UMGCINI - Empowering Rural Communities through Geospatial Data and Digital Connectivity

Clinton Heimann[1], Stephanus Minnie[2], and Mark C. Abrams[3]

[1] National Department of Agriculture Land Reform and Rural Development, South Africa - clinton.heimann@dalrrd.gov.za
[2] National Department of Agriculture Land Reform and Rural Development, South Africa - stephanus.minnie@dalrrd.gov.za
[3] Resource Advancement for Inquisitive Kids International, United States - abrams@extremegeo.net

Keywords: GIS, Geospatial Knowledge Infrastructure, Digital Economy

Abstract

Rural communities in South Africa confront substantial barriers to accessing and leveraging geospatial data, a critical tool for effective local governance, infrastructure planning, and sustainable development. Historically marginalized in the digital economy, these communities often lack essential technological resources, such as stable electricity and reliable internet access. The name "UMGCINI," a Xhosa term meaning "keeper" or "guardian," evokes the role of one who protects and preserves what is valuable. Translated as the "Keeper of Earth Layers," UMGCINI embodies the cultural commitment to safeguarding the land that has nurtured and sustained these communities across generations. The UMGCINI project envisions establishing robust, off-grid computing centres, empowering rural communities to manage, enrich, and maintain their geospatial data with accuracy, relevance, and accessibility. This mission also acknowledges South Africa's linguistic diversity, with its eleven official languages, underscoring the need for locally qualified, certified, and culturally adapted knowledge resources. A pilot project in Bloemfontein has demonstrated the use of DGNSS-enabled drone surveying to establish precise local controls tied to the South African geodetic framework. The aerial survey generates high-resolution (1.5 cm) geocoded imagery, ideally suited for property mapping and geodetic evaluation, achieving accuracy within 10 cm (CE90). In UMGCINI's final phase, local schools will join the initiative, further supporting language localization efforts and ensuring continuous feature validation and attribution, embedding the community's voice and expertise into the stewardship of their lands.

1.1 Introduction

Rural communities in South Africa face profound challenges in accessing and utilizing accurate, precise geospatial data essential for effective local governance, infrastructure planning, and sustainable development. Historically marginalized in the digital economy, these communities struggle with limited access to reliable internet, electricity, and essential technological resources. The scarcity of accurate, up-to-date geospatial data at the local level impedes their capacity for informed decision-making. It restricts their participation in the broader global information network, limiting the potential benefits such engagement could bring to their development and growth.

The Digital Doorway initiative, launched in 2013 by the Council for Scientific and Industrial Research (CSIR) in partnership with the Department of Rural Development and Land Reform (DRDLR), aimed to bridge the digital divide in South Africa. Through this initiative, over one hundred underserved rural communities received basic computing resources, empowering residents to engage in self-directed learning and access information even in remote locations with limited internet connectivity.

"UMGCINI," a Xhosa word meaning "keeper" or "guardian," reflects a role of protection and stewardship over something vital. Translated as the "Keeper of Earth Layers," UMGCINI embodies the tradition of safeguarding the lands that have nurtured communities for generations. It provides a dedicated, well-resourced space with internet access where locals can build and sustain a resilient data ecosystem, enabling them to manage and enrich local geospatial data. This empowers communities with geospatial data that is not only accurate and precise but also highly relevant, accessible, and tailored to support sustainable development, fostering both local engagement and enrichment.

South Africa's linguistic diversity, with its eleven official languages, adds unique challenges to localization efforts. In Xhosa, UMGCINI translates to "keeper" or "guardian," while in other languages it becomes "bewaarder" in Afrikaans, "umlindi" in isiNdebele and isiZulu, "mohlokomedi" in Sesotho sa Leboa and Sepedi, "mogodi" in Setswana, "umlondvolo" in siSwati, "mudzidzi" in Tshivenda, and "muchayeri" in Xitsonga. This rich linguistic landscape underscores the inherently local nature of knowledge, which calls for culturally attuned resources that are certified, enriched, and disseminated by the communities they serve.

Building on the foundation established by the Digital Doorway, the UMGCINI initiative is being developed as a more advanced, empowering solution for rural communities. By integrating commercial off-the-shelf (COTS) hardware and software, UMGCINI introduces localized Internet of Things (IoT) capabilities, enabling communities to manage geospatial data, curate locally relevant content, and actively engage in the digital economy.

This approach leverages existing technologies, creating a robust and accessible system that primarily requires integration. The impact of UMGCINI centres goes beyond data access; these centres foster a generation of locally educated individuals deeply invested in their communities and equipped to advocate for sustainable development, thereby cultivating a promising future for indigenous regions.

UMGCINI envisions resilient, off-grid computing centres serving as community hubs for data management and internet access, as illustrated in Figure 1. These centres will be powered by solar energy, equipped with localized servers, and feature advanced geospatial tools, ensuring their independence and adaptability within rural settings. The first UMGCINI prototype

is anticipated for delivery in the first quarter of 2025, marking a significant step toward achieving this vision.

Figure 1. UMGCINI – Conceptual diagram of a local geospatial hub with solar power, automated drone collection, geodetic control (DGPS/DGNSS), and satellite internet (STARLINK).

The UMGCINI centre is designed as a self-sustaining, high-tech hub, optimized to meet the unique needs of rural communities. On its roof, an automated DJI drone docking station shares space with a weather station, solar panels, and a Starlink or similar satellite communications antenna, establishing a robust setup for remote data gathering and connectivity. The second-floor functions as the community's Geographic Information System (GIS), Geographic Information Science or GIScience (GISc), and Geospatial Knowledge Infrastructure (GKI) hub, featuring high-end computers equipped with essential software to produce, curate, and certify a localized GKI ecosystem (GKIe). Here, digital infrastructure is created and integrated into the digital economy to address the challenges related to Rural Governance enabled through GIScience (Figure 2).

Figure 2. UMGCINI – Conceptual diagram highlighting the challenges of Rural Governance in GIScience.

Meanwhile, the first floor serves as a community maker space, providing resources for the hub's operations and maintenance and a space dedicated to self-directed education and innovation. This will also allow for other challenges like the cultural and gender divide to be overcome, effectively reducing the spatial divide. UMGCINI is intended to operate autonomously and is sustained by locally trained IT and GKI professionals who are permanent community residents.

UMGCINI aims to validate its effectiveness across rural communities by enabling consistent geospatial data generation and maintenance—an essential resource for local municipalities. It mitigates the detrimental effects of the cultural divide by eliminating the spatial divide and linking the various cultural groupings to foster cohesion. This initiative addresses the governance challenges between local, national, and global geospatial systems, ensuring that data remains accurate, timely, relevant, and locally authenticated.

Central to UMGCINI is the principle of localization, empowering local communities to manage, maintain, and certify information in their native languages. This contrasts with broader national or international models, often delivering geospatial data without engaging local stakeholders. This data must be interpreted to explain the unique challenges experienced in a local and culturally diverse environment.

The UMGCINI model combines advanced drone technology, satellite communications, Differential Global Navigation Satellite Systems (DGNSS), and automated geodetic control systems, equipping communities to collect, curate, and manage geospatial data across rural landscapes. This approach fosters bottom-up data ownership that feeds into larger information systems, supporting sustainable development in rural areas. A strategic assessment for the Municipality in Limpopo, commissioned by the Department of Agriculture, Land Reform and Rural Development (DALRRD) for 2023/24, underscored the need for secure, controlled, and reliable geospatial infrastructure—precisely the kind of support that UMGCINI units are uniquely designed to provide.

1.2 Localization and Curation at Local Scales

Global tech giants like Google, Meta, Amazon, Microsoft, and Apple, alongside numerous international location-based service providers, share an ambitious goal: to digitally localize every person, dwelling, and smart device worldwide. Their vision is to build a real-time digital economy, enabling location-based marketing powered by user-shared location data—a foundation underpinning a projected $1 trillion digital economy by 2030 (Zilkoski, 2022).

Integrating local communities into this global digital economy presents two primary challenges: localization and curation. While advancements in GEO AI allow for reliable extraction of roads and building footprints from satellite imagery, identifying the "what," “who,” and “why” of a specific location remains complex. Localization involves assigning a place’s local address and connecting it with standardized identifiers like postal codes. Additionally, governments are interested in understanding “who” resides at an address, capturing basic demographic details (age, gender, status), and, in commercial zones, identifying the “why”—the purpose of activities, whether residential, agricultural, commercial, or industrial.

Curation, the process of ensuring the currency and authenticity of geospatial information, is crucial to linking descriptive digital data with real-world human activity. As generative AI and digital fabrication tools advance, the need for authenticated digital records grows increasingly urgent, reinforcing the role of provenance in maintaining data integrity.

UMGCINI offers a dedicated “space” for the local generation and meticulous curation of location-based information, while RAFIKI extends a global network connecting these local curators

with digital ecosystem vendors. This partnership facilitates remote community engagement and supports the economic value of precise, well-maintained geodetic foundation data, forming a mutually beneficial bridge between local and global digital economies.

UMGCINI addresses a critical void in the digital economy: the lack of accurate, accessible geospatial data for rural regions. Traditionally, data management in these areas has been inefficient, often excluding community participation and remaining disconnected from larger geospatial systems. By creating a centralized geospatial data hub, UMGCINI facilitates the collection, generation, and dissemination of knowledge, laying the groundwork for a local Geospatial Knowledge Infrastructure ecosystem (GKIe).

To support effective localization and curation, UMGCINI integrates advanced GEO-AI technologies, automating the mapping of roads and buildings at scale. However, this automation depends on local validation, curation, and authentication to ensure data accuracy and relevance. Community involvement, such as through OpenStreetMap (OSM) events and hands-on feature identification, empowers residents to refine and verify data, producing a dataset that genuinely reflects the community's landscape.

By fostering local ownership of the data and the process, UMGCINI motivates ongoing engagement in the digital economy, ensuring that curated data accurately represents the realities on the ground. This curated geospatial data serves as a vital resource for local governance, enabling informed planning, infrastructure development, and disaster management at the village level. It also underpins local land management and taxation efforts.

Additionally, selling curated geospatial data to global digital economy stakeholders provides a revenue stream, enhancing UMGCINI's sustainability. This model promotes fourth-generation IoT skill development, creating employment opportunities and fostering local expertise, ultimately empowering rural communities to own and benefit from their geospatial data.

1.3 Proof of Concept

Starting a regional Geospatial Knowledge Infrastructure ecosystem (GKIe) from the ground up in resource-limited regions requires a practical, step-by-step approach that leverages available tools, open-source data, and community involvement. This framework addresses the needs of underserved areas, such as traditional regions in South Africa, and countries within the UN GGIM community that have not yet achieved readiness on the GGIM index (Geospatial World, 2022).

1. Establishing Foundational Geodetic Control

- Utilize Existing CORS Networks: Begin by identifying any available Continuously Operating Receiver System (CORS) networks within the region. These provide Differential GNSS (DGNSS) capabilities crucial for establishing accurate geodetic control.
- Contribute to future more dense CORS Network elements: The use of CORS network elements has dramatically changed with the adoption of drones and precision agricultural equipment. This must stimulate the rethinking of the CORS network in any country to support this new Differential GNSS (DGNSS) reality.
- Integrate Open-Source Terrain Data: Combine CORS data with open-source 30m terrain data and, where available, national airport surveys. These data points provide vertical and horizontal control baselines essential for accurate mapping and positioning.

2. Leveraging Open-Source Data and Community Crowd-sourcing

- Use OpenStreetMap (OSM) and Other Open Sources: Open-source platforms like OSM provide foundational data on infrastructure, including roads and buildings. Integrate this data as a baseline for local infrastructure mapping.
- Encourage Local Contributions and Crowd-sourcing: Empower the community to actively participate in data enrichment by crowd-sourcing information on smaller roads, landmarks, and informal settlements. This local input is invaluable for accurately representing areas often overlooked in national datasets and enhances local ownership.

3. Developing a Consistent High-Resolution Basemap

- Integrate 3D Spatial Data and Regularly Update: Aim for a consistent basemap with human-scale accuracy and resolution. Use open-source 3D spatial data and conduct periodic local surveys to capture real-time changes, ensuring the map accurately reflects the current infrastructure.
- Combine Data with Ground-Truth Observations: Regularly supplement imagery with observations from local stakeholders to maintain a realistic and practical basemap, essential for data coherence across sources.

4. Focusing on Local Validation and Attribution of Features

- Engage the Community in Data Review and Validation: Establish workflows where local stakeholders can validate and update data, especially critical features like roads and buildings. Creating an "official" community dataset allows the region to maintain an accurate, curated map that complements global open-source maps.
- Strengthen Data Ownership and Engagement: Regular community engagement in data curation strengthens data ownership and motivates long-term involvement, which is particularly vital in underserved areas.
- Establish data governance: The community will contribute to a large strategic focus in the geospatial environment, enabling rural communities to become integral to the national and international solution. This contribution, in turn, will foster a sense of self-worth in these remote spaces.

5. Prioritizing Geospatial Data for Key Applications

- Critical Infrastructure and Disaster Management: Focus on mapping essential assets like water sources, health facilities, roads, and evacuation routes. This is especially important in areas prone to natural disasters or where resource scarcity presents significant risks.
- Equitable Resource Allocation: Use the geospatial data to help governments and organizations allocate resources equitably based on population density, access to services, and other relevant criteria.
- Promoting Market Access and Investment: Leverage localized geospatial data to highlight economic opportunities, making rural and urban regions more attractive to potential investors.

6. Integrating with Broader Data Ecosystems and Cross-Referencing Global Maps

- Compare and Analyze Different Basemap Sources: Comparing government (*de jure*), commercial (*de facto*), and open-source basemaps can offer insights into data coverage and gaps. This step ensures that regional data aligns with broader geospatial systems.
- Understand Limitations of Machine Conflation: Machine conflation of basemaps, while promising, currently faces challenges due to inconsistent data standards and is generally effective only up to an 80% accuracy level. Thus, manual, community-driven validation remains essential for high-accuracy integration.

By implementing these steps, regions can build a responsive, accurate, and sustainable GKI that progressively improves in quality and integration with global geospatial systems. This structured approach enables regional GKIs to serve as vital resources for local planning, governance, and participation in the global digital economy.

The data collection, aggregation, and conflation process were effectively demonstrated in Mopeli-Bolata, South Africa, to explore the development of a Geospatial Knowledge Infrastructure (GKI) within varying time frames: one hour, one day, and one week. Remarkably, an initial 3D GKI context was established within the first hour, leveraging validation from the South African TRIGNET CORS DGPS network. This foundational data was combined with an existing OpenStreetMap (OSM) road network to provide comprehensive terrain, imagery context, and road mapping within a few hours.

However, building footprints were notably absent in this area. A sample set of OSM building footprints was created to address this gap for Phamong Primary School. This sample allowed for a comparative analysis of the consistency and variability across publicly accessible image basemaps, including the South Africa Central Directorate's National Geospatial Information (CD-NGI) with its 25 cm Ground Sample Distance (GSD) aerial imagery, as well as satellite imagery from Google and Bing, as illustrated in Figure 3. This example highlights the rapid establishment of a GKI baseline and the importance of validating data quality across multiple image sources to ensure consistency in geospatial datasets.

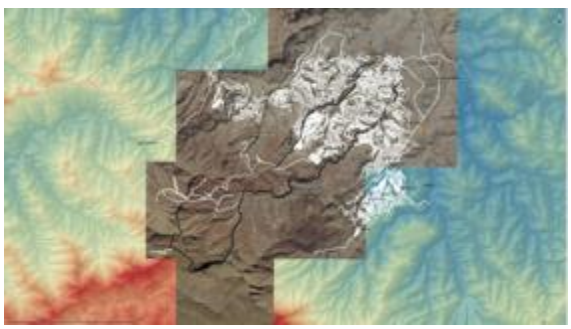

Figure 3. Open-Source Geographical Information System (GIS) of Mopeli-Bolata, South Africa, created from open-source data including terrain, imagery, road, and a few building footprints typical of rural areas where property boundaries are uncommon.

The results yield a surface with a vertical accuracy of 9 meters relative to DGPS measurements and a horizontal accuracy of 2 meters compared to airport survey markers at Tambo International Airport. Notably, when comparing the national (*de jure*) basemap with location-based services basemaps (such as Google and Bing), the differences observed are consistent with a 2-meter circular error probability at a 90% confidence level (CE90). The aggregated regional GKI dataset, approximately 13 GB in size, is organized into a GIS stack using QGIS 3.36, providing a robust, open-source GKI ecosystem suitable for situational awareness, planning, and navigation at the regional level. However, the open-source approach reveals limitations, as illustrated in Figure 4. The need for more building footprints in Mopeli-Bolata significantly restricts comprehensive regional planning. This lack of detailed structural data underscores further data enrichment to support nuanced, community-specific planning and infrastructure development.

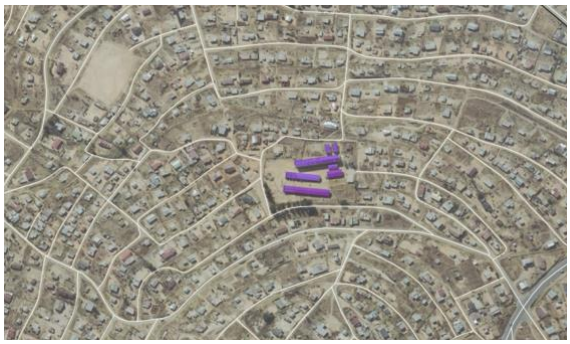

Figure 4. Open-Source Geographical Information System (GIS) near Phamong Primary School, Mopeli-Bolata, demonstrates the need for more building footprints.

Evolving to a basemap with sufficient quality to support cadastral mapping of property boundaries has been demonstrated in India (5 cm GSD and 5 cm accuracy). The SVATMITVA (Survey of Villages Abadi and Mapping with Improvised Technology in Village Area, 2025) project, a recently implemented Indian rural land mapping program, provides a unique and innovative solution.

Building on an inclusive approach to rural land mapping, adaptable for countries with uncoordinated land occupancy and mapping systems, involves a phased, scalable model grounded in a national or regional geodetic framework. This model allows countries to "start small," developing localized cadastral maps and databases that can gradually expand into a comprehensive, sustainable national Geospatial Knowledge Infrastructure (GKI), effectively integrated into the broader digital economy and ecosystem.

Critical Components of the Inclusive Rural Land Mapping Model:

1. Initial Focus on Localized Mapping:

Begin by mapping smaller regions, prioritizing areas with significant land tenure and occupancy challenges. Using a geodetic framework as the baseline, initial mapping efforts can establish precise control points that are vital for accurate land delineation.

2. Community Engagement for Validation and Data Collection:

Involve local communities in the mapping process to gather on-the-ground insights and validate data. This inclusiveness ensures

that the mapped data reflects the realities of land usage and occupancy while fostering local trust and ownership of the data.

3. Development of Consistent Regional Cadastral Maps:

Create cadastral maps at the regional level using standardized geospatial tools and open-source platforms. Establish databases that store information about land boundaries, ownership, and usage, enabling these databases to scale up as the mapping expands.

4. Integration with Digital Economy and National Ecosystems:

As regions develop consistent cadastral data, integrate these datasets into a national GKI. This phased approach allows for incremental expansion while maintaining data quality and consistency.

Enable data accessibility for public and private stakeholders, support agriculture, infrastructure planning, and environmental management applications, and further embed the GKIe into the digital economy.

5. Scalability and Sustainability:

The model is designed to grow sustainably, allowing additional regions to be mapped and integrated into the GKI without overwhelming resources. As the mapping scope expands, so does the capacity to incorporate the entire rural landscape into the national digital ecosystem, fostering economic development and supporting governance.

Through this approach, other countries can establish a foundational GKIe tailored to their unique geographic and socioeconomic contexts, building toward a comprehensive system that enhances land management and contributes to national and regional development.

Figure 5 illustrates this capability, showcasing how incremental land mapping efforts at the regional level can evolve into a robust, interconnected GKI system adaptable to diverse national landscapes and governance structures.

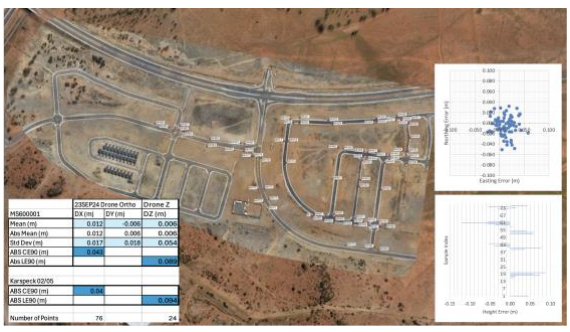

Figure 5. DGNSS-drone collected 1.5 cm orthoimagery with 5 cm circular error probability at 90% (CE90) absolute accuracy.

The UMGCINI project addresses a critical need in the digital economy by bridging the digital divide in rural South Africa. By integrating local communities into OpenStreetMap (OSM) mapping events within schools, UMGCINI provides valuable educational experiences and directly involves communities in the critical processes of feature identification, attribution, and data validation. This community-centered approach is foundational to UMGCINI's long-term objective: establishing a sustainable, community-owned geospatial knowledge infrastructure (GKI) that supports local development and economic engagement.

7. Implementation

UMGCINI is currently in its prototype stage, with the first deployment set for 2025. This initial rollout will integrate rural communities into the digital ecosystem, demonstrating the feasibility of connecting local communities to global digital systems via localized geospatial data curation.

UMGCINI aims to expand to traditional communities and municipalities across South Africa, creating a national network of connected communities fully integrated into a global GKI framework and the digital economy by utilizing open-source imagery, crowd-sourced data, and existing geospatial networks. UMGCINI will develop a consistent, human-scale basemap to aid regional planning, infrastructure development, and disaster management.

The first UMGCINI prototype is set for release in the first quarter 2025. To support its development and testing, UMGCINI seeks strategic partnerships with stakeholders interested in geospatial data services. Integrating UMGCINI with cutting-edge satellite internet will enable communities to manage and share local geospatial data, aligning with the following United Nations Sustainable Development Goals (SDGs):

- **SDG 9: Industry, Innovation, and Infrastructure** – UMGCINI provides the necessary infrastructure for data management and internet access, fostering innovation and sustainable industrial growth in rural areas.
- **SDG 11: Sustainable Cities and Communities** – By enabling data-driven planning, UMGCINI promotes inclusive, safe, and resilient communities where well-lit, connected spaces become hubs for learning and innovation.
- **SDG 17: Partnerships for the Goals** – UMGCINI exemplifies the strength of collaboration in achieving sustainable development through localized data curation and global integration.

UMGCINI also builds on the Digital Doorway model, supporting:

- **SDG 4: Quality Education** – Training community members in geospatial technology equips them to shape their futures, supported by a maker space and a global practice community.
- **SDG 8: Decent Work and Economic Growth** – UMGCINI empowers communities to document their local assets for the digital economy, creating employment opportunities and contributing to the global GKI.

Expanding UMGCINI across Africa could further empower rural communities on the continent by addressing common challenges in geospatial data management, connectivity, and digital inclusion. By partnering with local governments, international organizations, and the private sector, UMGCINI can scale its impact, fostering innovation, resilience, and economic growth throughout Africa while contributing to global SDGs.

8. Next Steps for UMGCINI in 2025:

1. Community and Municipal Engagement: Collaborate with municipalities and rural communities to assess specific geospatial needs and customize UMGCINI solutions accordingly.

2. Connectivity Partnerships: Form alliances with satellite internet providers to ensure reliable connectivity.
3. Prototype Development and Testing: Support the UMGCINI prototype scheduled for release in early 2025.
4. Network Expansion: Plan to extend UMGCINI's reach to other underserved areas, ensuring accessible, transformative technology for all.

Annual demonstrations will showcase the project's progress, fostering knowledge sharing and continuous improvement.

9. Near Future

UMGCINI is more than a project—it catalyzes change, empowering African youth to shape their future through technology and data. We invite your participation in bridging the digital divide and connecting South Africa's traditional regions to the global digital economy. In recent years, the notion of "one laptop per child" has symbolized the promise of technology for youth. However, as mobile technology advances, it is likely that the smartphone—not the laptop—will become the primary tool connecting people to the digital economy. Through location-based services, smartphones enable data collection, annotation, and curation with efficiency and portability. Article 19, adopted by the UN in 2016, underscores the importance of internet access, which is at the heart of the UMGCINI GKIe ("UN," 2021).

The adaptive, low-power nature of smart devices complements rural communities' needs, enabling data management at the edge with minimal energy requirements. For indigenous communities, UMGCINI offers a pathway to remote technical work. It provides an alternative to the current migratory work patterns, allowing individuals to stay connected to their roots while contributing to the digital economy.

UMGCINI represents an innovative approach to sustainable digital inclusion, positioning South Africa's rural communities at the forefront of geospatial data management. Join us in transforming rural Africa, empowering communities with technology, and creating a future where local knowledge fuels global progress.

Acknowledgments

The authors acknowledge the contribution of a community of geodetic surveyors, drone pilots, and technicians who work in rural communities every day collecting and curating this data. The leadership of the Survey of India and the SVAMITVA project is acknowledged for pioneering a surveying methodology that enables community engagement.

References

FRAMEWORK FOR IMPLEMENTATION OF SVAMITVA SCHEME Survey of Villages and Mapping with Improvised Technology in Village Areas https://svamitva.nic.in/DownloadPDF/Svamitva_Scheme_Framework(2021-2025).pdf

New Report on GKI Readiness Index, Value Proposition released at 2nd UN-WGIC, 12/10/2022, Geospatial World, https://www.geospatialworld.net/news/gki-readiness-index-wgic/

UN: Human Rights Council adopts resolution on human rights on the Internet [WWW Document], 2021. . Artic. 19. URL https://www.article19.org/resources/un-human-rights-council-adopts-resolution-on-human-rights-on-the-internet/ (accessed 10.31.24).

Zilkoski, David B., The inverted geospatial pyramid shows our vulnerability, GPS World, November 1, 2022. https://www.gpsworld.com/the-inverted-geospatial-pyramid-shows-our-vulnerability/