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Article

Evaluation of Horizontal Geometric Accuracy and Area Differences of the Indonesian Topographic Base Map (RBI) Using GNSS RTK Measurements

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Abstract. Accurate geospatial information is essential for land management and village-level spatial planning; however, medium-scale maps are often used in areas where large-scale geospatial data are unavailable. This study evaluates the horizontal geometric accuracy and area representation of the 1:50,000 Indonesian Topographic Base Map (RBI) using Global Navigation Satellite System Real-Time Kinematic (GNSS RTK) measurements as reference data. The study was conducted within a 29.937 ha area in Raden Village, Tanah Laut Regency, South Kalimantan Province, Indonesia. Horizontal accuracy assessment was performed using 12 boundary vertices identified from corresponding features in both the RBI map and field observations. Positional differences were quantified using the Root Mean Square Error (RMSE) and Circular Error at the 90% confidence level (CE90), while area differences were evaluated by comparing RBI-derived and GNSS RTK-derived boundaries. The results indicate RMSEx and RMSEy values of 11.638 m and 21.766 m, respectively, resulting in a CE90 value of 44.848 m. Although the evaluated RBI map satisfies the horizontal accuracy requirement for a Class 3 map according to BIG Regulation No. 6 of 2018, the CE90 value is close to the maximum allowable threshold of 45 m. In addition, the RBI-derived area underestimated the GNSS RTK-derived area by 9,332 m² (0.933 ha) or 3.12%. These findings suggest that 1:50,000 RBI maps are suitable for preliminary planning and general spatial analysis but are not recommended for detailed parcel delineation or applications requiring high positional accuracy.

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1. Introduction

Accurate spatial information is essential for land-use planning, boundary delineation, and area estimation because positional errors may directly affect technical decisions, budgeting, resource allocation, and project implementation outcomes. Reliable geospatial data are particularly important in rural areas, where spatial information supports land management, infrastructure development, and local planning processes [1-2]. In Indonesia, the increasing demand for evidence-based spatial planning has further emphasized the need for accurate and accessible geospatial datasets to support regional development and village-level decision-making [3]. However, in many rural regions, detailed large-scale spatial data are often unavailable or have not been updated regularly, resulting in the continued use of existing topographic datasets for local planning purposes.

The Indonesian Topographic Base Map (Rupa Bumi Indonesia/RBI) at a scale of 1:50.000 is one of the most widely used reference maps because it provides nationwide coverage and fundamental topographic information, including transportation networks, hydrological features, administrative boundaries, and land-cover elements. Nevertheless, because RBI maps are produced at a medium scale, they are subject to cartographic generalization, which may simplify feature geometry and introduce positional deviations between mapped features and actual field conditions [4–6]. Consequently, the reliability of RBI maps for village-scale land parcel analysis and area estimation requires careful evaluation rather than being assumed to be accurate by default.

Despite the limitations associated with medium-scale mapping, RBI maps at a scale of 1:50.000 continue to be widely used for preliminary land management, spatial planning, and infrastructure screening because they are readily accessible and provide consistent coverage across Indonesia. In contrast, large-scale maps (e.g., 1:1.000 or 1:5.000), which are more suitable for cadastral surveys and detailed parcel delineation, are often unavailable, outdated, or costly to acquire in many rural areas. This practical condition raises an important methodological question regarding the extent to which medium-scale RBI maps can provide reliable geometric information when applied to village-level analyses. The present study addresses this issue by evaluating a study area of approximately 29.937 ha, representing a common rural land management context in which readily available RBI data are frequently used to support preliminary planning decisions.

Although the study area is relatively small compared with the map scale, this characteristic provides an opportunity to examine the effects of cartographic generalization and scale-dependent representation on boundary delineation and area estimation. Previous studies have shown that spatial accuracy and analytical outcomes are strongly influenced by map scale, positional uncertainty, and the Modifiable Areal Unit Problem [7]. In addition, inconsistencies in boundary representation and digitization processes may introduce geometric discrepancies that affect area calculations and decision-making processes [8-9]. Recent research has also demonstrated that the accuracy of source maps directly influences the reliability of area estimation derived from spatial datasets [10]. Therefore, evaluating the performance of a 1:50,000 RBI map within a small study area is necessary to determine its suitability and limitations for village-level land planning applications.

Building upon the need to evaluate the suitability of medium-scale RBI maps for village-level applications, high-precision reference data are required to quantify the effects of cartographic generalization on boundary delineation and area estimation. Previous studies have demonstrated that GNSS RTK provides reliable centimeter-level positioning accuracy for geospatial assessments and serves as an effective reference for evaluating the quality of spatial datasets [11-12]. At the same time, recent studies in Indonesia have highlighted the increasing importance of accurate and accessible geospatial information for supporting detailed spatial planning, rural development, and land-use management [3],[13].

However, the reliability of spatial analyses depends strongly on the positional accuracy of the underlying geospatial data, particularly when medium-scale mapping products are applied to local planning contexts. Previous research has shown that map scale, positional uncertainty, and boundary representation can substantially influence spatial analysis outcomes and area estimation [7-8]],[10]. Although several studies in Indonesia have evaluated the accuracy of geospatial datasets for specific applications, such as digital elevation models and land-cover mapping [14-15], empirical studies directly assessing the geometric accuracy of RBI-derived boundaries using high-precision GNSS RTK measurements remain limited.

This research gap is particularly relevant because village-level planning activities frequently rely on readily available RBI maps despite their original purpose as medium-scale topographic products. Therefore, this study aims to evaluate the horizontal geometric accuracy of the 1:50,000 RBI map using GNSS RTK measurements as reference data and to quantify the area differences between RBI-derived digitized boundaries and field-measured boundaries within a 29.937 ha study area in Raden Village, Tanah Laut Regency, South Kalimantan Province, Indonesia. The selected study area represents a typical rural planning context where detailed large-scale mapping products are unavailable and medium-scale RBI maps continue to support preliminary land management decisions. The location of the study area is presented in Figure 1.

Figure 1. Study Area Location

Therefore, this study aims to evaluate the horizontal geometric accuracy of the RBI map at a scale of 1:50.000 using GNSS RTK measurements as reference data and to quantify the area differences between RBI-derived digitized boundaries and field-measured boundaries. The findings are expected to provide insights into the suitability of RBI maps for preliminary land-planning applications and contribute to the assessment of geospatial data quality in Indonesia.

2. Experimental Section

This study was conducted in Raden Village, Tanah Laut Regency, South Kalimantan Province, Indonesia, within RBI map sheet 1712-23, covering an area of approximately 29,937 ha. The study area represents a typical rural setting where medium-scale RBI maps are commonly used for preliminary land management and spatial planning due to the limited availability of updated large-scale geospatial data. The location of the study area is presented in Figure 1, while the spatial distribution of the boundary vertices used for geometric accuracy assessment is shown in Figure 2.

The datasets used in this study consisted of: (1) the Indonesian Topographic Base Map (RBI) at a scale of 1:50.000 for sheet 1712-23; (2) land-boundary coordinates obtained through GNSS RTK measurements; (3) coordinates of corresponding boundary vertices derived from RBI map digitization; and (4) control-point coordinates obtained from static GNSS observations. The equipment used included a CHCNAV X5 GNSS receiver set, a CHCNAV i50 GNSS receiver, tripods, pole sticks, measuring tapes, and a laptop computer. Data processing and analysis were performed using CHC Geomatics Office (CGO), Trimble Business Center (TBC), AutoCAD Civil 3D 2014, ArcGIS 10.3, Microsoft Excel, and Microsoft Word.

The research procedure began with a preliminary survey, literature review, and survey planning. Four control points (CP1–CP4) were established around the study area to support GNSS RTK observations and minimize the distance between the base station and rover. Static GNSS observations were conducted to determine precise coordinates for the control points. The first observation was performed at CP1 for six hours and connected to three Continuously Operating Reference Stations (CORS), namely CAPI, CBRK, and CTLT/TALA. Subsequently, a second static survey was conducted among CP2–CP4 using CP1 as the reference station with a one-hour observation period. The observation duration and network configuration followed the Indonesian National Standard for Horizontal Control Networks (SNI 19-6724-2002). The collected GNSS data were converted from HCN format to RINEX format using CHC Geomatics Office and processed in Trimble Business Center to obtain the final coordinates of the four control points, which were subsequently used as reference coordinates during GNSS RTK measurements. The use of GNSS RTK as a reference method is consistent with previous studies demonstrating its capability to provide centimeter-level positioning accuracy for geospatial applications [11-12].

GNSS RTK measurements were then conducted to collect land-boundary coordinates. The measured boundary vertices were exported from the field controller in comma-separated values (CSV) format and processed in AutoCAD Civil 3D to generate the reference land-boundary polygon. Twelve boundary vertices (TB1–TB12), representing changes in boundary direction and intersections with identifiable topographic features, were selected for geometric accuracy assessment. The selected vertices corresponded to field features that could be consistently recognized both in the RBI map and during field observations, including road edges, irrigation channels, embankments, and intersections between these features.

Although the National Standard for Spatial Data Accuracy (NSSDA), ASPRS Positional Accuracy Standards, and Regulation of the Geospatial Information Agency (BIG) No. 6 of 2018 generally recommend a minimum of 20 independent check points for formal horizontal accuracy assessment, the present study used 12 boundary vertices due to the limited extent of the study area and the absence of additional permanent features that could be unambiguously identified on the 1:50.000 RBI map [4].

Therefore, the results should be interpreted as a localized evaluation of boundary representation accuracy within the selected study area rather than as a comprehensive assessment of the positional accuracy of the entire RBI map sheet.To reduce spatial bias, the 12 boundary vertices were distributed across the entire perimeter of the study area and represented the northern, southern, eastern, western, and central sections of the land parcel, as illustrated in Figure 2.

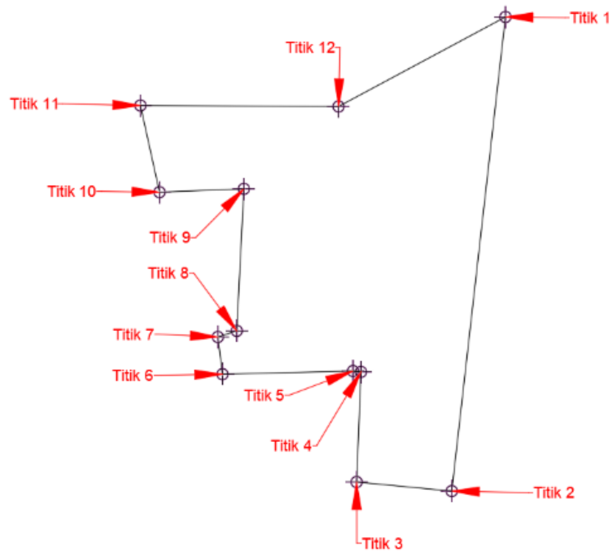

Figure 2. Spatial distribution of the 12 boundary vertices used for geometric accuracy assessment

Because individual land parcel boundaries are not explicitly represented on the 1:50.000 RBI map, boundary digitization was performed using a heads-up digitizing approach based on identifiable topographic features that coincided with the actual field boundaries. These features included road edges, irrigation channels, drainage networks, and embankments. Prior to digitization, the RBI map was georeferenced in ArcGIS 10.3 using the Indonesian Datum 1974 (ID-74) coordinate reference system based on the coordinate information provided on the map sheet. Boundary vertices were subsequently generated by identifying intersections and directional changes in validated topographic features corresponding to field-observed boundary configurations. Only boundary segments that could be consistently identified in both datasets were included in the analysis to minimize uncertainty caused by cartographic generalization and improve the reproducibility of the digitization process.

The horizontal geometric accuracy of the RBI map was evaluated by comparing the coordinates of the 12 corresponding boundary vertices derived from RBI digitization and GNSS RTK measurements. Positional differences in the x- and y-directions were calculated to determine the Root Mean Square Error (RMSE) according to Equation 1.

$$\mathrm{RMSE}_r = \sqrt{\mathrm{RMSE}_x^{\,2} + \mathrm{RMSE}_y^{\,2}}$$

The Circular Error at the 90% confidence level (CE90) was subsequently calculated according to Regulation of the Geospatial Information Agency (BIG) No. 6 of 2018 using Equation 2.

$$\mathrm{CE90} = 1{,}5175 \times \mathrm{RMSE}_r$$

The resulting CE90 value was compared with the horizontal accuracy thresholds established for RBI maps at a scale of 1:50.000. In addition, the area derived from RBI-based digitization was compared with the area obtained from GNSS RTK measurements using a coordinate-based numerical method to quantify area differences and evaluate the suitability of the RBI map for preliminary land-planning applications.

3. Results and Discussion

Static GNSS observations were conducted to establish four control points (CP1–CP4) that served as reference points during RTK measurements. The observations were performed using a network-based approach in accordance with SNI 19-6724-2002. The first observation connected CP1 to three Continuously Operating Reference Stations (CORS), namely CAPI, CBRK, and CTLT/TALA, while the second observation connected CP2–CP4 to CP1. The processing results showed fixed solutions for all baselines and successfully passed the 95% Chi-Square test, indicating that the observation quality met the required standards for further analysis. In addition, the obtained PDOP values were below the maximum threshold specified in the Indonesian standard, demonstrating acceptable satellite geometry during data acquisition.

Prior to digitization, the RBI map was georeferenced using four coordinate reference points located at the corners of the map sheet. Since the RBI map uses the Indonesian Datum 1974 (ID-74), the georeferencing process was performed within the corresponding geographic coordinate system in ArcGIS. The resulting RMS error was 0.0000000587069°, which is substantially lower than the maximum allowable georeferencing error of 0.00005° for a 1:50,000 map. This result indicates that the RBI map was accurately registered and suitable for subsequent spatial analysis and digitization.

3.1 Horizontal Geometric Accuracy Assessment

The horizontal geometric accuracy of the RBI map was evaluated by comparing the coordinates of 12 boundary points derived from RBI-based digitization with the corresponding coordinates obtained from GNSS RTK measurements. The analysis followed the geometric accuracy standard specified in the Regulation of the Indonesian Geospatial Information Agency (BIG) No. 6 of 2018 using the Circular Error at the 90% confidence level (CE90).

Table 1. Coordinate differences between GNSS RTK measurements and RBI-derived boundary vertices

Vertex	XGNSS (m)	YGNSS (m)	XRBI (m)	YRBI (m)	ΔX (m)	ΔY (m)	ΔX^2 (m^2)	ΔY^2 (m^2)	Horizontal Error (m)
TB1	237191.167	9589963.695	237173.793	9589928.968	17.3740	34.7269	301.8559	1205.9576	38.8360
TB2	237093.528	9589103.024	237076.154	9589068.297	17.3740	34.7269	301.8559	1205.9576	38.8360
TB3	236920.652	9589119.483	236904.158	9589087.809	16.4936	31.6738	272.0388	1003.2296	35.7109
TB4	236928.638	9589319.387	236911.264	9589284.660	17.3740	34.7269	301.8559	1205.9576	38.8360
TB5	236914.108	9589320.956	236896.734	9589286.229	17.3740	34.7269	301.8559	1205.9576	38.8360
TB6	236676.975	9589315.189	236681.540	9589294.338	-4.5655	20.8015	20.8438	432.7024	21.2966
TB7	236668.589	9589382.769	236673.154	9589361.968	-4.5655	20.8015	20.8438	432.7024	21.2966
TB8	236702.868	9589393.911	236707.4345	9589373.110	-4.5655	20.8015	20.8438	432.7024	21.2966
TB9	236715.877	9589651.653	236720.4425	9589630.852	-4.5655	20.8015	20.8438	432.7024	21.2966
TB10	236562.512	9589645.652	236567.0775	9589624.851	-4.5655	20.8015	20.8438	432.7024	21.2966
TB11	236527.850	9589802.977	236532.4155	9589782.176	-4.5655	20.8015	20.8438	432.7024	21.2966
TB12	236887.897	9589801.187	236892.4625	9589780.386	-4.5655	20.8015	20.8438	432.7024	21.2966
Total							**1,265.3689**	**4,885.9788**	
RMSE X (m)								11.6382	
RMSE Y (m)								21.7661	
RMSE r (m)								24.6811	
CE90 (m)								44.8480	

Table 1 presents the coordinate differences between the 12 boundary vertices derived from RBI map digitization and those obtained from GNSS RTK measurements. The results indicate that positional discrepancies varied across the evaluated vertices, with horizontal errors ranging from 21.297 m to 38.836 m. The largest positional errors were observed at vertices TB1, TB2, TB4, and TB5, whereas the smallest errors occurred at vertices TB6 to TB12.

The calculated RMSEx and RMSEy values were 11.638 m and 21.766 m, respectively, resulting in a horizontal RMSE (RMSEr) of 29.551 m and a CE90 value of 44.848 m. According to Regulation of the Geospatial Information Agency (BIG) No. 6 of 2018, the maximum allowable CE90 value for a Class 3 RBI map at a scale of 1:50,000 is 45 m [4]. Therefore, the evaluated RBI map formally satisfies the minimum horizontal accuracy requirement for Class 3. However, the resulting CE90 value is only 0.152 m below the maximum permissible threshold, indicating that the map accuracy is at the lower limit of acceptable performance.

A notable finding is the substantial difference between positional errors in the x- and y-directions. The RMSEy value was approximately 87% greater than the RMSEx value, indicating a dominant positional shift in the north-south direction. This pattern suggests that positional errors in the evaluated RBI map were anisotropic rather than randomly distributed. Similar findings have been reported in studies demonstrating that map accuracy is strongly influenced by source data quality, georeferencing procedures, and cartographic representation at different scales [16-17]. Furthermore, Comber and Harris (2022) emphasized that spatial analyses conducted using datasets with mismatched scales are particularly susceptible to systematic bias and spatial uncertainty [7].

Several factors may explain the predominance of error along the y-axis. First, systematic distortions may have been introduced during the georeferencing process, particularly if the reference points used during map compilation were unevenly distributed or inadequately represented the spatial variability of the study area. Previous studies have demonstrated that the spatial configuration and distribution of control points significantly influence the magnitude and direction of positional errors in geospatial datasets [17-18]. Second, positional shifts inherited from the source imagery and topographic datasets used in RBI map production may become more apparent when medium-scale products are applied to relatively small study areas, where even modest displacements can substantially affect local analyses [7],[19].

Third, cartographic generalization processes, including feature simplification, displacement, and smoothing, may disproportionately affect linear features such as irrigation channels and embankments that predominantly extend along the north-south axis within the study area [5-6]. The representation of geographic features across different map scales inherently requires selective reduction of geometric complexity, which may alter feature orientation and positional relationships [16]. Consequently, directional biases may emerge when generalized features are used to represent detailed parcel boundaries. Similar findings have been reported in studies showing that positional uncertainty increases when medium-scale datasets are applied to small spatial units or decision-making contexts that require high geometric precision [8],[20].

Although the present study does not permit the dominant source of error to be identified conclusively, the observed directional bias indicates that the positional uncertainty associated with the RBI map is systematic rather than random. This finding suggests that the reliability of RBI-derived boundary information depends not only on compliance with formal accuracy standards but also on the compatibility between map scale, source data quality, and the intended application of the spatial dataset [10].

3.2 Area Difference Analysis

To evaluate the influence of map scale and cartographic generalization on area estimation, the land area derived from GNSS RTK measurements was compared with the area obtained from RBI map digitization. GNSS RTK measurements served as the reference dataset because of their high positional accuracy and their suitability for boundary delineation at the parcel level. The comparison was conducted to quantify the magnitude of area differences between the two datasets and to assess the reliability of the 1:50,000 RBI map when applied to a small study area. Differences in area estimates were expected because the RBI map represents land features through generalized geometries that may not fully capture local boundary complexity. The results of the area comparison are presented in Table 2.

Table 2. Comparison of land area derived from GNSS RTK measurements and RBI map digitization

Data Source	Area (m^2)	Area (ha)	Difference (m^2)	Difference (ha)	Difference (%)
GNSS RTK (reference)	299,370	29.937	–	–	–
RBI digitization	290,038	29.004	-9,332	-0.933	-3.12

Table 2 shows that the area derived from RBI map digitization was 290,038 m^2 (29.004 ha), which is 9,332 m^2 (0.933 ha) or 3.12% smaller than the area obtained from GNSS RTK measurements. Although this percentage difference appears modest, it represents a substantial discrepancy considering that the study area covers only 29.937 ha. The results indicate that applying medium-scale topographic data to small land parcels can introduce meaningful uncertainty in area estimation.

The observed area difference cannot be attributed solely to the nominal scale of the RBI map but is more directly associated with the effects of cartographic generalization on boundary representation. Because individual parcel boundaries are not explicitly depicted on the 1:50,000 RBI map, the digitization process relied on topographic features such as irrigation channels, road edges, drainage networks, and embankments that corresponded to field-observed boundaries. During map production, these features are commonly subjected to simplification, smoothing, and displacement processes to improve map readability at medium scales [5-6].

A comparison between the GNSS RTK-derived boundary and the RBI-derived boundary indicates that several irregular boundary segments and abrupt changes in direction were represented as straighter and less complex lines in the RBI map. This effect was particularly evident at vertices TB1, TB2, TB4, and TB5, which exhibited the largest positional discrepancies in Table 1. These vertices are located along boundary sections characterized by multiple directional changes and narrow linear features, making them more susceptible to geometric simplification. Consequently, peripheral sections of the parcel were effectively truncated, producing a smaller polygon area. Similar findings have been reported in studies demonstrating that spatial generalization modifies geometric characteristics, alters feature orientation, and reduces the level of detail represented in maps, particularly when medium-scale datasets are applied to local analyses [21–24].

The area underestimation identified in this study is also consistent with previous research showing that positional uncertainty and boundary simplification can substantially influence area estimates derived from spatial datasets. Area calculations based on generalized spatial representations are susceptible to systematic bias, particularly when applied to small spatial units [25]. Vectorization and feature extraction processes may introduce geometric discrepancies that propagate into area calculations [26]. The reliability of map-based inferences depends strongly on the quality and scale compatibility of the underlying geospatial data [27]. Uncertainty in cadastral parcel boundaries can significantly affect registered parcel areas and influence land-related decision-making processes [28].

Furthermore, coarser spatial resolutions may obscure local spatial variability and reduce the reliability of analyses conducted at finer scales [29].

The findings highlight important practical limitations in the use of 1:50,000 RBI maps for village-level land analysis. Although the evaluated map satisfies the minimum horizontal accuracy requirement for a Class 3 map, the observed reduction in area demonstrates that compliance with positional accuracy standards does not necessarily guarantee reliable representation of parcel geometry. Geospatial products designed for broad regional applications may produce substantial uncertainty when used for analyses involving small spatial units [30]. The adequacy of spatial datasets depends on their ability to represent real-world geographic variation at the intended scale of application [31]. Recent studies have also emphasized that accurate spatial delineation is essential for supporting the integration of land administration and spatial planning systems [32]. Therefore, RBI maps at a scale of 1:50,000 should be used cautiously for preliminary planning and general spatial analysis, whereas applications requiring precise area estimation and boundary delineation should rely on large-scale geospatial datasets and high-precision GNSS measurements.

4. Conclusion

This study evaluated the horizontal geometric accuracy and area representation of the 1:50,000 Indonesian Topographic Base Map (RBI) using GNSS RTK measurements as reference data within a 29.937 ha study area in Raden Village, Tanah Laut Regency, South Kalimantan Province. The results indicate that the evaluated RBI map achieved an RMSEx of 11.638 m, an RMSEy of 21.766 m, and a CE90 value of 44.848 m, which formally satisfies the horizontal accuracy requirement for a Class 3 RBI map according to Regulation of the Geospatial Information Agency (BIG) No. 6 of 2018. However, the CE90 value was only 0.152 m below the maximum allowable threshold, indicating that the positional accuracy of the map is at the lower limit of acceptable performance.

The results also revealed a pronounced directional bias, with the positional error in the y-direction exceeding that in the x-direction, suggesting the presence of systematic positional uncertainty associated with georeferencing procedures, source data quality, or cartographic generalization processes. Furthermore, the area derived from RBI digitization underestimated the GNSS RTK-derived area by 9,332 m² (0.933 ha) or 3.12%. Visual comparison of the boundary datasets showed that irregular boundary segments and abrupt changes in direction were simplified into straighter lines, resulting in the truncation of peripheral sections of the parcel.

These findings demonstrate that compliance with formal positional accuracy standards does not necessarily ensure reliable boundary representation for village-level applications. Although 1:50,000 RBI maps remain suitable for preliminary planning, regional screening, and general spatial analysis, they should not be used for detailed parcel delineation, cadastral mapping, legal boundary determination, or applications requiring precise area estimation. Large-scale geospatial datasets and high-precision GNSS measurements remain essential for these purposes.

This study is limited by the use of 12 boundary vertices within a relatively small study area, which constrains the generalizability of the findings. Future studies should incorporate a larger number of independent check points and evaluate multiple study areas with varying topographic characteristics to provide a more comprehensive assessment of RBI map performance at the village level.

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