Spatial Data Integration of Inter-Agency Land Parcel Data for Multipurpose Cadastre Development

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Abstract
The management and organization of spatial information in the land sector are critical for delivering reliable and efficient land services. For government authorities, spatial data must be accurate, up to date, and accessible to multiple users. A multipurpose cadastre supports this objective by enabling the reuse of land parcel data across administrative, fiscal, and planning functions. However, the development of a multipurpose cadastre is often constrained by duplication, inconsistency, and heterogeneity in land parcel datasets managed by different institutions. This study investigates the integration of inter-agency land parcel data derived from the Land Registration Map and the Land and Property Tax Map in Gonilan village, Indonesia. It identifies and analyses key technical and institutional challenges encountered during the integration process, including geometric inconsistencies, positional discrepancies, and differences in parcel representation. A geometry-based spatial alignment approach was applied to harmonise parcel boundaries and improve spatial consistency while preserving attribute information. To validate the spatial accuracy of the integrated dataset, a UAV-based orthophoto survey was conducted, supported by Ground Control Points (GCPs) and Independent Check Points (ICPs). The resulting horizontal accuracy achieved an RMSE of 0.0598 m and a CE90 of 0.0908 m, meeting the requirements for a 1:1000-scale map. The results demonstrate that spatial harmonisation significantly improves dataset compatibility and supports the development of a unified cadastral database. However, substantial discrepancies in parcel geometry and numbering persist in certain areas, requiring field verification and interagency coordination. The study highlights that effective multipurpose cadastre development depends on robust geospatial techniques, sustained inter-agency collaboration, and data governance.

Keywords: Geometric Harmonisation, Inter-Agency Interoperability, Land Parcel Data, Multipurpose Cadastre, Spatial Data Integration

1. Introduction

The processing and management of spatial data in the land sector are fundamental to effective land administration, serving as the backbone of transparent, efficient, and accountable land governance. When spatial data is properly organized and utilised, it strengthens sustainable development initiatives, improves public service delivery, and ensures equitable access to land information for all stakeholders including government agencies, private-sector actors, and local communities [1]. However, this potential can only be realized through robust land data management practices that enable seamless integration of information across institutions. Because land-related data is often fragmented across multiple agencies [2], coordinated collaboration and interoperable systems are essential to ensure accuracy, reduce redundancy, and support evidence-based decision-making. Therefore, establishing a comprehensive and well-structured spatial data management framework is not merely beneficial but a foundational requirement for modern land administration [3].

Effective data management provides substantial economic and developmental benefits, enabling governments to deliver reliable and trustworthy spatial information [4]. For policymakers, access to accurate and up-to-date data is not simply important it is indispensable. High-quality data forms the basis for transparent, measurable, and accountable governance. In land administration, such data typically includes spatial components (e.g., polygons representing land parcels) accompanied by textual attributes that describe their legal, physical, or administrative characteristics [5] and [6]. Integrating spatial and attribute information within a single platform is the core strength of a Geographic Information System (GIS). GIS technology is widely applied across various sectors, supporting functions such as local government asset management, revenue administration, infrastructure planning, and land governance. This integration not only enhances data accuracy but also improves decision-making and service delivery across institutional boundaries.

Land administration policies inevitably rely on both spatial and textual data. One key source of spatial administrative data is the Land Registration Map (LRM), as defined by Government Regulation 24/1997 [7] as a map depicting land parcels recorded in official land books. The LRM is produced and maintained by the Land Office at the regency or city level as integrated digital records, in which spatial land parcels are linked to their textual attributes. These records are accessible to the public via a web-based Geographic Information System (GIS) portal to reference registered land parcels. Conversely, taxation-related land administration is governed under the Republic of Indonesia's Law on Regional Taxes and Levies [8] and is managed by local revenue offices. Their primary spatial dataset is the Land and Property Tax Map (LPTM), which organizes land parcels into smaller tax blocks at the village level.

The existence of these two separate datasets leads to duplication, inconsistency, and heterogeneity in land parcel information. While the Land Office uses the LRM as the authoritative reference for issuing land certificates, the Regional Financial and Asset Management Agency (*Badan Pengelolaan Keuangan dan Aset Daerah* – BPKPAD) does not. BPKPAD relies on the LPTM to levy taxes. Discrepancies in spatial attributes particularly land area, building footprint, and parcel boundaries can directly affect service quality and the accuracy of tax assessments. Furthermore, it can affect the efficiency of the administrative process and the revenue generated from property taxes [9]. Such discrepancies indicate that addressing spatial misalignment at the dataset level alone is inadequate when underlying governance and data-sharing mechanisms remain fragmented. Effective integration requires a common infrastructure that enables standardised data management and interoperability across agencies. Ultimately, these issues highlight the absence of an integrated multipurpose cadastre [10] and [11], and a functioning Spatial Data Infrastructure (SDI) capable of supporting consistent, interoperable land administration across institutions [12] and [13].

A multipurpose cadastre is a system designed to inventory comprehensive public data on all aspects of land, including legal rights, fiscal responsibilities, land management, and development activities [10]. Its primary function is to provide standardised, authoritative geospatial information on land parcels to a wide range of stakeholders. The effectiveness of such a system is greatly supported by a Spatial Data Infrastructure (SDI), which facilitates cross-agency spatial data sharing and interoperability [13] and [14]. However, this ideal situation has yet to be achieved in most local governments in Indonesia [12]. Within this framework, attribute data describing the characteristics of each land parcel serves as the core component of a multipurpose cadastre [15].

There are some challenges in land administration and land and property taxation, including data availability and completeness, data currency and updating frequency, different spatial referencing systems, institutional fragmentation, and limited interoperability between datasets [3][16][17] and [18]. On a more technical aspect, one of the main challenges in Indonesia is the use of different identifiers for the same land parcels. The LRM utilises Parcel Identification Numbers (NIB – *Nomor Identifikasi Bidang*), while the LPTM uses Tax Object Numbers (NOP – *Nomor Objek Pajak*), with no established cross-referencing mechanism linking the two. This disconnects, combined with the use of different coordinate projection systems, significantly complicates efforts to integrate the datasets. The importance of adopting Knowledge Models to define common entities and applying linked-data technologies to bridge differences across datasets was highlighted by [19]. Such approaches enable more effective data harmonisation, allowing information to be consistently shared, understood, and utilised across institutional boundaries. These fundamental differences between the LRM and LPTM spanning projection systems, attribute structures, and unique parcel numbering are summarized in Table 1.

Table 1: The differences between the land registration map and the LPTM in Indonesia

Aspect	Land Registration Map	Land and Property Tax Map
Coordinate system	Transverse Mercator (TM-3°) 49.1 South	Universal Transverse Mercator (UTM) 49 South
Attribute Data	ID, Region ID, Region Code, Subdistrict, Village, Type of Land Rights, Year of Land Certificate, NIB, Registered Land Area, Measured Land Area, Measuring instrument, Measuring method	NOP, Registered Land Area, Measured Land Area
Unique Number	Parcel Identification Numbers (NIB – *Nomor Identifikasi Bidang*)	Tax Object Numbers (NOP – *Nomor Objek Pajak*)

This situation is not ideal to support a multipurpose cadastre. Therefore, it is necessary to harmonise and integrate land parcel data from the LRM and the LPTM into a single, spatially consistent dataset. Harmonisation and integration are also part of Indonesia's digital transformation effort. Such integration is expected to reduce data duplication, improve consistency, and enhance interoperability among land-related information systems. While the modernization of land administration has accelerated, its integration with local government business processes remains limited. Access to spatial elements is somewhat restricted, let alone to detailed information about land parcels [3].

Data integration refers to the process of merging multiple data sources by linking different types of information such as spatial and attribute data into a unified and coherent database [20]. However, integration and data exchange are often challenged by semantic heterogeneity arising from variations in geospatial data formats, structures, and acquisition methods [21]. These issues are especially pronounced when datasets originate from different primary data collection processes. For land-related activities, data integration is particularly required in the cadastral domain [2] and [22], especially to support a multipurpose cadastre. In aligning spatial land parcel data from the LRM and LPTM, previous efforts have typically relied on basic spatial operations, such as translation, rotation, and overlay analysis [23]. While useful for minor adjustments, these techniques are inadequate for areas where the datasets differ substantially in geometry, spatial position, or attribute content. Gonilan Village, Indonesia, exemplifies such a case and therefore serves as the focus of this study.

Based on the identified challenges, the Replace Geometry tool was determined to be the most suitable method for aligning the LRM and LPTM parcel datasets and producing a single, harmonised spatial layer. The anticipated outcome is that the integrated, spatially aligned land parcel data will contribute to the development of a multipurpose cadastre, thereby supporting more accurate land administration, taxation, and planning processes.

2. Study Area

The spatial integration of the LRM and LPTM was carried out in Gonilan Village, located in Kartasura District, Sukoharjo Regency, Central Java Province, Indonesia. According to data from the Geospatial Computerized Land Office System (GeoKKP – *Geospasial Komputerisasi Kantor Pertanahan*) managed by the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (ATR/BPN – *Kementerian Agraria dan Tata Ruang/Badan Pertanahan Nasional*), Gonilan Village encompasses an area of 141.63 hectares and is situated approximately 14.6 kilometers from the capital of Sukoharjo Regency and 5.6 kilometers from the City of Surakarta. The area is predominantly built-up, consisting of residential neighborhoods, educational facilities, and office complexes. The study location map for this research is presented in Figure 1.

Figure 1 illustrates the location of Gonilan Village, highlighted in orange, situated in the northern part of Sukoharjo Regency. Since 1999, Sukoharjo Regency has experienced steady population growth, contributing to increasingly complex patterns of urban development. Population statistics from BPS Sukoharjo Regency (2025) confirm this trend: population growth increased by 8.63% between 1999 and 2009, by 5.78% between 2009 and 2019, and by 2.75% between 2019 and 2024. In comparison, Gonilan Village has experienced even more notable growth, with a dramatic 92.48% increase from 2009 to 2019 and 4.64% from 2019 to 2024. These demographic changes underscore the growing importance of accurate and reliable spatial data to support land administration and urban planning in the area.

Several factors, including the expansion of nearby educational institutions, drive population growth in Sukoharjo Regency. Two major contributors to this growth are Universitas Muhammadiyah Surakarta (UMS) and Assalaam Modern Boarding School, both located near Gonilan Village. UMS accommodates an estimated 28,000 students, while Pondok Assalaam hosts more than 2,000 students

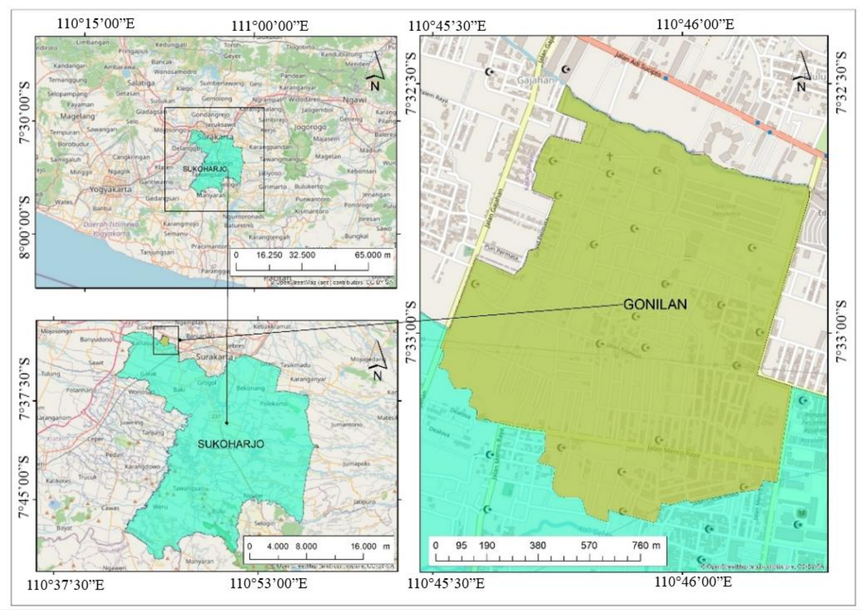

Figure 1: Location of Gonilan Village, Sukoharjo Regency, Central Java Province, Indonesia (basemap: OpenStreetMaps)

Table 2: Dataset specifications

No.	Data Type	Year	Data Format	Number of Parcels	Area (m²)
1	Land Registration Map	2023	.shp	4,292	1,417,359
2	Land and Property Tax Map	2023	.shp	2,461	1,116,325

The influx of students, alongside broader urban expansion, has accelerated land-use changes most notably the continued growth of residential areas. These demographic and spatial dynamics underscore the increasing need for an adaptive, efficient, and well-coordinated land administration system to support sustainable development [24].

Updating land data is essential to accurately represent field conditions, minimise boundary disputes, and ensure fair and precise tax assessments. In Gonilan Village, the need for spatial data integration has become increasingly urgent, especially for updating the LPTM. However, BPKPAD Sukoharjo the institution responsible for managing the tax map has not yet adopted a systematic or routine data maintenance process. As a result, most updates are recorded only sporadically and rely heavily on voluntary reports from landowners, such as in cases of parcel subdivision, consolidation, or changes in ownership. This reactive approach contributes to persistent discrepancies and underscores the importance of implementing a structured, continuous data-update mechanism.

3. Data and Methods

3.1 Land Parcel Data

This study employed two primary spatial datasets: the LRM obtained from the Land Office and the LPTM acquired from BPKPAD of Sukoharjo Regency. Table 2 summarizes the specifications of both datasets, including the total number of parcels and overall land area. Each dataset was sourced directly from the respective institutions in 2023, ensuring that the analysis was based on the most recent available records. Both agencies provide land parcel data in the same format shapefiles (.shp) which facilitates subsequent integration efforts. However, despite this technical compatibility, significant discrepancies remain between the datasets. The LRM contains 1,831 more parcels (an increase of 42.66%) and covers an additional 301,034 m² (21.24%) of land area compared to the LPTM. These differences arise primarily from systematic updates carried out exclusively on the LRM, including parcel subdivision and consolidation, partial land releases, and the removal of expired land rights. In contrast, updates to the LPTM are typically performed only upon request from landowners and often omit certain features, such as roads and canals. The resulting geometric differences and their spatial overlay are shown in Figure 2.

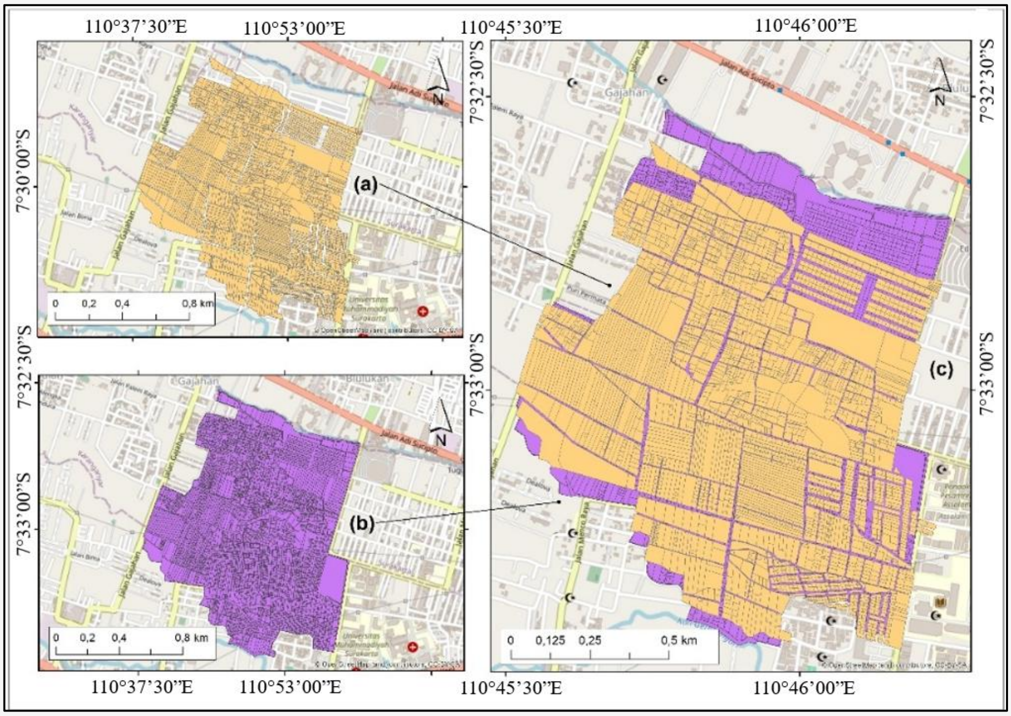

Figure 2: (a) Land and Property Tax Map, (b) Land Registration Map and (c) their overlay

Table 3: Comparison of attribute data between the land registration map and the land and property tax map

Attribute Data of Land and Property Tax Map joined with the DHKP table	Attribute Data of Land Registration Map
NOP, Registered Land Area, Measured Land Area, Registered name of the tax subject, Address, Registered Land Area from DHKP, Registered Property Area from DHKP.	ID, Region ID, Region Code, Subdistrict, Village, Type of Land Rights, Year of Land Certificate, NIB, Registered Land Area, Measured Land Area, Measuring instrument, Measuring method

Table 4: Summary of taxpayer address verification results

Address Location	Number of Tax Subjects	Percentage
Within Gonilan Village	1,539	58.34
Outside Gonilan Village	1,099	41.66
Total recorded in DHKP	2,638	100.00

Visually, the geometric shapes of land parcels in the LRM and LPTM for Gonilan Village differ significantly, as presented in Figure 2(c). The overlay of the two datasets reveals substantial misalignment. As shown in Figure 2, the LRM covers a wider spatial extent, with the purple-shaded areas extending beyond the orange areas that represent the LPTM's coverage. This discrepancy is most noticeable along the northern, eastern, and southern boundaries, where the LRM includes additional parcels that do not appear in the LPTM. While Figure 2 highlights these geometric differences, Table 3 complements the visual comparison by presenting a detailed overview of the attribute data from both datasets. It outlines the specific variables compared, such as NOP for tax maps and NIB for land registration maps. The attribute data from the LPTM were joined with the Property Tax Assessment List (DHKP – *Daftar Himpunan Ketetapan Pajak*) to complete the tax subject information. In the DHKP, the recorded address may refer to either the taxpayer's domicile or the location of the taxable property. Verification of the joined data revealed that a portion of the listed addresses did not correspond to locations within Gonilan Village. As summarized in Table 4, only 58.34% of tax subjects are registered within the village, while 41.66% are associated with addresses outside the area. This finding indicates that many entries refer to the taxpayer's place of residence rather than the land parcel’s actual location.

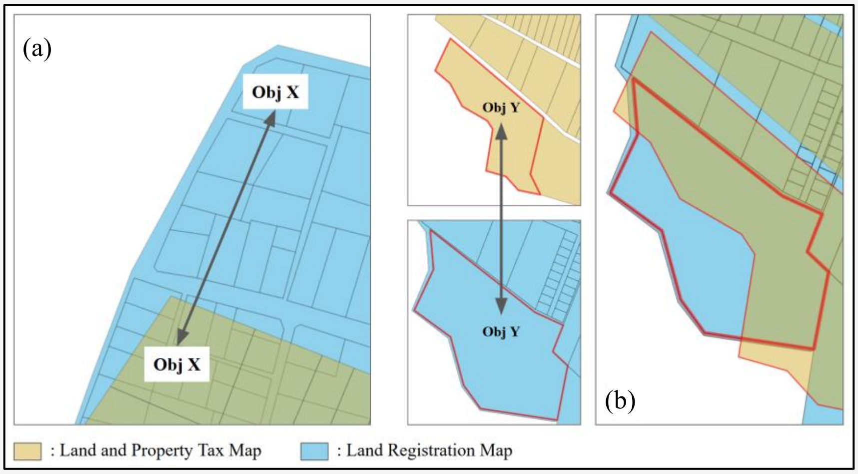

Figure 3: Land parcels on the Registration Map and Land and Property Tax Map before integration

3.2 Spatial Relations

To assess spatial discrepancies between the two datasets, the spatial relationships of corresponding land parcels in the LRM and LPTM were examined. Understanding these relationships was crucial to determining the most appropriate tools for preparing the data before integration. If the geometries had been well-aligned, tools such as Spatial Join could have been applied directly. Spatial Join commonly known as "Join Attributes by Location" in GIS software creates a new spatial dataset by linking attribute information from separate layers based on spatial proximity or overlap. This method is highly effective when datasets share compatible or consistently aligned geometries.

However, the accuracy of Spatial Join depends heavily on the geometric precision and positional consistency of the input data. In this study, such conditions were not met. As illustrated in Figure 3, many polygons exhibit mismatches in shape, position, and area, resulting in disjoint or only partially overlapping spatial relationships. Due to these inconsistencies, basic geometric transformation tools (e.g., move, rotate, overlay) and standard spatial join methods proved insufficient for achieving meaningful integration. This analysis highlighted the need for more advanced harmonisation techniques to correctly align datasets prior to integration. In Figure 3(a), the land parcel labeled "Obj X" corresponds to the same physical area in both datasets, yet its position and geometric shape differ significantly. The spatial relationship between the two versions of "Obj X" is disjoint, indicating that the parcels do not overlap. In Figure 3(b), parcel "Obj Y" also corresponds to the same administratively recognized land parcel, but its geometry, position, and area differ across the datasets. Unlike "Obj X," parcel "Obj Y" exhibits an overlapping spatial relationship, whereas other parcels display a mix of intersecting or disjoint relationships.

These differences arise primarily from variations in data acquisition methods and the use of different coordinate projection systems. The LRM parcel boundaries were established using terrestrial survey techniques complemented by satellite observations, resulting in higher geometric accuracy. In contrast, the LPTM parcel boundaries were produced through digitization or delineation based on satellite imagery, which can introduce positional and shape inaccuracies. This irregularity and heterogeneity in parcel geometry underscore the need for data integration. Harmonising the datasets is essential to address substantial discrepancies including differences in the number of parcels recorded in the LRM and LPTM and to support more accurate and reliable land administration.

3.3 Geometric Integration

Basic geometric transformations such as translation, rotation, reflection, and dilation were insufficient to resolve the substantial spatial discrepancies between the two datasets, particularly in areas where parcel boundaries differed significantly in shape, position, and topology [25]. These conventional transformations are effective only for systematic or uniform distortions and cannot adequately address complex geometric inconsistencies arising from different data-acquisition methods, mapping scales, or boundary delineation practices. Consequently, a geometry-level harmonisation approach was required to achieve meaningful spatial alignment between datasets.

To address this challenge, a geometry replacement procedure was applied to align the geometries of the Land and Property Tax Map

(LPTM) parcels with those of the Land Registration Map (LRM), which served as the spatial reference dataset. This approach enables substituting of a feature's geometry while preserving its associated attribute information [26] and [27], allowing parcel shapes and boundaries to be updated without altering administrative or taxation-related data. In practical applications, the need for geometry replacement is often driven by substantial discrepancies in data-acquisition methods, coordinate systems, and update frequencies across datasets. The Replace Geometry tool is used to address integration issues between two types of spatial data that, from a of coordinate-systems perspective, were acquired using entirely different methods. For example, LPTM uses the UTM projection system, while LRM uses the TM-3° projection system. LRM were obtained through direct measurement using terrestrial methods and satellite observations with a Geodetic-type GNSS receiver, and data updates are frequently performed when landowners submit requests for land parcel measurements. Meanwhile, LPTM uses satellite image digitization for data acquisition, and its spatial data has not been updated since its initial publication.

Furthermore, this issue is compounded by the fact that the number of land parcels on LRM is significantly larger than that on LPTM. Consequently, the use of the "replace geometry" tool is a practical and innovative solution to address this problem, as the integration of these two spatial datasets is performed parcel by parcel. This approach minimises integration errors when performed automatically on a large dataset. By maintaining attribute integrity, geometry replacement supports data consistency and prevents the loss of critical non-spatial information used in land administration and taxation processes.

In this study, geometric adjustments were performed to ensure that each LPTM parcel matched its corresponding LRM geometry. The Replace Geometry functionality available as a Plugin in QGIS [28] was used to update parcel boundaries based on identified counterparts in both datasets. The study employs a point-based geometry adjustment approach, in which all geospatial objects, such as lines and polygons, are decomposed into their most fundamental elements points. This approach is adopted because points are easier to manipulate and enable localized adjustments without compromising the overall structure of the dataset. The method involves identifying positional discrepancies between the dataset to be corrected and a reference dataset, followed by selecting the points exhibiting mismatches. These points are then adjusted by shifting their positions to more accurate locations based on the reference data [26]. The replacement process was conducted manually, parcel by parcel, to ensure precise alignment and to minimise the risk of mismatches or topological errors. Although this manual workflow is labor-intensive, it allowed for careful verification of each parcel and proved effective in areas with substantial geometric variation, where automated matching techniques would likely fail. This approach highlights the practical trade-off between processing efficiency and spatial accuracy in cadastral data integration tasks.

3.4 Harmonisation and Integration

Inconsistent spatial data originating from multiple institutions requires a series of structured integration steps to produce a unified, reliable spatial dataset. According to [20], spatial data integration involves a systematic workflow illustrated in Figure 4 that begins with the identification and evaluation of inconsistencies within each dataset to be merged. These inconsistencies may include differences in geometric accuracy, attribute definitions, data collection methods, and update cycles. When substantial discrepancies are detected, the datasets must undergo a series of adjustments before integration can proceed. Such preparatory processes, often referred to collectively as data harmonisation [29] involve aligning data formats, standardising coordinate reference systems, reconciling attribute structures, and ensuring the completeness and compatibility of metadata.

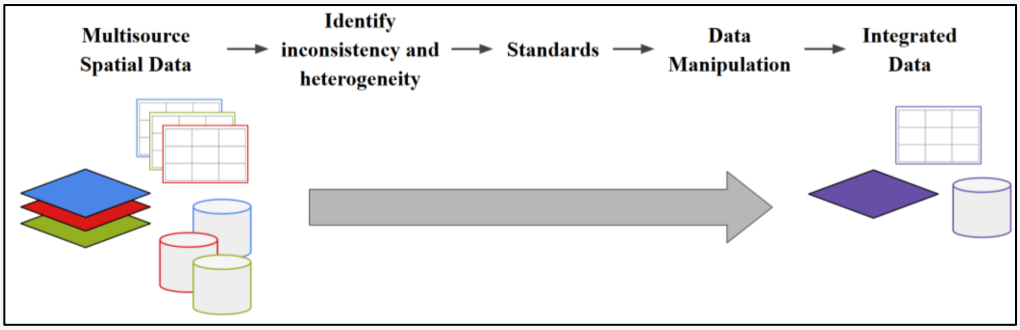

Figure 4: Stages of spatial data integration (adapted from: Mohammadi, Rajabifard, and Williamson, 2010)

Table 5: Data discrepancy problems and solutions

Data Difference	Solution
Projected Coordinate System	Coordinate transformation from UTM 49 S into TM-3° 49.1 (based on the reference)
Geometric shape of spatial data	Replace Geometry Tool
Attribute data and a Unique number	Spatial Join for integrating attributes.

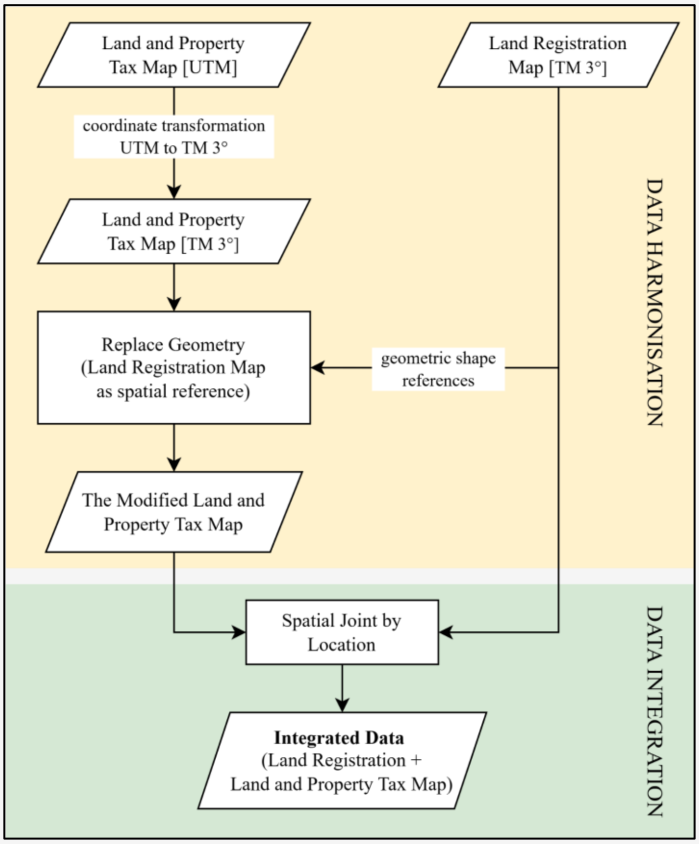

Figure 5: Stages of harmonisation and integration of land parcels data

These harmonisation steps are critical not only for ensuring technical interoperability but also for maintaining the integrity and usability of the resulting integrated spatial dataset, which ultimately supports more accurate analysis and decision-making in land administration. The process of harmonising spatial data involves several critical technical steps, including synchronizing spatial reference frameworks and coordinate systems, establishing precise boundary geometries for land parcels, and resolving misalignments across datasets to achieve consistent, accurate spatial representations [22]. In this study, harmonisation efforts focused on two key spatial datasets: the LPTM and the LRM. Each dataset was produced for different administrative purposes and maintained by different institutions, resulting in notable variations in spatial accuracy, boundary delineation, and parcel definition.

Table 5 summarizes the inconsistencies identified between the LPTM and the LRM, highlighting the specific areas requiring technical adjustments prior to integration. Based on the inconsistencies identified in the land parcels of Gonilan Village, as summarized in Table 4, data harmonisation is required before the datasets can be reliably integrated into a single spatial layer. The Replace Geometry Tool was selected as the most suitable method for resolving geometric discrepancies between the datasets while preserving their associated attribute information. This approach allows spatial boundaries from one dataset to be substituted with more accurate geometries from another, thereby improving overall spatial consistency. The complete harmonisation and integration workflow undertaken in this research is illustrated in Figure 5.

Based on the harmonisation workflow shown in Figure 5, the first step is to perform a coordinate transformation to align the projected coordinate systems of both datasets with the LRM's TM-3°. Once the coordinate systems are synchronized, geometric adjustments are performed using the Replace Geometry Tool, which modifies the LPTM parcel boundaries to match the corresponding geometries in the LRM. At this stage, the two datasets have not yet been merged; each retains its original attribute structure even though their geometries have been aligned. Therefore, a Spatial Join tool is required to integrate the attribute information, resulting in a single spatial dataset with consistent parcel geometries derived from the LRM. The changes in both geometric and attribute data before and after the harmonisation and integration process are illustrated in Figure 6.

In Figure 6, the geometric data are depicted as simplified trapezoid shapes, while the corresponding attribute data are illustrated in tabular form. Through the harmonisation and integration process, the parcel geometries are standardised to conform to the LRM specifications, ensuring consistent boundary representation across the dataset. At the same time, attribute information from both the LRM and the LPTM is consolidated into a unified attribute table that seamlessly merges the relevant fields from each source. This combined dataset provides a more complete and coherent representation of land parcel information, supporting more accurate analysis and improved land administration workflows.

3.5 Field Data Verification

To assess whether the integrated dataset accurately reflects actual field conditions, this study employed orthophoto-based verification. The technical specifications of the orthophoto used for this purpose are provided in Table 6. Verification was carried out through detailed visual inspection, in which the integrated parcel boundaries were compared directly against the high-resolution orthophoto imagery. This process enabled evaluation of the spatial accuracy of the integrated data and identification of any remaining geometric inconsistencies. Table 6 outlines the specifications of the orthophoto map used for field data verification in this study. A drone-based survey was selected as the data-acquisition method because it enables the generation of recent, high-precision orthophotos suitable for detailed, small-area analysis. Drone surveys are not only cost-effective and time-efficient but also offer flexible data-collection capabilities. The resulting orthophoto has a spatial resolution of 3.0 cm, allowing exceptionally detailed visualisation of surface features. This high-resolution imagery enables accurate visual verification of spatial data by presenting distortion-free representations of actual field conditions. The orthophotomap serves as a reliable reference for assessing and validating the geometric accuracy of land parcels.

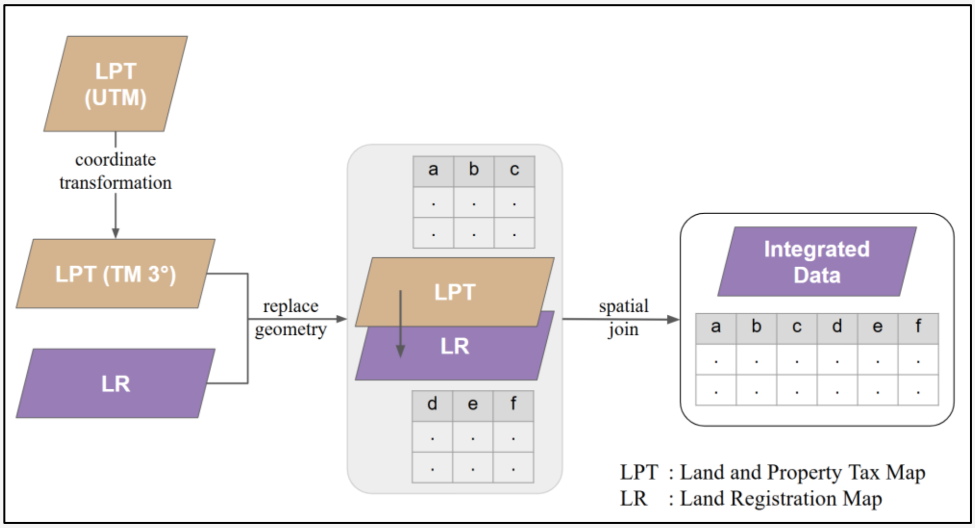

Figure 6: The changes in geometric and attribute data of the land parcels data

Table 6: Orthophoto map specification

No	Parameter	Information
1.	Drone	DJI Phantom 4 Pro
2.	Camera	include in Drone
3.	Camera Resolution	24 MP
4.	Flight Altitude	100 m
5.	Ground Control Points (GCP)	5 pcs
6.	Independent Control Points (ICP)	5 pcs
7.	Ground Sampling Distance (GSD)	3.08 cm/px
8.	CE90	0.082 m

Table 7: Horizontal accuracy calculation (Ce90) Gonilan Village

ICP Point	X_{ortho} [m]	Y_{ortho} [m]	X_{GNSS} [m]	Y_{GNSS} [m]	$(\Delta X)^2$ [m]	$(\Delta Y)^2$ [m]	ΔS [m]
GCP1	339805.103	664848.253	339805.059	664848.270	0.002	0.000	0.002
GCP2	339706.721	664836.075	339706.657	664836.072	0.004	0.000	0.004
GCP3	339750.234	664762.754	339750.170	664762.703	0.004	0.003	0.007
GCP4	339768.362	664804.350	339768.335	664804.404	0.000	0.003	0.004
GCP5	339841.570	664641.139	339841.565	664641.194	0.000	0.003	0.003
GCP6	339796.978	664732.418	339796.939	664732.428	0.002	0.000	0.001

In addition to visual verification, quantitative accuracy assessment was conducted using six Independent Check Points (ICP). The coordinates derived from orthophoto interpretation were compared with those obtained from geodetic GPS measurements, which were treated as ground truth. The positional differences in both the X and Y directions were calculated and used to derive the Root Mean Square Error (RMSE) and the Circular Error at the 90% confidence level (CE90). The detailed results are presented in Table 7. The analysis shows that the RMSE is 0.0598 m, and the CE90 is 0.0908 m. This indicates that 90% of the horizontal positional errors are within approximately 9 cm. According to Regulation No. 6 of 2018 of the Geospatial Information Agency (Badan Informasi Geospasial/BIG), this level of accuracy meets the standard requirements for a 1:1000 scale map, class 1.

These results confirm that the orthophoto provides high positional accuracy and can serve as a reference for validating the integrated land parcel datasets. Furthermore, the achieved accuracy shows that the integration process maintains spatial quality standards suitable for large-scale cadastral applications.

4. Results and Discussions

4.1Data Integration and Geometric Harmonisation

A fundamental prerequisite for developing a multipurpose cadastre is the adoption of a standardised spatial reference system, including a consistent coordinate projection across all datasets [10] and [20]. In this study, LPTM employed the UTM projection, while LRM followed the national projection system, Transverse Mercator 3° (TM-3°), as mandated by Republik Indonesia (2019). To ensure spatial compatibility, the LPTM coordinate system was transformed into TM-3°, aligning it with the LRM, which served as the geometric reference for subsequent integration. This transformation step was essential for achieving spatial consistency prior to harmonisation and dataset merging. The results of the coordinate transformation process for the LPTM are presented in Figure 7. The coordinate transformation applied to the LPTM is illustrated by comparing the X and Y values of five randomly selected sample points, as shown in Figure 7. For instance, the original coordinates of sample point (a) were recorded as (473,876.62 m; 9,165,723.24 m) in the UTM projection system. After transformation into the TM-3° projection system, these coordinates shifted to (339, 405.43 m; 665, 278.08 m). Similar before-and-after coordinate values for sample points (b) through (e) are also presented in Figure 7, demonstrating the magnitude and consistency of the transformation process across multiple locations. Once the coordinate systems were aligned, the Replace Geometry Tool was applied to correct parcel shapes in the LPTM. Figure 8 illustrates the geometric differences before and after this adjustment, highlighting how the tool effectively realigned parcel boundaries to match the LRM reference geometries.

In Figure 8, the blue-colored parcels indicate the land parcels whose geometries were modified using the Replace Geometry tool. Through this process, the parcel boundaries were adjusted to align with the correct spatial reference, while the original attribute information was preserved. However, in this study, the Replace Geometry tool was not sufficient for all cases.

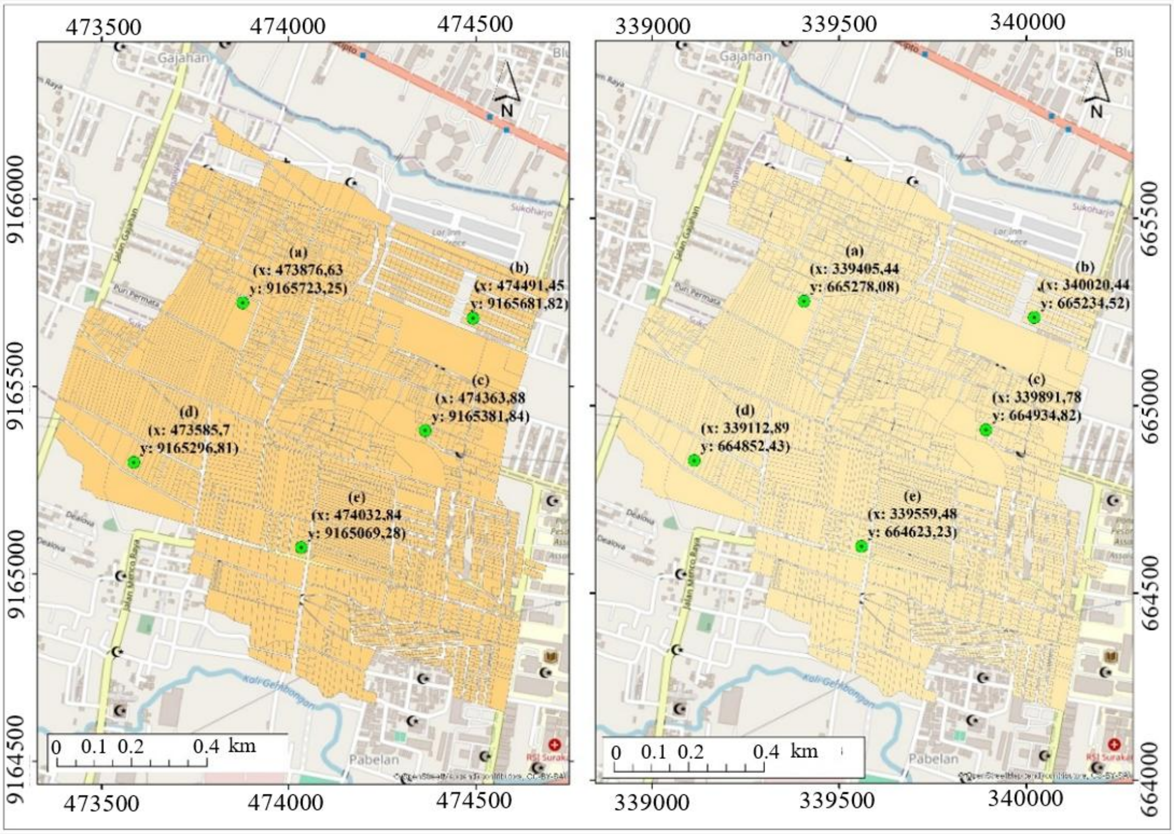

Figure 7: Land and property tax map (a) UTM, and (b) TM-3° projection

Figure 8: (a) Land parcels of the LPTM before and after (b) changes were made using the Replace Geometry Tool

Some parcels could not be aligned due to substantial discrepancies between the datasets. Two specific areas in Gonilan presented notable challenges, as illustrated in Figure 9. The re-survey was conducted separately for two focus areas. Parcel delineation was first performed using high-resolution UAV imagery.

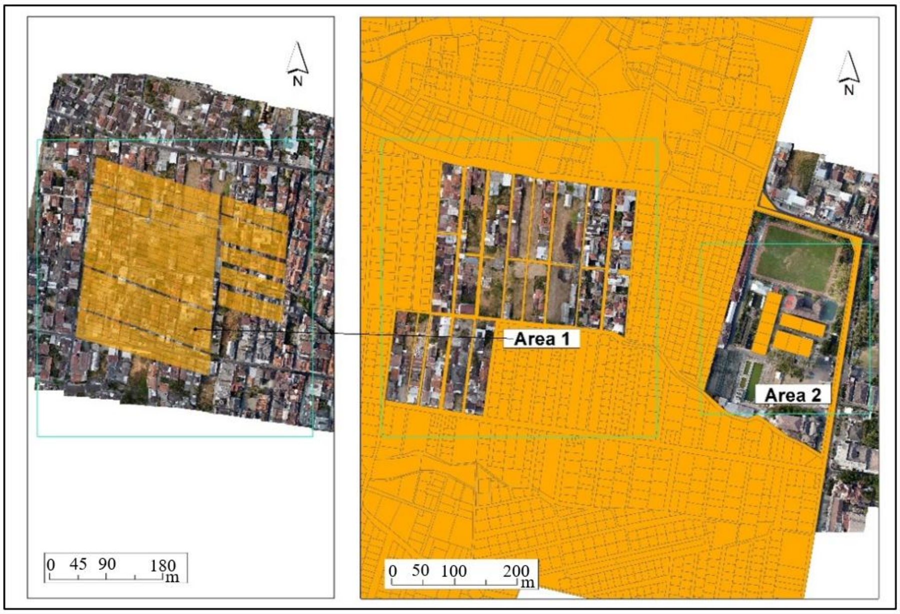

Figure 9: Land parcels on the LPTM that have not been successfully integrated with the LRM

This was followed by a field survey on selected parcels, focusing on approximately anomalous land parcels. The field survey was carried out with the assistance of local village officials, who accompanied the team to the parcel locations. Direct observations and interviews with landowners revealed that the Land and Property Tax records for the sampled parcels were inconsistent with both the physical parcel boundaries and the legally registered land certificates.

In Area 1, the parcel orientations differ markedly between the two datasets appearing vertically in the LRM (green) but horizontally in the LPTM (red). This substantial orientation mismatch made it difficult to accurately identify and pair corresponding parcels. In Area 2, an additional challenge emerged: eleven parcels recorded in the LPTM had no identifiable counterparts in the LRM, indicating a potential omission or a fundamental inconsistency between the datasets. To address these discrepancies, field verification was carried out directly at the parcel locations. This on-site assessment was crucial for determining whether the integrated dataset aligned with actual ground conditions and for validating the correctness of the harmonised spatial information.

In Area 1, a total of 10 parcels were added following visual inspection and field verification. However, approximately 200 parcels could not be matched between the two datasets due to highly irregular and overlapping spatial configurations. The discrepancies were not limited to differences in orientation (horizontal vs. vertical) but also included significant variations in spatial position, with parcel boundaries neither overlapping nor intersecting. These substantial geometric inconsistencies made it impossible to resolve the issues solely through direct spatial data integration. To address these challenges, a parcel-by-parcel resurvey was undertaken as a practical and reliable solution. This field verification process is essential for reconciling the spatial data with actual parcel boundaries on the ground, ensuring accurate alignment in both geometry and location.

In Area 2, field verification confirmed the presence of 11 parcels recorded in the LPTM, each of which already has an assigned NOP. In contrast, the LRM represents this same location as a single, larger parcel with a recorded area of 38,406 m², within which the 11 LPTM parcels fall under an "are within" spatial relationship. This discrepancy stems from differences in how the two datasets define and record parcel boundaries, particularly regarding parcel subdivision. The mismatch in the number of parcels at the same geographic setting is consistent with findings by [10], who reported similar inconsistencies in Serengan District, Surakarta City. An illustration of this discrepancy is shown in Figure 10.

In Figure 10, the three parcels identified as A, B, and C in the LRM appear to correspond to a single merged parcel in the LPTM. This discrepancy occurred because the subdivision of land rights initially split into three parcels and formally processed at the Ministry of ATR/BPN had not been communicated to BPKPAD, resulting in outdated parcel records in the LPTM. A contrasting situation is observed in Area 2, shown in Figure 11, where the

LRM records only one large parcel, while the LPTM identifies 11 smaller parcels nested within the same boundary.

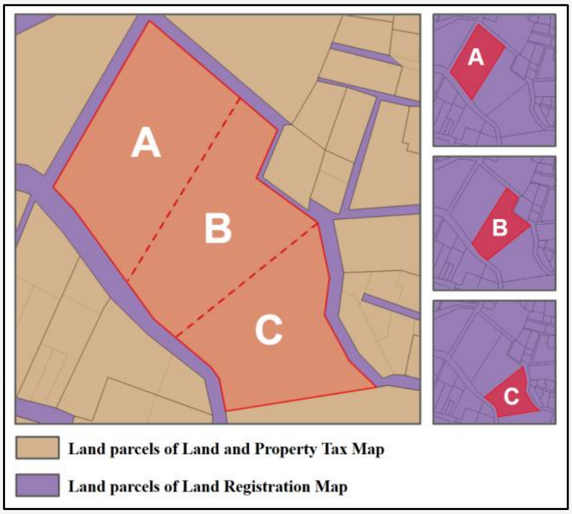

Figure 10: Discrepancy in the number of land parcels at the same location

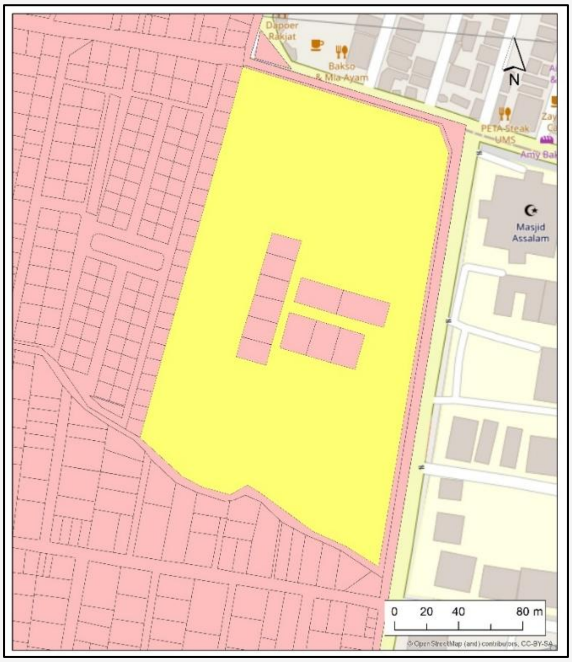

Figure 11: The 12th land parcel of area 2

To reconcile this mismatch, the integration process in this study treated Area 2 as consisting of 12 parcels: the 11 detailed parcels from the LPTM and an additional parcel representing the original large unit from the LRM, highlighted in yellow. This approach ensured that both the authoritative boundary and the finer subdivision were preserved in the integrated dataset.

Initially, the boundary delineations were attempted using a photogrammetric technique; however, this method proved insufficient, as the digitized boundaries did not accurately correspond to the LPT-based parcels. Therefore, for future work, direct boundary resurvey using surveying instruments (e.g., Total Station or GNSS receivers) is recommended. The resurvey data for anomalous parcels could not be fully incorporated into the dataset due to significant inconsistencies between the spatial records. These inconsistencies require resolution through coordinated efforts among the BPN and BKAD.

The attribute data for all land parcels in Area 2 including the twelfth parcel shown in Figure 11 are incomplete when compared between the LPTM and the LRM. Of the 12 parcels in Area 2, 11 parcels have an assigned NOP but lack a NIB, while the 12th parcel has a NIB but does not have a corresponding NOP. This imbalance reflects gaps in cross-agency data updates and highlights the need for stronger institutional coordination. Effective collaboration among the relevant authorities is essential to achieve accurate, reliable data integration. BPKPAD, as the agency responsible for issuing Land and Property Tax identifiers, must ensure the timely and proactive assignment of NOPs for all registered parcels. At the same time, close coordination with the Land Office is crucial so that any parcel changes such as subdivision or consolidation are promptly recorded and synchronized across both systems. This alignment ensures that the registered land area and the associated tax object data remain consistent. The unified spatial dataset resulting from integrating the LRM and LPTM is shown in Figure 12.

4.2 Geometric Accuracy Assessment

The final integrated dataset comprising all parcels that could be successfully aligned, excluding the unresolved areas (Areas 1 and 2) is presented in Figure 12. For visualisation purposes, the spatial geometry in Area 1 was displayed using the LRM as the sole reference because matching parcels from the LPTM was not possible. Overall, this study demonstrates that the Replace Geometry Tool offers a practical and efficient approach for parcel-level, geometry-based spatial data harmonisation. The tool enables correction of parcel geometries without losing attribute information, reduces data duplication, and aligns parcel boundaries with an authoritative reference dataset. However, the process remains time-consuming because it requires manual adjustments parcel by parcel. As such, the Replace Geometry tool is not well-suited for large-scale spatial integration efforts or for resolving complex topological inconsistencies that extend beyond simple geometric mismatches.

While the qualitative assessment demonstrates the effectiveness of the geometric harmonisation process, a quantitative accuracy evaluation will provide a clearer understanding of the improvement achieved. This geometric accuracy assessment was conducted to evaluate the alignment between the integrated dataset and the reference data. The accuracy assessment measured alignment between test and reference datasets by two parameters: positional and area accuracy. A purposive sampling technique was applied to ensure the representativeness of parcels with varying levels of geometric discrepancy. The sample was determined based on the total population and an acceptable margin of error using the Slovin formula. Positional accuracy is evaluated by calculating the Euclidean distance between the centroids of LPTM (test data) and LRM (reference data) land parcel polygons. Displacement analysis of LRM and LPTM parcels was conducted in both built-up and non-built-up areas. Among 350 built-up area samples, most (220) showed a displacement of 11-50 meters; 16 were less than 10 meters; and 114 exceeded 50 meters. Of the 23 non-built-up area parcels, 17 had a displacement greater than 50 meters; the remainder were within 11-50 meters. Area accuracy is determined by the discrepancy between the digital area (SHP) of the LPTM and the physical area in the LRM (reference). The tolerance threshold for discrepancies is 10%, set in accordance with SISMIOP (Property Tax Information Management System) technical guidelines for fiscal data synchronization in Indonesia. This 10% serves as the threshold for classifying a parcel as either a valid result (inlier) or an anomaly requiring further verification. Area discrepancy between LRM and LPTM parcels was examined in built-up (n=350) and non-built-up (n=23) areas. In built-up areas, 274 parcels exceeded the 10% threshold, and 76 were within it. In non-built-up areas, 17 parcels exceeded the threshold, and 6 were within the tolerance range.

These findings demonstrate that a large portion of parcels exhibit significant positional and area discrepancies, especially in built-up areas, confirming that the two datasets are substantially misaligned. The geometry-based harmonisation alone is insufficient without field verification and institutional synchronization. Similar challenges have been reported in cross-border spatial data integration, such as between Germany and the Czech Republic. Semantic and geometric discrepancies arose from differences in data models and projection systems. They were addressed through shared standards and a unified coordinate reference system (ETRS89/UTM). However, boundary inconsistencies still required joint field surveys for validation [30].

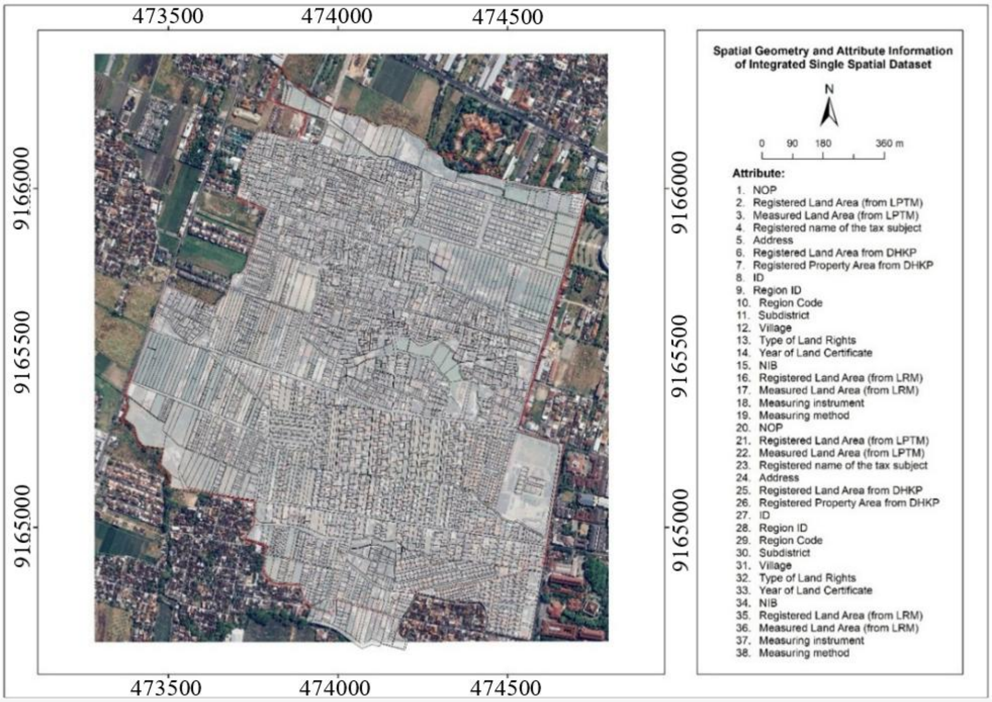

Figure 12: Spatial geometry and attribute information of the integrated single spatial dataset

4.3 Institutional Arrangement

The method applied in this study is particularly useful in cases where interoperability issues arise between datasets that are expected to have identical geometries but instead exhibit anomalies due to variations in data acquisition methods, projection systems, or spatial data processing workflows. However, several limitations remain unresolved. One key challenge is the inability to comprehensively analyse specific data sources due to severe geometric and positional anomalies in the LPTM across multiple blocks. These inconsistencies were significant enough that corresponding parcels could not be reliably identified, even through direct field surveys at the study site. Furthermore, the method is relatively time-consuming, as the geometry replacement process must be performed parcel by parcel, limiting its practicality for large-scale integration efforts. This limitation significantly impacts scalability, making it less efficient for larger-area applications. Automating this workflow is challenging due to the irregular and unsystematic nature of spatial discrepancies resulting from variations in historical mapping methods, survey techniques, and unique local conditions. Such irregularities make it difficult to apply standard rules or automated processing consistently across all cases. Dataset misalignment may require context-specific adjustment. Therefore, field verification remains crucial to ensure data accuracy. Semi-automated approaches to identify spatial discrepancies may help, but manually checked remain necessary to maintain integrity and precision.

Overall, the results indicate that spatial data integration for land administration is inherently both a technical and an institutional challenge. Geometry-based harmonisation approaches can effectively reduce inconsistencies between land parcel datasets, particularly where discrepancies stem from differences in data acquisition methods, coordinate reference systems, or data processing workflows. However, the findings also underscore the limitations of purely technical solutions when addressing substantial geometric, positional, or topological discrepancies. In such cases, spatial alignment tools alone are insufficient to ensure data reliability and interoperability. Effective integration for multipurpose cadastre development requires a broader framework. It requires institutional cooperation that includes, among other things, data-sharing protocols or a legal framework to ensure that the use of the database remains consistent over time, which can be achieved through a formal cooperation between the institutions through a Memorandum of Understanding (MoU). The MoU must outline agreements on several key points, including the timeline for data integration, rights and obligations, and the technical aspects of data integration. To improve technical interoperability between systems, the following aspects need to be agreed upon: data formats and metadata standards, standardisation of data models, including parcel identifiers, attribute structures, and topology rules. For institutional interoperability, it requires a clear delineation of institutional roles in data creation, validation, updating, and sharing. Furthermore, it should cover procedures for handling discrepancies, including mechanisms for joint verification and field validation.

Cooperation between organizations requires trust among parties and should include protecting sensitive information while enabling authorized stakeholders to access data, as well as agreements on data ownership, liability, and accountability. Through these arrangements, the integrated cadastral database can be maintained as a dynamic, reliable system that supports sustainable land administration and accurate taxation. This arrangement highlights that technical integration must be complemented by robust institutional and legal frameworks to achieve long-term interoperability.

The proposed synchronization protocol consists of two main stages: initial harmonisation and continuous synchronization. In the first stage, land parcel data from the Land Registration Map (LRM) and the Land and Property Tax Map (LPTM) are integrated into a single, spatially consistent dataset, with the LRM established as the authoritative reference for parcel geometry to ensure alignment to a common standard, given its higher positional accuracy derived from field-based surveys and geodetic measurements. The Land and Property Tax Map (LPTM) serve as the authoritative source for taxation attributes (e.g., NOP and tax-related information). Any changes in parcel geometry (e.g., subdivision, consolidation, boundary adjustment) must originate from and be validated by the Land Office before being shared with other systems. Attribute updates related to taxation are managed by the LPTM agency, synchronized with the integrated database through standardised data exchange protocols, and fed back to the system accessible to authorized parties. Continuous synchronization should be implemented through web-based mechanisms such as Application Programming Interfaces (APIs) or Web Feature Services (WFS), enabling systematic data exchange between agencies.

5. Conclusions

Land administration challenges in Indonesia, particularly at the local level, largely stem from the use of multiple, uncoordinated data sources and fragmented institutional responsibilities. In Karanganyar Regency, as an example, land parcel information is managed separately by different institutions, resulting in limited data integration and inconsistent spatial representations. The absence of integrated spatial datasets contributes to discrepancies in parcel area measurements, misalignment of parcel locations, and various administrative inconsistencies. Due to the difference in dataset characteristic—particularly in data acquisition methods and projection systems—direct merging cannot be performed without prior harmonisation.

The case study in Gonilan Village illustrates that harmonisation extends beyond simple coordinate transformation; geometric alignment is equally essential to ensure spatial accuracy. The Replace Geometry tool proved an effective solution for aligning parcel geometries, enabling corrections to boundary shapes while preserving attribute information. Nevertheless, some discrepancies remained unresolved due to substantial geometric and positional differences between the datasets, underscoring the need for complementary approaches, such as field surveys and institutional coordination.

While this research successfully harmonised and merged spatial data into a unified dataset, it did not fully achieve the level of interoperability required for a complete multipurpose cadastre. The remaining inconsistencies particularly those stemming from significant geometric mismatches and unresolved parcel discrepancies highlight that technical methods alone cannot address all integration challenges. Advancing toward full interoperability will require coordinated collaboration among key stakeholders, especially between the National Land Agency and local authorities. Community engagement is also essential to verify ground conditions and ensure that spatial data accurately reflects real parcel boundaries. At the same time, policy support is needed to standardise procedures, strengthen institutional roles, and ensure long-term data maintenance.

Ultimately, the development of a multipurpose cadastre at the local and regional level, such as in Karanganyar Regency, requires not only precise technical harmonisation but also a governance framework that promotes data sharing, institutional alignment, and public participation. Despite the challenges identified in this study, the findings demonstrate that an interoperable land information system is achievable within local administrative contexts. By integrating robust geospatial methods with strong inter-agency collaboration, inclusive stakeholder engagement, and supportive regulatory frameworks, land administration authorities worldwide can progressively develop multipurpose cadastres that improve operational efficiency, enhance transparency, and strengthen public service delivery.

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