An Automated Framework for Cadastral Parcel Adjustment Using UAV Orthophotos, SAM, and ICP

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Abstract

Accurate cadastral boundary data is essential for land administration, yet inconsistencies remain in many registered parcels in Indonesia due to legacy georeferencing systems, fragmented survey methods, and non-uniform base maps. This study presents an automated pipeline for improving the spatial quality of cadastral polygons by leveraging UAV photogrammetry, artificial intelligence, and geometric adjustment techniques. High-resolution orthophotos (5 cm GSD) were acquired over Cimahi City, Indonesia, using a VTOL UAV platform at 300 meters altitude. A zero-shot segmentation approach based on the Segment Anything Model (SAM) was employed to extract boundary indication segments, which were then classified into five land cover types using a Random Forest model. The SAM-derived segments were preprocessed using geometric rules (simplification, orthogonalization, and centerline extraction) and used as reference layers for alignment with existing cadastral polygons. Parcel grouping into blocks was performed automatically based on spatial proximity. Block-level alignment was conducted using the Iterative Closest Point (ICP) algorithm, followed by hierarchical least squares adjustment at three levels (LS1, LS2, LS3), depending on residual magnitude. Outliers were detected through statistical analysis of displacement vectors and flagged for shape and attribute matching. The methodology was tested on two urban villages—Karangmekar and Baros—comprising 177 blocks and 6,198 parcels. Results showed significant improvement in spatial accuracy, with mean displacement reduced from 0,8 meters to 0.4 - 0.5 meters. Geometric quality metrics (compactness, rectangularity, elongation, etc.) confirmed increased parcel regularity post-adjustment. The integrated workflow supports scalable cadastral data enhancement and is suitable for deployment in national land registration initiatives.

1. Introduction

Cadastral registration forms a fundamental pillar of agrarian governance in Indonesia. It guarantees legal certainty over land ownership, supports spatial planning, enhances land-based taxation, and underpins infrastructure development. Recognizing the urgency of land data integration, the Indonesian government launched the Complete Systematic Land Registration (CSLR) program in 2017, aiming to achieve full cadastral coverage of the country's land parcels by the end of the decade. The program targets the mapping and certification of over 126 million land parcels across urban and rural areas.

As of early 2025, approximately 107 million parcels have been recorded in the national cadastral database. However, a substantial portion of these records still suffer from spatial inconsistencies such as overlaps, gaps, duplicated geometries, or poor geometric alignment with physical boundaries. In addition, more than 13 million parcels that have been measured through field surveys remain unmapped spatially, often due to missing or outdated base maps. These deficiencies hinder land service efficiency and pose risks for tenure security, land dispute resolution, and digital integration of land information systems.

To address these issues, the National Land Agency (ATR/BPN) has adopted UAV photogrammetry as an officially supported mapping method to generate high-resolution orthophotos, typically with 5 to 10 cm ground sampling distance (GSD). These orthophotos serve as authoritative base maps for land registration and are especially valuable in rural and peri-urban areas where conventional surveys are logistically challenging. Several technical standards and operational guidelines have been issued to ensure the consistency and quality of UAV-based data acquisition and processing.

Moreover, UAV photogrammetry offers several advantages over airborne and satellite photogrammetry, including higher spatial resolution, lower operational costs, flexible mission planning, and accessibility to remote areas. These characteristics make UAVs highly suitable for producing parcel-level base maps required in CSLR workflows. In addition, UAV deployment allows on-demand data acquisition and faster orthoimage generation, which accelerates the land registration process—especially in rural or newly developed zones.

Despite these technological improvements, cadastral updating workflows remain partially manual. In particular, existing correction processes—such as block adjustments using least squares estimation—require trained operators to identify control points along parcel boundaries. This dependency on manual intervention limits the scalability of spatial anomaly correction in the context of a nationwide land registration program.

Advances in artificial intelligence (AI) offer potential solutions to this bottleneck. Zero-shot segmentation models such as the Segment Anything Model (SAM) can automatically extract boundary indications from UAV imagery without retraining, while geometric algorithms such as the Iterative Closest Point (ICP) enable flexible alignment between detected boundaries and existing cadastral polygons. These techniques, when combined with robust mathematical adjustment and shape matching, can support automated parcel refinement.

This paper proposes a method that integrates UAV photogrammetry and AI-based boundary analysis into a client-server framework, aiming to streamline parcel adjustment workflows and enhance the spatial quality of cadastral datasets. The approach aligns with national priorities under the CSLR program and provides a scalable technical pathway toward more accurate and intelligent land information systems.

2. Related Works

UAV photogrammetry has since become a widely adopted approach for cadastral mapping due to its ability to produce high-resolution and up-to-date orthophotos at relatively low cost and with flexible deployment. Šafář et al. (2021) demonstrated its integration into the official cadastral workflow of the Czech Republic. Similarly, Koeva et al. (2016) applied UAV imagery in Rwanda to support parcel delineation in areas lacking reliable base maps. Compared to satellite or manned aerial platforms, UAVs offer finer ground sampling distances—typically under 10 cm—making them suitable for capturing detailed parcel boundaries in both urban and rural settings.

Building upon the growing capabilities of AI in spatial data analysis, recent research has shown that deep learning models are increasingly effective in delineating visible parcel boundaries. For instance, Crommelinck et al. (2019) demonstrated the use of Mask R-CNN for precise boundary delineation from high-resolution imagery. This progress has been extended to agricultural land, where Vafaeinejad et al. (2025) utilized the Segment Anything Model (SAM) to reduce digitization time by up to 40% while achieving an IoU of 92%, leveraging SAM's key advantage as a foundation model that requires no additional training. Further refinement of SAM using LoRA has proven even more effective, with Hadir et al. (2025) showing its superior performance compared to other deep learning models in delineating complex agricultural parcels.

To address parcel anomalies, Safra and Doytsher (2006) introduced mutually-nearest and normalized-weight matching techniques followed by rubber-sheeting to adjust inconsistencies. In parallel, Vantas and Mirkopoulou (2025) employed clustering to detect and classify typical error patterns in cadastral data, facilitating automated recognition of spatial anomalies.

In terms of geometric alignment, the Iterative Closest Point (ICP) algorithm has been widely used to minimize spatial discrepancies between datasets, including adaptation for cadastral polygon alignment (Besl and McKay, 1992). For further refinement, block-level least squares adjustment models have been proposed as effective tools for improving spatial consistency, incorporating translation, rotation, and scale parameters (Kaufmann and Steudler, 1998).

In Indonesia, efforts to improve the spatial quality of cadastral parcel data have been ongoing for decades. One of the earliest contributions was made by Suparman (1992), who proposed an incremental development framework for land information systems (LIS) that included geometric correction methods such as block adjustment, rubber-sheeting, and partial polygonization. His methodology, designed for implementation within local government capacities, emphasized resolving issues of incomplete parcel registers, absence of reference systems, and dynamic database updates. This early work laid an important foundation for subsequent innovations in scalable cadastral data improvement. However, following Suparman's work, efforts to systematically improve the spatial quality of cadastral data were not continued either by academic researchers or by the National Land Agency (BPN). It was not until 2024 that a renewed focus on this issue emerged, led by our research group.

Recent works by our research group have advanced the use of AI-based methods for cadastral boundary enhancement. Ihsan et al. (2024) demonstrated how SAM can automatically extract parcel boundary indications from UAV orthophotos, producing displacement vectors usable as proxies for control points. Complementing this, Satwika et al. (2024) applied a least squares adjustment method to enhance Indonesia's cadastral maps, focusing on the preservation of parcel shape and area while introducing visual indicators such as error ellipses. While Ihsan et al. emphasized boundary segmentation and control point derivation, Satwika et al. addressed local misalignments and geometric inconsistencies using a single-stage adjustment model. The present study extends both efforts by integrating automatic boundary extraction, block-based ICP alignment, and hierarchical multi-stage adjustment strategies.

While these works offer strong foundations, few studies have attempted to integrate these components into a unified, operational workflow that supports real-world land administration needs. The current study builds on these previous efforts by combining UAV-based photogrammetry, zero-shot segmentation using SAM, ICP alignment, block adjustment, and shape matching into a scalable pipeline. Moreover, the approach is designed within a client-server architecture, reflecting the need for distributed processing in national cadastral systems. To our knowledge, this is one of the first practical implementations that merges AI-based boundary detection with adjustment modeling on UAV data in support of systematic land registration.

3. Methodology

This study presents a modular workflow that integrates UAV photogrammetry, artificial intelligence, and spatial adjustment techniques to refine cadastral parcel geometries. The methodology consists of several interconnected steps, as illustrated in Figure 1.

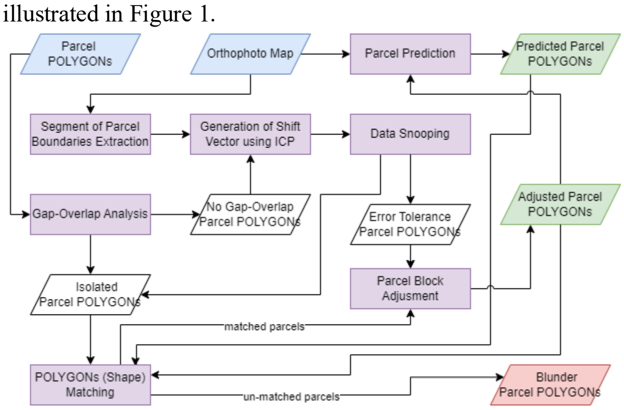

Figure 1. Methodology

3.1 Input Data and Study Area

High-resolution UAV orthophotos were acquired over the entire administrative area of Cimahi City, West Java, Indonesia, which spans a total area of 40.37 square kilometers and includes 15 urban villages (kelurahan). The aerial mapping was conducted in mid-2023 as part of the city's official geospatial modernization initiative, in collaboration with the Cimahi City Government, the Department of Public Works and Spatial Planning (DPUPR), Institut Teknologi Bandung (ITB), and the Cimahi Land Office.

The campaign aimed to generate up-to-date base maps and administrative boundary layers for urban planning and cadastral applications. The resulting dataset was produced at a mapping scale of 1:1,000 and formally validated by the National Geospatial Agency (BIG).

The UAV platform used for the project was a VTOL (Vertical Take-Off and Landing) fixed-wing system, chosen for its ability to efficiently cover large urban areas while operating from constrained environments. Flights were conducted at an altitude of 300 meters, capturing images with a Ground Sampling Distance (GSD) of approximately 5 cm. The flight planning ensured sufficient forward and side overlap for photogrammetric processing, with operational safety measures aligned with national aviation guidelines. Figure 2 presents the VTOL fixed-wing UAV platform used in this project, shown alongside the technical field team during deployment. The aircraft integrates vertical take-off and landing capabilities with efficient fixed-wing flight, enabling effective aerial coverage over urban environments such as Cimahi.

Figure 2. VTOL fixed-wing UAV platform and Team

For the purposes of this study, two urban villages (kelurahan) were selected as representative pilot areas. These areas include diverse land use patterns and parcel characteristics, making them suitable for evaluating the robustness and adaptability of the proposed parcel adjustment method. The orthophotos were integrated with existing cadastral polygon datasets obtained from the Cimahi Land Office, which served as the reference input for spatial alignment and adjustment.

3.2 Parcel Boundary Segmentation Using SAM

The UAV orthophotos were processed using the Segment Anything Model (SAM), a foundation model for image segmentation developed to support zero-shot learning. In this study, SAM was deployed in automatic mask generation mode, where the model generates multiple segmentation masks per image tile without any user-defined prompts. This mode allows the model to extract visible boundaries and homogeneous regions directly based on low-level image features such as texture, edges, and contrast.

From the automatically generated masks, a filtering step was performed to retain only those that matched typical land parcel boundary characteristics—such as closed shapes with consistent geometry, adjacency to roads or building outlines, or alignment with vegetation lines. These candidate segments served as the boundary indications that guided the alignment and adjustment of existing cadastral polygons in later stages.

The use of zero-shot segmentation ensured that the entire process remained fully automatic, enabling scalability to large datasets without the need for manual intervention or interactive annotation.

3.3 Land Cover Classification and Geometry Processing

Following boundary segmentation, land cover classification was performed on the UAV orthophotos to support parcel interpretation and anomaly detection. A supervised machine learning approach was applied using the Random Forest algorithm, which has proven effective in high-resolution image classification tasks due to its robustness to noise and ability to handle heterogeneous data.

Training samples were manually labeled on representative image tiles covering different zones of the study area. The classifier was trained using spectral and textural features derived from the RGB bands of the orthophoto. The resulting classification produced five main land cover classes: Buildings, Water bodies, Roads, Vegetation, and Open areas (bare soil, non-vegetated ground).

This classification supported both the filtering of relevant boundary segments and the prediction of potential parcel shapes based on contextual land use. In particular, boundaries adjacent to buildings and roads were prioritized as likely parcel delimiters, while boundaries within open or vegetated zones were further assessed for consistency and shape validity.

3.4 Geometric PreProcessing and ICP Alignment

To reduce spatial inconsistencies in the cadastral dataset, a geometric alignment process was carried out using the Iterative Closest Point (ICP) algorithm. The existing cadastral polygons were aligned collectively at the block level to the SAM-derived boundary segments, which were assumed to more accurately represent the physical parcel boundaries observable in UAV orthophotos.

Prior to ICP alignment, the SAM-derived boundary segments underwent geometric preprocessing to improve their suitability as alignment references. This included:

- Simplification, to reduce noise and small fluctuations along the polygon edges,
- Orthogonality enhancement, to regularize edges—particularly in built-up areas where boundaries are expected to be rectilinear,
- Centerline extraction, to generate lines within the gaps between adjacent SAM polygons. These centerlines often correspond to actual parcel boundaries, for example, between the walls of two neighboring houses or between buildings and small alleys.

Once the SAM-based boundary layers were refined, an automated spatial grouping step was performed to cluster individual parcels into cadastral blocks based on topological adjacency and proximity. This ensured that spatially coherent parcel groups were aligned as a unit.

For each block, the algorithm identified corresponding point pairs between the vertices of the cadastral block and the processed SAM-derived reference geometry (edges or centerlines). A rigid 2D transformation (translation and rotation) was computed to minimize the global distance between the source and target geometries.

The resulting block-level displacement vectors served as control inputs for the subsequent least squares block adjustment phase. This approach allowed for structured, spatially aware alignment that respects both the integrity of cadastral topology and the physical indications observed in high-resolution UAV imagery.

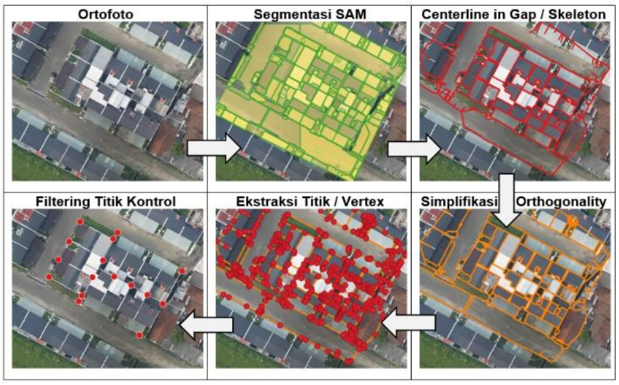

Figure 3. An illustration to produce a land parcel segment/border with possible control points for block adjustment.

3.5 Inlier Detection and Block Adjustment

After the ICP alignment process, each cadastral block was associated with a set of displacement vectors describing the spatial shift between original polygon vertices and the nearest SAM-derived reference geometry. These vectors were analyzed to detect inliers (reliable matches) and outliers (potential anomalies) prior to block adjustment.

Once the displacement vectors were obtained, inlier and outlier detection was performed through statistical analysis of their magnitude and directional consistency. For each cadastral block, the mean and standard deviation of vector lengths and angular deviations were calculated. Vectors that exhibited large deviations from the mean, either in terms of length or direction—typically beyond two standard deviations—were considered to be outliers, as they likely reflected misalignments or unreliable correspondences. In contrast, vectors that remained within a statistically consistent range were classified as inliers and subsequently used as input for the block adjustment process. This adaptive, data-driven method allowed for robust differentiation between reliable and anomalous matches across varying spatial conditions, while also avoiding rigid thresholding that may not generalize across diverse environments.

This approach allowed for adaptive detection that was sensitive to local geometric variations and did not rely on hardcoded distance thresholds. It also provided a basis for excluding erroneous or ambiguous matches, particularly in areas with incomplete boundary information or irregular SAM segmentation.

Once the inliers were identified, a block adjustment was performed using a least squares adjustment (LSA) method. The adjustment aimed to minimize the residuals between adjusted parcel vertices and the corresponding boundary indications derived from SAM. The process was carried out in three sequential stages:

- Stage 1: Rigid transformation using translation and rotation at the block level,
- Stage 2: Similarity transformation by adding uniform scaling,
- Stage 3: Individual parcel adjustment using a full 2D similarity transformation (two translations, one rotation, one scale) for each parcel within the block, if residuals remained significant.

This hierarchical approach ensured that adjustments were both topologically coherent and geometrically refined, allowing localized correction without disrupting the global structure of the cadastral blocks.

3.6 Outlier Correction via Shape and Attribute Matching

Although the main focus of this paper is on parcel alignment and inlier adjustment, some parcels identified as outliers through displacement analysis could not be corrected using block adjustment alone. These outliers typically exhibit large geometric deviations or lack sufficient boundary reference from the SAM-derived segments. In many cases, such discrepancies are not caused by recent mapping errors, but originate from legacy cadastral data collected using local reference systems. In Indonesia, for example, many older land parcels were mapped using non-georeferenced local systems, often referred to as “flying parcels”, which were drawn relative to neighboring parcels without connection to a consistent geodetic control network. As a result, these parcels may be mispositioned, rotated, or scaled inconsistently relative to the physical ground features captured in UAV orthophotos.

To address such complex outliers, supplementary correction strategies are under development as part of ongoing research and will be presented in future publications. One of the approaches currently being explored involves shape-based matching using Fourier descriptors, which encode parcel geometries in the frequency domain for similarity comparison against known or predicted shapes. In parallel, attribute-based matching methods are being investigated using graph-based representations of cadastral and contextual information, enabling semantic linking between unmatched parcels and candidate references within the spatial knowledge base.

While these techniques are still under refinement, their integration is expected to support more robust correction of isolated or anomalous parcels, particularly in areas with complex land use or irregular topology.

3.7 Geometric Evaluation

To assess the effectiveness of the Segment Anything Model (SAM) and subsequent adjustment procedures in improving cadastral boundary accuracy, we conducted a geometric evaluation using both shape-based and vector-based indicators. The evaluation aimed to measure how well the adjusted cadastral parcels aligned with the visible boundaries extracted from SAM-derived segments.

The first part of the evaluation focused on geometric fragmentation analysis, which quantified the number of splits in SAM polygon masks caused by intersecting cadastral boundaries. Three adjusted datasets—LS1, LS2, and LS3—were compared based on how frequently the adjusted parcels fragmented the underlying SAM polygons. A lower number of fragments was interpreted as a stronger geometric alignment, suggesting that parcel boundaries more closely followed visible real-world features. Effectiveness scores were calculated based on the relative reduction in fragmentation compared to the unadjusted data, and analyzed per cadastral block and across adjustment stages.

In addition to fragmentation, we analyzed displacement vectors obtained from the ICP process to evaluate the spatial improvement of each cadastral block. For every block, we computed the mean and standard deviation of displacement magnitudes before and after adjustment. A consistent reduction in average displacement and variance was observed, particularly in the LS2 and LS3 datasets, indicating improved geometric conformity with the SAM-derived reference. These statistics were supplemented with vector diagrams, visualizing the direction and intensity of parcel shifts across selected blocks, further validating the quantitative improvement.

Together, these two evaluation strategies—fragmentation-based and displacement-based—provided a comprehensive geometric assessment framework. They demonstrate that the proposed methodology not only improves boundary shape coherence but also enhances positional accuracy in relation to real-world imagery.

4. System Architecture and Implementation

To ensure scalability and modularity in processing cadastral data, the proposed system was implemented using a client-server architecture. This architecture separates computationally intensive tasks—such as segmentation and anomaly detection—from interactive spatial adjustment and visualization, allowing for both centralized processing and distributed usage across regional land offices.

The server-side is developed using a Python-based REST API framework and is responsible for the main AI-driven components. These include the automatic segmentation of UAV orthophotos using the Segment Anything Model (SAM), which produces boundary indication segments without manual prompting. Additionally, the server handles spatial anomaly detection by analyzing displacement vectors generated through ICP alignment and supports parcel prediction by synthesizing geometric patterns from land cover classifications. Although not the primary focus of this paper, an ongoing module is also being developed to perform outlier correction via shape and attribute matching, using Fourier descriptors and knowledge graph representations. All intermediate and final results are stored in a PostgreSQL/PostGIS spatial database, which acts as the central repository for both raw and adjusted cadastral data.

On the client side, a custom plugin was developed for the QGIS desktop platform, serving as the user interface for surveyors or cadastral officers. The plugin enables users to upload orthophoto tiles and cadastral polygon layers, select cadastral blocks, and retrieve boundary indication segments and anomaly diagnostics from the server. Using this information, the client executes ICP-based alignment per cadastral block, followed by least squares-based block adjustment in up to three stages (rigid, scaled, and parcel-level transformations). Visualization tools allow users to view residual displacement vectors, fragmentation metrics, and adjusted geometries. Final outputs can be exported in various formats (GeoJSON, Shapefile) or synchronized directly with the server's spatial database.

Communication between client and server follows a lightweight protocol based on HTTP POST and GET requests, using GeoJSON or WKT formats to transmit geometries. All spatial operations preserve coordinate reference systems and are designed to comply with standard OGC specifications. This architecture allows institutional land agencies to deploy centralized AI services—hosted on local servers or in the cloud—while enabling regional offices to perform parcel-level refinement independently and efficiently.

Overall, the system provides a flexible and operationally practical platform that bridges AI-based automation with human-in-the-loop spatial decision-making. It is designed not only for research use but also for real-world deployment in national cadastral improvement initiatives.

5. Experiment and Results

5.1 Study Area and Dataset Overview

The proposed method was tested on two pilot areas in Cimahi City, West Java, Indonesia: Karangmekar and Baros, representing different urban environments with varying parcel densities and land use patterns. Both areas were covered by the UAV mapping campaign conducted in 2023 as part of the city's geospatial modernization initiative. The orthophotos used in this study were captured using a VTOL UAV at an altitude of 300 meters, with a Ground Sampling Distance (GSD) of approximately 5 cm, and processed to a mapping scale of 1:1,000.

Figure 4. Overlay of cadastral parcel polygons on UAV orthophoto background in Karangmekar

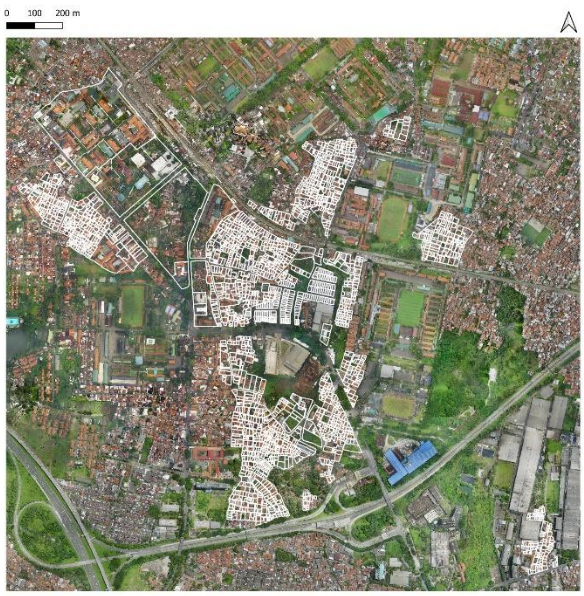

Figure 5. Overlay of cadastral parcel polygons on UAV orthophoto background in Baros

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The Karangmekar dataset consists of 81 cadastral blocks comprising 3,227 parcels, while Baros includes 96 blocks with 2,971 parcels. Existing cadastral polygons for both areas were obtained from the Cimahi Land Office and served as the input geometry for alignment and adjustment. SAM-derived boundary segments were generated from UAV orthophotos for the full extent of both kelurahan, and the processing pipeline was applied identically to both datasets.

These two urban villages were selected to evaluate the robustness and generalizability of the proposed method, given their contrasting block structures and cadastral data quality. Karangmekar contains denser housing with smaller parcels, while Baros exhibits more irregular patterns and transitional land use. The inclusion of both allows for a broader assessment of geometric correction effectiveness across diverse cadastral scenarios.

5.2 Adjustment Results and Fragmentation Reduction

To evaluate the geometric improvement of cadastral boundaries after adjustment, we compared the number of polygon splits introduced to SAM-derived boundary segments by the original cadastral data and by the three adjusted versions: LS1 (rigid block adjustment), LS2 (scaled block adjustment), and LS3 (individual parcel-level adjustment). The number of splits was used as a proxy for fragmentation, with fewer splits indicating better alignment between cadastral polygons and the SAM-derived reference geometry.

A comparison between the original parcel boundaries and the adjusted datasets (LS1, LS2, and LS3) reveals a clear enhancement in spatial accuracy when corrections are guided by the Segment Anything Model (SAM). As shown in the Figure 16, the original boundaries frequently intersect segmented objects, indicating a misalignment with real-world physical features. This pattern reflects inconsistencies in the cadastral dataset, where parcel lines fail to conform to observable terrain or built-environment edges.

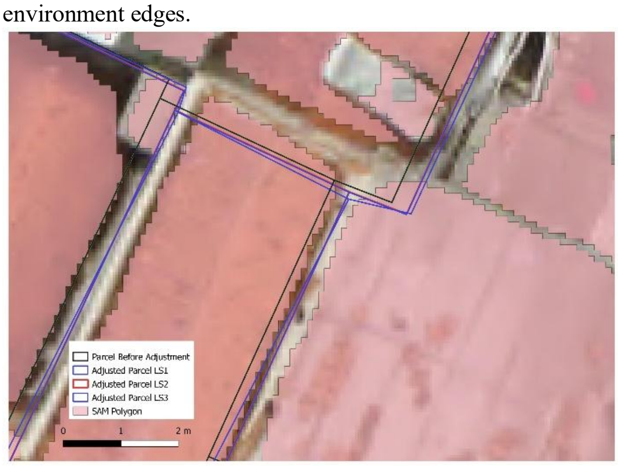


Figure 6. Overlay of original and corrected parcel boundaries (LS1–LS3) on SAM segmentation

The results, summarized in Table 1, show a consistent reduction in fragmentation across both study areas. In Karangmekar, the number of polygon splits decreased from 16,359 in the original dataset to 15,777 after LS1, 15,695 after LS2, and 15,209 after LS3. In Baros, fragmentation decreased from 22,143 (original) to 21,679 (LS1), 21,583 (LS2), and 20,896 (LS3). This represents an overall reduction of approximately 4–7% in geometric fragmentation after full parcel-level adjustment (LS3), indicating improved boundary alignment and fewer artificial splits.

These results indicate that even the initial block-level adjustment (LS1) already contributed significantly to improving the fit between legal cadastral data and physical boundary evidence. However, further refinement through scaling and parcel-level transformation (LS2 and LS3) was crucial for capturing more nuanced geometric relationships, especially in irregular or tightly packed areas.

Dataset	Karangmekar	Baros
Original (Unadjusted)	16,359	22,143
LS1 (Rigid)	15,777	21,679
LS2 (Scaled)	15,695	21,583
LS3 (Parcel-level)	15,209	20,896

Table 1. Number of SAM Polygon Splits by Cadastral Boundaries Before and After Adjustment

Visual inspection further confirmed that parcel boundaries in the LS3 dataset more accurately aligned with road edges, building outlines, and inter-building gaps, reflecting the improvements suggested by the fragmentation metrics.

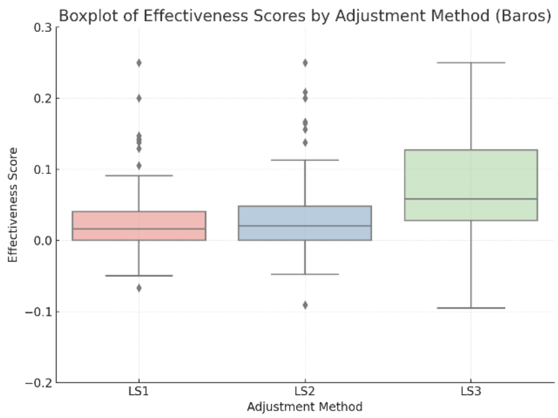


Figure 7. Boxplot of effectiveness scores for each adjustment

These trends are further confirmed by the distribution of effectiveness scores across all blocks. The boxplot visualization highlights LS3 as the most effective method, with the highest median score and a broader spread of high-impact cases. In contrast, LS1 and LS2 show limited variation and generally low effectiveness across the study area. These results suggest that integrating SAM into correction workflows—particularly those similar to LS3—substantially enhances the positional accuracy of cadastral boundaries, aligning them more closely with real-world object geometry.

Figure 8 illustrates the mean displacement magnitude and standard deviation across cadastral blocks before and after successive adjustment stages (LS1–LS3). Prior to adjustment, several blocks exhibited mean displacement exceeding 2 meters, with notable variance within blocks. The application of block-level transformation (LS1) substantially reduced both the mean and variance, although certain blocks still retained internal inconsistencies. LS2, which introduced scaling, further homogenized the displacement distribution. Finally, LS3 (parcel-level adjustment) resulted in near-uniform alignment, with most blocks showing mean displacements below 1 meter and minimal variance, confirming the cumulative effectiveness of the hierarchical adjustment framework.

Figure 9 depicts the mean and standard deviation of displacement directions across blocks before and after hierarchical adjustment. Initial vectors exhibited wide directional dispersion, reflecting inconsistencies in legacy mapping. The LS1 adjustment significantly aligned block-level directions, though internal variation persisted. LS2 further reduced directional spread, especially in blocks with non-uniform deformation. Finally, LS3 achieved near-uniform alignment, with most blocks converging toward a common directional mean and minimized intra-block variance. This progression confirms the effectiveness of multi-stage correction not only in magnitude but also in directional coherence.

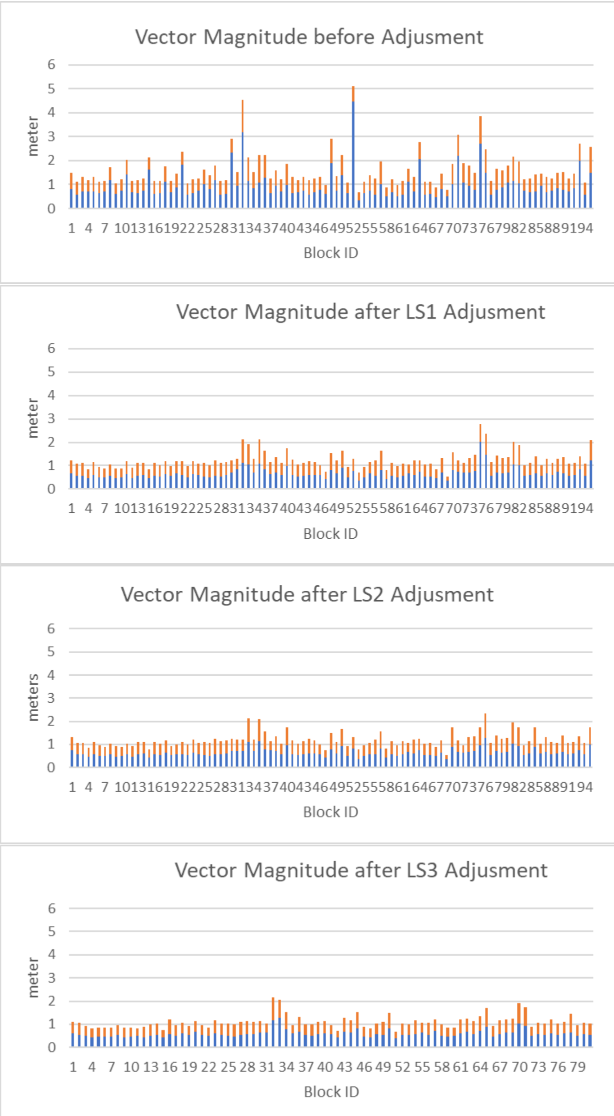
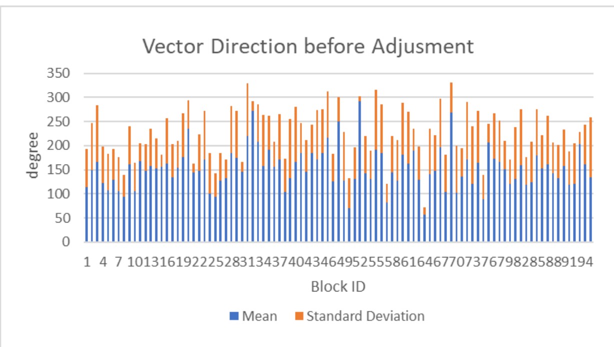


Figure 8. Vector Displacement Magnitude



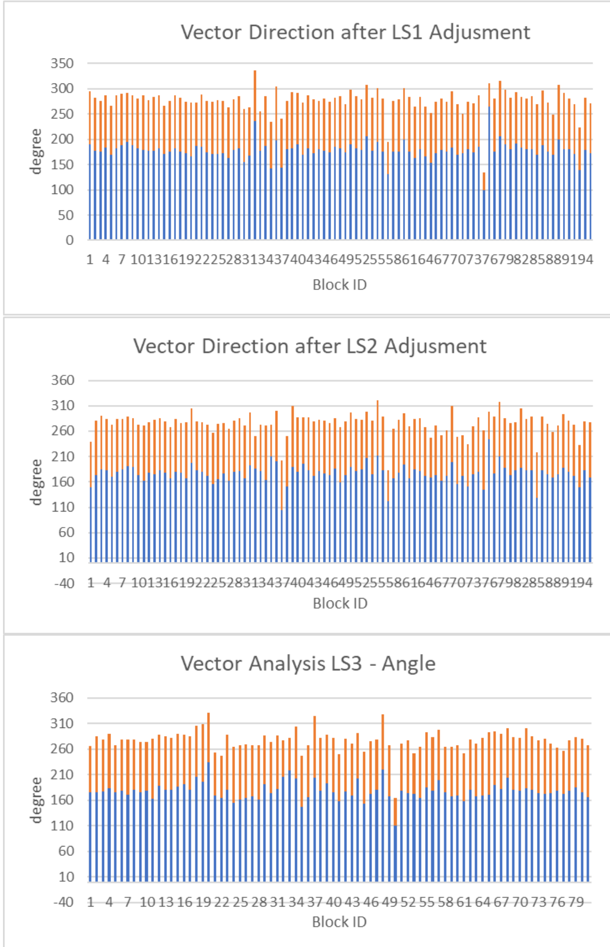


Figure 9. Vector Displacement Direction

5.3 Discussion of Performance

The results from both fragmentation and displacement analyses highlight the overall effectiveness of the proposed UAV-AI-based adjustment method in improving cadastral spatial quality. Across both study areas, there was a consistent and significant reduction in polygon fragmentation and average displacement, particularly after the final adjustment stage (LS3). These improvements were not only evident numerically, but also visually through cleaner alignments with SAM-derived features such as building outlines, alleyways, and vegetation edges.

The hierarchical adjustment model—progressing from rigid (LS1) to scaled (LS2) and finally to parcel-level transformation (LS3)—proved especially valuable in balancing computational simplicity with geometric accuracy. In many well-structured urban blocks, LS1 or LS2 alone produced sufficiently accurate results. However, in more irregular or historically misreferenced areas, LS3 was essential to reduce residual errors and adapt to local anomalies.

It is also worth noting that outlier parcels—those with large displacement vectors or poor fit to SAM boundaries—remained even after LS3. These often corresponded to legacy data mapped using local reference systems (flying parcels), or areas where physical boundaries were obscured due to tree canopy, construction, or occlusion. For these cases, additional correction techniques involving shape and attribute matching are still under development and will be covered in future work.

From an operational perspective, the client-server architecture enabled efficient task separation: AI-driven boundary detection and anomaly analysis were processed centrally, while block-level refinement was handled interactively through the QGIS client. This modular design supports scalable deployment across regional cadastral offices and aligns with institutional workflows in Indonesia, where UAV mapping is now officially used for land registration basemaps under the PTSL program.

Overall, the integration of UAV photogrammetry, SAM-based segmentation, ICP alignment, and least squares adjustment represents a promising direction for automated, high-accuracy cadastral data improvement, especially in regions with legacy inconsistencies or lacking reliable base maps.

6. CONCLUSION

This study presented an integrated workflow for parcel boundary adjustment using UAV orthophotos, the Segment Anything Model (SAM), and geometric correction via ICP and least squares adjustment. The approach was designed to enhance the spatial quality of existing cadastral datasets in an automated manner, with minimal operator intervention.

Applied to two urban villages in Cimahi City, Indonesia, the method demonstrated consistent improvements in both geometric alignment and spatial consistency, as measured through fragmentation reduction and displacement analysis. The hierarchical adjustment strategy—from block-level rigid transformation to parcel-level fine tuning—proved effective in correcting legacy cadastral distortions, including those originating from earlier sporadic survey and mapping efforts that lacked geodetic control or consistent spatial referencing.

The integration of AI-based segmentation, statistical inlier detection, and adjustment modeling, combined with a client-server architecture, allows the system to scale for broader institutional deployment. This is particularly relevant in the context of Indonesia's national land registration program (PTSL), where millions of parcels still require accurate spatial delineation.

Future work will focus on extending the framework to support outlier correction using shape and attribute matching, and to integrate 3D cadastral representation for urban vertical development and complex land tenure. The method also opens possibilities for temporal change detection, enabling continuous updating of cadastral maps using recurrent UAV surveys.

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