

Five Pillars of GIS Automation for Scalable Land Tenure Documentation

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1 Introduction

Secure and documented land tenure is foundational for economic development, environmental stewardship, and social stability. Yet in developing countries, it is estimated that up to 90 percent of landholdings are not documented, administered, or protected¹, constraining the landholders' long-term security of occupation and use of the land, their access to government services, formal land markets and potentially credit. Weak tenure administration systems often impede sustainable resource management and productive land use, limit investment, and create overlapping or conflicting claims that cause disputes that can escalate into conflict.

Conventional approaches to land documentation—reliant on paper-based surveys, manual sketch mapping, and subsequent data digitization—are slow, costly, and difficult to scale. Traditional field surveys can take months or years to translate into formal land registry records, and errors introduced during data entry or interpretation compound over time. This limits coverage and undermines institutional and land market confidence in the data. As a result, governments and development partners are increasingly exploring automation-driven, GIS-enabled workflows that can reduce operational costs, ensure data integrity, and quickly deliver scalable outputs.

Recent frameworks such as the Fit-for-Purpose Land Administration (FFPLA) approach² and the UN-GGIM Framework for Effective Land Administration (FELA)³ emphasize the need for flexible, inclusive, and scalable systems. These frameworks call for land data to be complete, current, consistent, and interoperable—principles that align closely with automation-driven GIS methods. When well designed, workflows can accelerate mapping of land parcels, enhance data accuracy, reduce cost per parcel, and facilitate seamless integration into land information systems and national land registries, thus accelerating the provision of land tenure security.

This paper presents a five-pillar structured approach to automation-driven land tenure documentation that can be applied in both government-led and community-driven efforts. There are consistent challenges in the typical tenure documentation processes that can be improved through the structured automation approach outlined in this paper. A standardized data infrastructure is central to scalability, interoperability, and long-term sustainability of land tenure documentation systems and this can be achieved through simple innovations in GIS automation. Standard, trusted, interoperable data is also crux to inter-agency data sharing and can lead to more collaboration and transparency at the government

¹ UN-Habitat. (n.d.). *Land tenure security*. Retrieved from <https://unhabitat.org/topic/land-tenure-security>

² Enemark, S., Bell, K. C., Lemmen, C., & McLaren, R. (2014). *Fit-for-Purpose Land Administration* (FIG Publication No. 60). International Federation of Surveyors (FIG) & The World Bank. Retrieved from <https://www.fig.net/resources/publications/figpub/pub60/Figpub60.pdf>

³ United Nations Committee of Experts on Global Geospatial Information Management. (2020, May). *Framework for Effective Land Administration* (E/C.20/2020/29/Add.2). United Nations. Retrieved from https://ggim.un.org/meetings/GGIM-committee/10th-Session/documents/E-C.20-2020-29-Add_2-Framework-for-Effective-Land-Administration.pdf

level, and eventually laying the groundwork for more advanced data modeling such as computer assisted mass appraisal, blockchain registries, and AI boundary extraction.

2 Challenges and Rationale

Manual approaches are typically limited by five key challenges: operational inefficiency and high costs; inconsistent data standards; fragmented institutional systems; limited capacity and scalability constraints; and risks to data reliability and institutional trust. This section explores the nuances those challenges pose in the land tenure documentation process.

Operational Inefficiency and High Costs: Traditional land documentation processes involve multiple manual stages—field sketching, paper forms, data entry, and map production—that each introduce delays and errors. Ranges for costs vary across the globe but the World Bank cites that in countries such as Rwanda, Namibia, Madagascar, Tanzania, and Ethiopia the average cost per parcel in a systematic land registration program was about US\$50 per parcel, and could be lowered US\$10–US\$20 through the use of aerial orthophoto maps and rectified satellite imagery.⁴ The USAID-funded Mobile Applications to Secure Tenure program, which used piloted a set of digital tools for land registration, reported that mobile applications for surveying plots moved the registration cost from USD\$40 per parcel in Tanzania, to USD\$20.57 per parcel during the pilot phase, and going all the way down USD\$7.85 per parcel when implemented at scale in 2019.⁵ Technological advancements have shown to lower the cost of land registration but this would still equal billions of dollars to scale up tenure efforts across Sub-Saharan Africa. Advancements with the use of technology need to continue in order to reduce the costs of surveying, registering land, digitizing records, the costs of documenting communal and individual land tenure will fall. Additionally, manual processes can create delays between field capture and issuance of documents that span months and in some cases years, creating backlogs and reducing public confidence in the system.

Inconsistent Data Standards: Manual approaches often produce data that varies across teams, districts, or projects. Field teams may use different coordinate systems (e.g., WGS84 vs. local UTM zones), inconsistent attribute schemas, and varying spatial precision. This heterogeneity makes data merging and analysis difficult and time consuming, creates boundary overlaps or gaps, and can result in outputs being rejected by government cadastral authorities and undermines social acceptance of the process.

Fragmented Institutional Systems: Land governance is typically fragmented across multiple agencies (e.g., land administration, forestry, environment). Responsible authorities often maintain siloed data systems with limited interoperability. Without standardized data structures and application programming interfaces (APIs), integrating new tenure datasets into existing systems or sharing boundary information between institutions is cumbersome, prone to duplication, and can lead to conflicting authoritative records and confusion and disputes on the ground.

⁴ World Bank (2016, June). *Project Appraisal Document on a Proposed Grant to the Republic of Mozambique*. Available at: <https://documents1.worldbank.org/curated/en/160861467817940751/pdf/PAD1497-PAD-P149620-OUO-9-IDA-R2016-0161-1-Box396267B.pdf>

⁵ Reydon, Bastiaan (2021, May). “Land Administration and Systematic Titling: Methods and Cost Trends.” *Proceedings of the FIG Working Week 2021*. Available at: https://www.fig.net/resources/proceedings/fig_proceedings/fig2021/papers/ws_09.2/WS_09.2_reydon_10927.pdf

Limited Capacity and Scalability Constraints: Scaling land documentation from pilot to district or national level increases demands on technical expertise, hardware, management and technical oversight. Manual quality control is not feasible at large scales, and errors spread as systems grow. In a low or no tech environment, scaling up outputs requires proportional increases in personnel and budget, which many institutions cannot afford to establish or sustain.

Risks to Data Reliability and Institutional Trust: Data inconsistencies: such as missing attributes, outdated records, or occasional coordinate errors; can naturally make government agencies cautious about adopting or integrating mapping outputs. The issue is less about blame and more about the absence of clear, reasonable standards that all actors can align with. When authorities articulate such standards, help validate data against them, and offer technical support to meet those requirements, community-generated or NGO-produced datasets can more easily become part of formal systems. This shifts the approach from governments having to redo the work themselves toward enabling partners to produce data that is accurate, interoperable, and institutionally trusted.

3 Automation-Driven Approach

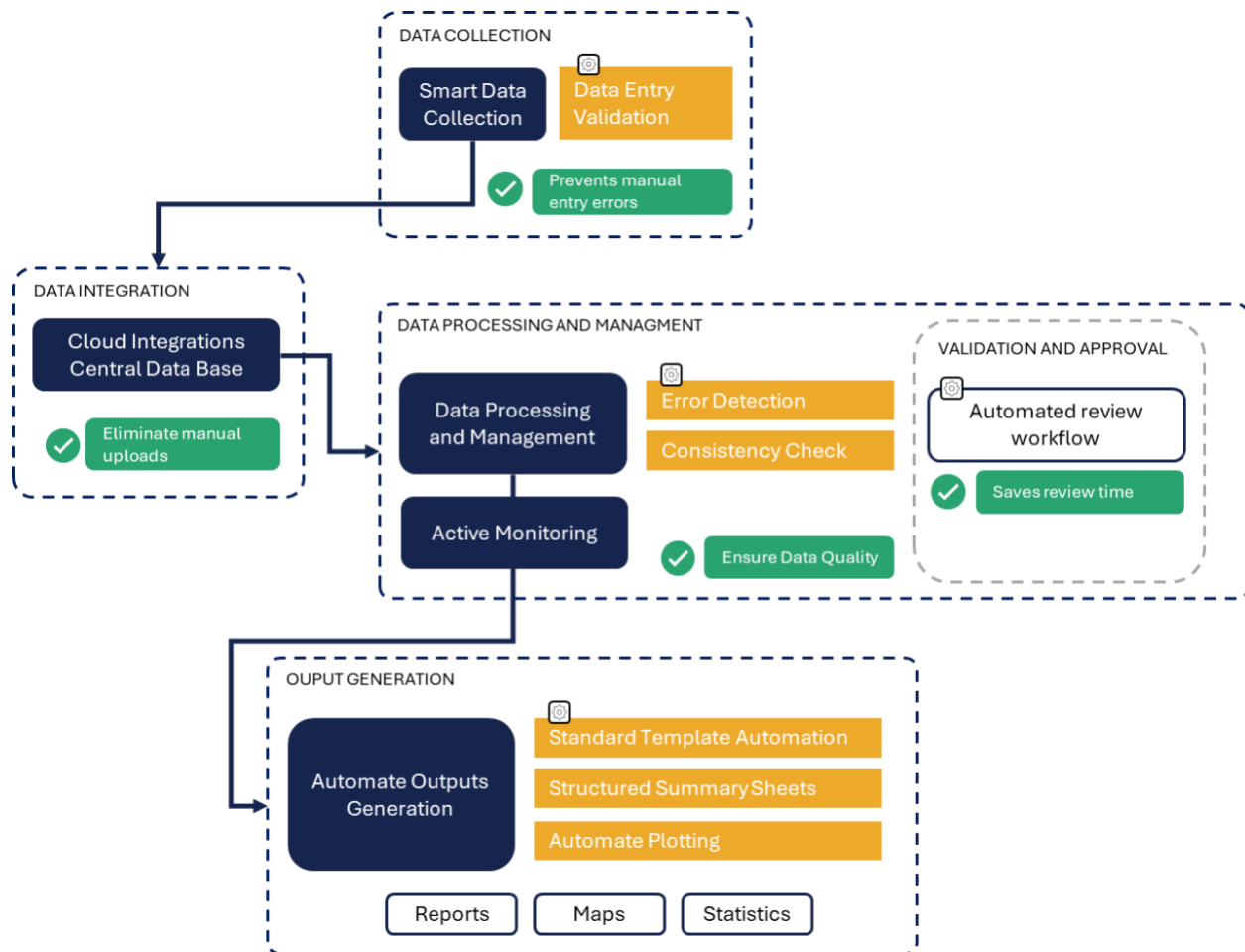
An automation-driven approach addresses the challenges of manual approaches by combining standardized data models, digital field capture tools, cloud-based databases, automated quality control, and standardized outputs. This section outlines five key pillars that can be adapted to either government-led or community-supported initiatives.

- 1. **Standardized Data Capture**
- 2. **Automatic Data Flow to Central Database**
- 3. **Automated Quality Control (QC)**
- 4. **Automated Outputs and Document Generation**
- 5. **Data Interoperability and Standardization**

The approach identifies repetitive, time-consuming, or error-prone tasks and implements digital solutions to perform them automatically or semi-automatically. Rather than being built around a specific software package, the methodology is tool-agnostic: it emphasizes workflow and standards so that different technology stacks (proprietary or open-source) can be employed as needed in each context.

This methodology also necessitates special attention to local knowledge and context at the configuration stage. Before deployment, local partners (community leaders, surveyors and data collectors and government liaisons) and context dictate the requirements of the survey forms, data fields, and workflows to fit the local legal and cultural context. This is merely a framework that should be adjusted according to each context.

Figure 1: Automated Tenure Workflow Graphic



1. Standardized Data Capture

In contrast to manual/paper-based data collection using sketch maps, written attribute forms, and GPS coordinate logs, mobile applications (e.g., Survey123, ODK, Kobo Toolbox) allow field teams to collect geospatial data (e.g., parcel boundaries) at high accuracy and attributes with preconfigured rules-based forms. These forms can enforce adherence to:

- Mandatory fields (e.g., claimant ID, land use code, tenure type);
- Coordinate system and accuracy thresholds;
- Dropdown value lists for standardized codes; and
- Built-in logic (e.g., communal vs. individual tenure).

Use of automated rules-based forms eliminate transcription errors and inconsistent, erroneous or unacceptable data collection that does not adhere to standards and requirements. Introduction of standard digital forms that align with contextual requirements, ensures that data is ready for automated processing immediately after collection.

2. Automatic Data Flow to Central Database

Cloud-based spatial databases (e.g., PostGIS, Geoserver, or enterprise ArcGIS Server) enable real-time data synchronization—where field updates are instantly sent to the central database when connected to the internet—or offline synchronization, where data collected without connectivity is automatically uploaded once a connection is restored. Advantages of a central Cloud-Based database include:

- Version control and data lineage tracking;
- Multi-user access with role-based permissions;
- Automated backups and security measures; and
- API integration with other government systems.

Automating the data flow from survey/data collection device to server ensures that the information from hundreds of surveys aggregates instantly in a single location without manual uploading of files. This architecture allows multiple field teams to collect data simultaneously while maintaining a single authoritative source accessible to government or other applicable reviewing institutions. This not only saves time but also reduces the risk of data loss. No more USB drives or Excel sheets that can be misplaced. A centralized database also means that various stakeholders can track field progress live and data can be readily input into project monitoring dashboards.

3. Automated Quality Control (QC)

As new data comes into the system, a series of automated quality control (QC) checks and geoprocessing routines run on the central server. Automated QC scripts or built-in platform capabilities in GIS ModelBuilder, Python, or R can readily validate or reject data for:

- Topology: detect gaps between parcels, boundary overlaps, or self-intersections;
- Attribute completeness and valid code lists;
- Coordinate reference consistency; and
- Area computation and comparison to allowable thresholds.

These automated geoprocessing steps allow technology to handle repetitive tasks, reducing the burden on staff to manually and meticulously review every entry. Automated QC reduces error detection time from days to minutes, enabling only validated parcels to proceed to map and document generation. This contrasts with traditional approaches where issues might only be discovered after data collection, requiring return visits to the field to correct and validate data that are both costly and reflect poorly on the credibility of the data collection effort with the community.

4. Automated Outputs and Document Generation

Automated scripts can populate map layouts and legal document templates directly from validated spatial data. This enables:

- Generation of tenure certificates with boundary maps, claimant data, and legal references;

- Batch export of hundreds or thousands of parcels simultaneously; and
- Linkage to parcel-based taxation systems or valuation databases.

Once the data passes quality checks, systems can automatically generate standard map outputs and documents. This approach reduces manual processing time per document and provides immediate preliminary visual outputs that can be discussed within the community as needed.

5. Data Interoperability and Standardization

A standardized data collection structure ensures that outputs are organized to meet the contextual requirements and can assist with integrating data into official/national cadastral and registry systems. Best practices include:

- Maintaining metadata on the Coordinate Reference System, data quality, and capture methods;
- Using interoperable formats (GeoJSON, GML, LandXML); and
- Assigning globally unique parcel identifiers.

By following these types of standards for data format, it can reduce the friction often encountered between government entities with data produced by the community. Such measures enable horizontal interoperability across agencies and vertical integration into national systems. Keeping data interoperable helps to eventually integrate systems across institutions. Interoperability allows this data compatible and exchangeable across other services, such as land valuation, property tax systems, and land use planning or resource management, enriching the data sets and creating robust, sustainable, and usable information across different land-related government agencies and departments.

4 Use Cases

This section presents three implementations of the automation-driven approach in different contexts:

- District government-led village boundary mapping in Indonesia;
- Large-scale customary forest and parcel mapping in Myanmar; and
- State government-led issuance of Individual and Community Forest Rights in India.

Each of the cases demonstrates how GIS automation increased scale, efficiency, and data integrity, while producing standardized outputs acceptable to government agencies.

Table 1: Summary of Case Study Results

Country	Scale	Workflow Highlights	Outputs	Efficiency Gains
Indonesia	1 village covering 9 hamlets	Mobile capture, cloud sync, auto-typology	Boundary maps that are validated by district offices	Validation reduced from weeks to days
Myanmar	3,000,000 + ha	Mobile forms, cloud QC, bulk document gen	30,000 tenure documents issued	5x faster per-parcel processing
India	64,000 Parcels, 58,000 households	Data Collection, Automated Map Preparation	70% claim approval rate upon submission to relevant authorities ⁶	700% Efficiency Gain in time spent

Indonesia: District-Level Village Boundary and Land Use Mapping

Indonesia's Ministry of Home Affairs (MoHA) has supported district governments in determining, setting (delineation and demarcating) and legally formalizing village boundaries as part of broader government decentralization efforts. In Central Lombok District, the district government partnered with technical NGO Yayasan Puter Indonesia to implement a fully automated GIS workflow for village boundary setting, while additionally collecting social, cultural and natural resource, and land use data.

In Labulia Village, field teams used GPS-enabled mobile data collection forms configured with a land use list, standard natural and cultural resource categories, and GPS capabilities to record points in WGS84 coordinates. Once online, data synchronized to a server. Automated QC processes checked for overlapping polygons, slivers, and attribute completeness. Draft maps and project dashboards were generated immediately upon QC approval using preformatted templates, with various government institutions able to review and approve of the boundaries days after data collection completion.

The project was implemented in three months, with three weeks spent on data collection and one week for processing and validation, capturing the village boundaries that spanned over one thousand hectares with over four thousand households within those boundaries. Both village and district officials lauded the quality and quantity of the data, with the Labulia Village Administration noting the results of this activity can be used to improve the village administration information system, while simultaneously adhering to the standards of MoHA the database and supporting the Government of Indonesia One Map Policy⁷. The data's adherence to standard schemas enables seamless integration with official systems.

Myanmar: Large-Scale Community Forest and Parcel Mapping

In upland regions of Myanmar, civil society organizations and local authorities have supported documenting community forests and smallholder parcels to strengthen tenure security. Over the course of this work, mapping was conducted across more than three million hectares.

Multiple teams collected parcel and forest boundaries with standardized data schemas across different surveys that were deployed. A decentralized process allows individuals in different locations to be assigned tasks for completion and moves the data to the next step automatically, making the processes more efficient. All teams used a unified coordinate system and field coding schema. Data synchronized to

⁶ Internal reporting from relevant authorities, not publicly available.

⁷ Details on the One Map Policy and implementation can be found here: <https://onemap.big.go.id/>

a centralized cloud platform where automated scripts flagged geometry overlaps, missing attributes, and inconsistent IDs. Once processed and approved, tenure documents based on preset layouts (with maps, claimant names, parcel IDs, and legal references) in PDF format were automatically generated.

Depending on the pace of field data collection and validation, tenure documents can be produced at a massive scale. The integrate processes allows the generation of tenure documents within hours of completion of field activities due to the data workflow being automated and teams working simultaneously, validating data as it comes into the data center. To achieve scale, documents were generated in batches rather than individually, allowing for documents to be produced simultaneously as opposed to processing records individually. Over 30,000 tenure documents were produced in batch runs in total. Manual methods had previously required months of digitization and layout per area. The standardized data model allowed datasets to flow neatly into the other toolkits. This case illustrates how automation enables rapid scale-up in remote areas, while maintaining technical quality to oversee large forested areas, as well as individual parcels.

Previously, the implementing team managed various Excel and shapefiles locally, which often led to duplication and made data management and integration difficult. Additionally, transferring files across different systems often resulted in data corruption and quality issues.

India - Forest Rights Act (FRA) Documentation

In Gujarat's tribal belt, civil society organizations (CSO) have been working to support Scheduled Tribe⁸ communities in securing land rights under the Forest Rights Act (FRA). This case from Gujarat demonstrates how automation-driven GIS workflows can be adapted for community-led forest tenure formalization at scale.

Field teams deployed mobile-based survey forms to capture both spatial and textual claim attributes (parcel boundaries, claimant details, supporting documents). Over the course of five years, over 60,000 hectares were mapped using this method, with the survey forms configured to collect the information necessary for revenue and forest authority officials to review the claims. Data synchronized directly to the cloud platform, enabling error-checking scripts to flag missing attributes, geometry overlaps, and coordinate inconsistencies. Field teams reported that this process took two days, whereas previously it took 16 days, a 700% increase in efficiency⁹, without factoring in the additional benefits of increased quality output and improved transparency.

As data flowed in, the system was configured to auto-number claims and parcels to avoid duplication and maintain consistency. On the ground data collectors and data validators were trained on modules pertaining to automation of map series generation, ensuring survey teams could rapidly create claim maps aligned with FRA required templates. A workflow was established for smooth data sharing between surveyors, CSO offices, and government verification bodies. Automated monitoring dashboards were developed, which enabled live tracking of survey progress, claim status, and approval rates as the work progressed.

⁸ Scheduled Tribes (STs) in India refer to the various indigenous communities or tribes that are recognized by the government for special protection and assistance.

⁹ This figure is based on internal operational project data reporting.

The Indian advisory services firm, LandStack, produced an assessment in 2024 evaluating the impact of this technology and methodology in the land and forest tenure sector, examining the implementation of the team in Gujarat¹⁰. LandStack noted the following efficiency gains:

- 74% of surveyors reported a major reduction in time for mapping;
- 79% of claimants said the process became easier with mobile-based mapping;
- 70% of participants expressed high trust in the digital outputs; and
- 79% of participants felt the evidence was better than manual methods because of accuracy and boundary clarity.

5 Scaling and Future Opportunities

A pro-digitization administration and policy is at the core of this work. Institutions will need to budget not only for initial deployment of technology (capital costs) to ensure ongoing digitization, but also for long-term system upkeep (recurrent cost) in addition to developing processes for continual data updating, which are critical for sustaining integrity, reliability and ultimately, trust in the system. Automation-driven tenure documentation addresses the core operational challenges of scale, cost, and data quality. Clean, standardized data creates opportunities for additional land governance functions and aligns with global best practices.

Scaling automation requires:

- Legal and Regulatory Instruments: Official standards defining valid digital documents, recognition of digital signatures, and alignment of automated outputs with cadastral legal definitions;
- Capacity Building: Broad-based training for field teams, mid-level GIS analysts, and registry officials in digital capture, QC, and system and data maintenance;
- Infrastructure: Reliable and affordable access to internet and mobile data service, affordable access to cloud servers, connectivity, data backup, security protocols, and version control systems; and
- Data Governance: Policies on data ownership, privacy, sharing, and metadata standards.

Digital, interoperable data then presents opportunities for linkages with other systems and can serve as the jumping off point for enabling other systems and institutional initiatives, of which quality land and tenure data serves as the basis. Those services and initiatives include:

Computer-Assisted Mass Appraisal (CAMA): CAMA systems use statistical models to estimate property values at scale for taxation and planning. According to the International Association of Assessing Officers, accurate CAMA requires a variety of data sets with corresponding maps that include: Unique parcel identifiers; parcel boundary maps; property attributes (land use, improvements, condition); and market transaction data¹¹.

¹⁰ Landstack. (2024). *Relevance of CADASTA Platform vis-à-vis Forest Rights Act Implementation in India*. Retrieved from: <https://acrobat.adobe.com/id/urn:aaid:sc:va6c2:afbf0d77-e44a-4586-bc3a-6aec6262e8bd>

¹¹ International Association of Assessing Officers (IAAO) (2019). *Standard on Mass Appraisal of Real Property*.

Automated tenure mapping can provide the foundational spatial and attribute data needed for CAMA. For example, standardized parcel polygons can be linked with building footprints, utility access, and transaction records. Once these datasets are in place, valuation models can rapidly produce property value estimates for thousands of parcels, improving the equity and efficiency of land-based taxation.

Blockchain-Based Land Registries: Blockchain technology offers potential for tamper-proof recording of land rights, as well as transactions of rights and restrictions or encumbrances on the rights. However, effective blockchain registries require: standardized parcel IDs and geometry; verifiable data lineage and audit trails; and digital signatures supported by legal frameworks

Automated workflows can produce standardized, high-integrity data suitable for blockchain integration. In this model, validated parcels and their associated data can be hashed¹² and securely anchored on-chain with cryptographic proofs, ensuring both authenticity, integrity and irreversibility. Although legal adoption remains at an early stage in several countries, several pilots (e.g., Sweden, Georgia) demonstrate how standardized digital land information, when combined with blockchain, can strengthen registries by guaranteeing the veracity of parcels and their supporting records.

AI-Assisted Boundary Extraction: AI models combined with computer vision can now partially interpret possible land parcel boundaries from satellite or drone images^{13,14}. To work well, these AI models need accurate training data. Automated workflows help by creating clean, consistent boundary datasets. An AI ‘boundary model’ can suggest parcel boundaries which community members and trained field teams can then either verify or resolve in the field. The use of AI models provides opportunity and holds promise to significantly reduce field-based surveying of physical boundaries and, if realized, would expedite the determination and surveying of boundaries in the process of securing land tenure.

6 Conclusion

Automation-driven GIS workflows offer a practical path to scale land and forest tenure data collection and documentation while ensuring consistency, data quality, and institutional acceptability. The proposed areas of automation can work with a variety of tools that fit the budget of the implementing entity and technical team capacity, making it flexible and adaptable to various contexts. The use cases from Indonesia, Myanmar, and Uganda demonstrate that these methods can cut processing times from weeks to days, reduce costs, and improve/streamline data integration into formal systems.

While automation clearly delivers results in terms of efficiency and data quality, its potential will be fully realized when governments, communities, and other institutional actors adopt policies and legal frameworks that recognize and support digitalization. Embedding these innovations into laws, regulations and technical standards will ensure that digital documents have full legal validity, thereby fostering a stronger, more inclusive, and sustainable transition toward digital tenure systems.

¹² A hash is a short, unique code that acts like a digital fingerprint of data—any small change creates a completely different code. It helps verify data integrity, detect tampering, and support immutable records in blockchain systems.

¹³ An example of AI for boundary detection explanation with visuals can be found here:
<https://developers.arcgis.com/python/latest/samples/land-parcel-extraction-using-edge-detection-deep-learning-model/>

¹⁴ This approach is acceptable as long as a visible, on-ground feature marks the property boundary and the imagery used has adequate positional accuracy (e.g., suitable ground sampling distance or pixel resolution)

By prioritizing clean, standardized data infrastructure, such approaches create foundations for advanced applications like Computerized Assisted Mass Appraisal (CAMA) land valuation models, blockchain land rights registries, and AI-assisted boundary extraction, which depend on reliable parcel-level data. Crucially, these workflows are compatible with both government-led and community-supported efforts, supporting institutional mandates while expanding coverage. Investing in these foundational elements of GIS automation will enable tenure systems that are scalable, interoperable, and resilient, positioning institutions to meet land governance goals at national scale.

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