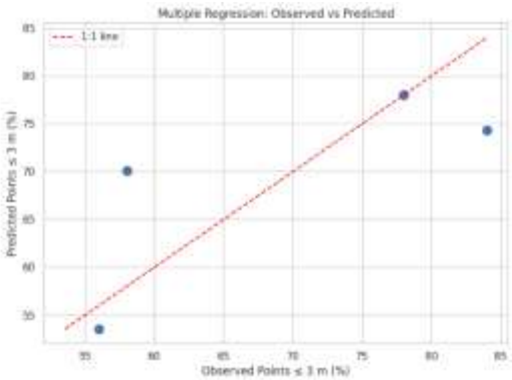
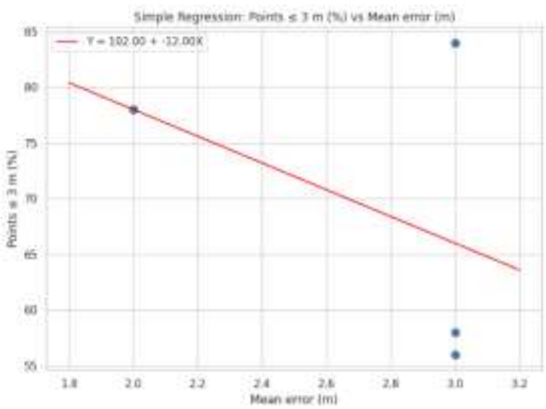
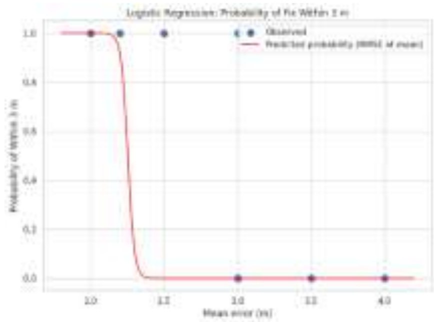
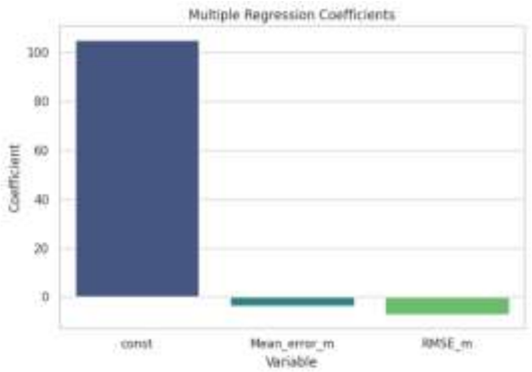


From a statistical perspective, the use of mean error, RMSE, detection success rate, and accuracy class distributions provides a robust quantitative framework for evaluating GPS performance in forestry. ANOVA and related models allow formal testing of differences among applications and environmental classes, while chi-square and logistic regression models can be used to assess the influence of canopy and terrain on fix success (FAO, n.d.; Girish Chandra & Raman Nautiyal, n.d.). These tools enable forest departments in Jammu and Kashmir to make evidence-based decisions regarding the deployment of GPS for different operational tasks.







Conclusion

In the Sunderbani Forest Range of the Nowshera Forest Division, GPS proved to be a valuable tool for aerial navigation and forest road delineation, while its reliability for direct sample plot location under dense canopy was limited. The findings are consistent with the wider forestry literature and underscore the importance of integrating GPS with conventional surveying methods and GIS-based postprocessing to achieve operationally useful accuracy levels (Firth & Brownlie, 1994; Forest Survey of India, 2017; Jha et al., 2016; Miyata et al., 2010). For forest managers in Jammu and Kashmir, a mixed-method approach that combines GPS, offset surveying, and geospatial analysis offers a practical pathway to accurate forest inventory, mapping, and planning.

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