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List of Acronyms

ANICiiS
Agence Nationale d'Ingénierie Clinique d'Information et d'Informatique de Santé (DRC)

BCR
Bureau Central de Recensement/Central Bureau of Census (DRC)

DPS
Division Provinciale de la Sante/Provincial Health Department (DRC)

DRC
Democratic Republic of the Congo

EA
Enumeration area

ECZ
Electoral Commission of Zambia

GIS
Geographic Information System

GPS
Geographic Positioning System

INS
Institut National de la Statistique/National Institute of Statistics (DRC)

LGA
Local Government Area (Nigeria)

MLGH
Ministry of Local Government and Housing (Zambia)

NASRDA
National Space Research and Development Agency (Nigeria)

NSDI
National Spatial Data Infrastructure

OSG
Office of the Surveyor General (Zambia)

POIs
Points of Interest

Pre-EAs
Pre-enumeration areas

VTS
Vaccination Tracking System

ZamStats
Zambia Statistics Agency
Glossary

Administrative units
Delineations of units or areas as recognised by the government. They are used to determine electoral units, the allocation of government resources, geographic jurisdictions, and more.

Attribute table
A database or tabular file containing information about a set of geographic features, usually arranged so that each row represents a feature and each column represents one feature attribute.¹

Census mapping
The process of dividing a country into smaller units of land, during which enumeration area boundaries and type are clearly described and the number of communally based services identified.

Enumeration area
The operational geographic units for the collection and management of census data.

Enumerators
Or census takers, they collect household and demographic data by canvassing households within their assigned enumeration areas.

Gridded population data
Take the form of a raster dataset composed of grid cells and provide population estimates associated with each grid cell (as opposed to a more typical areal unit). The grid cell size determines the spatial resolution of the gridded population data.

Geographic Information System
A system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.²

Health catchment areas
Functional units used to plan, manage, and implement the distribution of healthcare services, the organisation of surveillance, and the allocation of resources. Health areas often aggregate to health zones and/or larger administrative units.

Microplan
A population-based set of quantitative and qualitative data for delivering healthcare interventions. They contain technical details and can be adapted as needed at every level, whether by national institutions, healthcare workers, or community participants.³

Operational units
Unofficial or non-authoritative delineations of a given area for the functional distribution of resources, humanitarian services, or other interventions.

**Participatory mapping**
A map-making process that attempts to make visible the association between land and local communities by using the commonly understood and recognised language of cartography.4

**Settlement**
A settled area of permanently inhabited structures and compounds that can range from small rural areas to expansive urban zones.

**Settlement layer**
A dataset that provides settlement points or polygons and their names to spatially locate, identify, and visualise human settlements.

**Statistical areas**
Delineations of areas for statistical purposes, such as enumeration areas, health areas, metropolitan/micropolitan statistical areas, urban areas, and census-designated places.

**Subnational boundaries**
The extent or limit of a specified geographic area, such as a block, census tract, county, or place. A boundary may follow a visible geographic physical feature and may signify administrative, political, survey, or other areas. For census purposes, subnational boundaries provide the nesting frame for statistical units and enumeration areas for enumerators to count the population within that given area.

**Points of interest (POIs)**
Point features, or geo-referenced points, that depict infrastructure, buildings, and landmarks.

**Pre-enumeration areas**
Small areal units that can be used in preparation for census cartography (or mapping) that conform to the specification of an enumeration area (in terms of estimated population, area, etc.) but are considered to be approximate and should be validated during census cartography.

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Up-to-date, harmonised subnational boundaries are a key component of development efforts, informing emergency operations, routine operations, planning, and statistical infrastructure. And yet many countries in the developing world face significant obstacles to creating such boundaries. Some countries still use paper maps rather than digital maps, preventing the use of standardised boundary files across different organisations and/or government agencies. Meanwhile, other countries that do use digital maps have not harmonised these data across institutions, and furthermore often lack capacity in geospatial data generation and digital management, measurement tools, and financial resources. To address these challenges, GRID3 partners with governmental bodies and other stakeholders to support the harmonisation, production, and use of digitised legal/administrative units, operational units, and statistical areas.

One form of GRID3’s support centres on the improvement and harmonisation of operational units, which are used to guide the distribution of resources, humanitarian services, and other aid. In Nigeria, GRID3’s support has built upon the country’s polio eradication efforts; using various government data sources, GRID3 facilitated the harmonisation of separate datasets of administrative units and helped to make progress towards a centralised, high-quality, validated, and complete dataset of subnational boundaries. This dataset can be instrumental for a wide range of interventions, including microplans for polio and other immunisation services, as well as tracking the local-level implementation of projects in the education and financial sectors. Similar to the Nigerian case, GRID3’s work in the Democratic Republic of Congo’s Haut-Lomami and Tanganyika provinces was based on data gathered for polio vaccination campaign planning. However, in DRC the focus was on generating a dataset of health catchment boundaries; GRID3 worked with stakeholders to map these boundaries at a participatory event coordinated with in-country provincial coordinators and Geographic Information System (GIS) technicians. A set of comprehensive, accurate, and nested health areas and health zones data layers were produced; in total, this work improved 590 health areas in 27 different health zones across a 234,825 km² area.

A second type of GRID3 boundaries delineation support centres on cases where authority over boundaries is distributed among different agencies; in this scenario, GRID3 works to bring these disparate authorities together to collaborate on boundary harmonisation. This was the circumstance in Zambia, where GRID3 supported stakeholders by coordinating a workshop that generated concrete suggestions for improving boundary harmonisation processes. Over the course of the workshop, GIS technicians from participating ministries aimed to harmonise ward and district boundaries by referring to official district narratives, topographic maps, and aerial imagery. Following the workshop, district boundaries were validated and then shared with provincial and local planners. All 116 district boundaries were aligned to topography and harmonised with wards at the same mapping scale. Within five months, district shapefiles were endorsed and shared with nine government ministries, as well as with provincial and district planners stationed at the local level. The district shapefiles have also been uploaded to Zambia’s national data platform.
A third aspect of GRID3’s work focuses on how boundaries harmonisation can support census efforts. The design and delineation of enumeration areas (EAs) and other census management areas for field enumeration is the geographic foundation for census datasets and a vital component of national censuses. In countries such as DRC (where a census has not been conducted for several decades) creating appropriately-sized EAs is difficult, given the lack of recent population estimates or an existing EA dataset. To address this challenge, GRID3 is developing a semi-automated delineation approach to create small geographic units in preparation for census cartography, referred to as “pre-EAs.” This approach utilises geospatial processing tools to produce pre-EA boundaries using geospatial datasets on features such as roads, buildings, rivers, and high-resolution gridded population data. The estimated population for each small unit is then calculated from high-resolution gridded population data, with units subsequently merged to meet the criteria specified in terms of population size, geographic area, and any other constraints. The result is a complete set of boundaries that can be used for census planning.

While GRID3 has already made important innovations in its boundaries work, there are shortcomings in its support to governments and other stakeholders that remain to be addressed: many district narratives that were relied upon in the mapping process often contained topographical errors and inconsistencies; EA boundary alignment was not a part of the Nigeria, DRC, and Zambia work, and should be incorporated in order to make boundary alignment in those countries more comprehensive; and traditional boundaries and health facility catchment areas were not aligned, but should be eventually. GRID3 will continue to collaborate with its partners both within and outside government to address these shortcomings, and to more generally develop additional innovative approaches to linking boundary harmonisation with broader campaigns in order to make development more sustainable.
Introduction

Subnational boundaries refer to the extent or limit of a specified geographic area, such as a block, census tract, county, or place. A boundary may follow a visible geographic physical feature and may signify administrative, political, survey, or other areas. For census purposes, subnational boundaries provide the nesting frame for statistical units and enumeration areas (EAs) for enumerators to count the population within that given area.

Up-to-date, harmonised subnational boundaries are a key component of development efforts in several different respects. Among other benefits, they support effective emergency operations; improve routine operations; make development planning more targeted and impactful; and contribute to a robust foundation for statistical infrastructure.

Emergency operations

Accurate subnational boundaries are a cornerstone of effective emergency interventions. They facilitate the identification of populations in need, the scale of aid required, and the proper distribution of responsibility among the authorities overseeing aid provision. For example, accurate boundaries can facilitate effective contact tracing and immunisation campaigns for disease outbreaks; or they can enable administrators to delegate responsibilities over areas affected by flooding so as to ensure that the entire population of an impacted area receives the help it needs.

Routine operations

Correctly defining an area’s boundaries allows policymakers to make accurate judgments about the scale and scope of routine operations. For example, accurate boundaries can ensure that routine immunisation efforts reach all communities within a given area; facilitate the accurate and timely allocation of resources, such as bednets and human capital (e.g. community health workers, doctors and nurses, or teachers); prevent gaps/overlaps in services delivered (preventing issues like stockouts or the wasteful doubling-up of resources); and facilitate the transmission of accurate information to all administrative levels, allowing officials to know how and where to allocate resources.

Planning

Subnational boundaries help planners accurately evaluate a given area’s needs and design interventions accordingly. For example, accurate boundaries can facilitate financial inclusion campaigns; ensure the correct placement/integration of electricity grids; effectively identify locations where new schools, clinics, and other infrastructure can make the greatest impact; and provide consensus and/or clarity about how to design interventions in contentious border areas.

Statistical infrastructure

Accurate subnational boundaries provide an accurate, reliable means of grouping data, creating a consistent reporting framework and consistent survey design methods. For example, accurate boundaries can allow for the accurate delineation of disaster zones via the overlaying of a flood risk map onto an area and then aggregating to the ward level.
Many countries still use paper maps rather than digital maps, which prevents the use of standardised boundary files across different organisations and/or government agencies, as well as preventing timely and standardised data management.

Despite a widespread understanding of the importance of accurate, up-to-date boundaries, many countries face significant obstacles to creating them; as a result, these countries see suboptimal returns for their development efforts. Many countries still use paper maps rather than digital maps, which prevents the use of standardised boundary files across different organisations and/or government agencies, as well as preventing timely and standardised data management. Meanwhile, many countries that do use digital maps have not harmonised data across institutions, neither spatially nor from a data management perspective. In these cases, there is also often a lack of institutional capacity in geospatial data generation and digital management, measurement tools, and financial resources.

GRID3’s boundaries work

GRID3 (Geo-Referenced Infrastructure and Demographic Data for Development) is a programme funded by a grant from the Bill & Melinda Gates Foundation and the United Kingdom’s Foreign, Commonwealth and Development Office. It is implemented by Columbia University’s Center for International Earth Science Information Network, the United Nations Population Fund, WorldPop at the University of Southampton, and the Flowminder Foundation. GRID3’s primary mission is to help build spatial data solutions that make development goals achievable. To accomplish this, GRID3 draws on the expertise of its partners in government, the United Nations, academia, and the private sector to design adaptable and relevant geospatial solutions that are based on developing countries’ capacity and development needs.

GRID3 supports the harmonisation, production, validation, and use of legal/administrative units, operational units, and statistical areas by partnering with stakeholders in a given country—specifically, partnering with governmental bodies that have jurisdiction over boundaries and with other stakeholders that can provide or help to create data on boundaries delineation. GRID3’s role in this process changes depending on a country’s needs. In all cases, GRID3 draws upon various approaches and data to increase the capacity of its in-country partners, working to ensure that governments can take ownership of the process so that they are situated to carry out further boundaries work after GRID3 has completed its engagement. A major avenue of GRID3’s boundaries work is supporting the development of boundaries data in digital formats.

5. The College of William & Mary’s Geospatial Evaluation and Observation Lab (geoLab) also contributes to GRID3’s boundaries work.
There are several important benefits to having boundaries digitised:

1. Digital boundaries can be shared and updated in a simple and transparent manner, and can be made available to anyone who has access to a computer.

2. Having digital boundaries allows stakeholders to compare boundaries information against other digital information (e.g. landscape features or infrastructure) for the purposes of validation.

3. Having digital boundaries allows for the integration of spatial data into other digital tools (for example, digital boundaries can be integrated into software that is used by vaccinators to ensure they are covering the entirety of their designated health area).

GRID3 uses three classifications in its boundaries work: administrative or legal units, operational units, and statistical areas.6

- **Administrative units**: Delineations of units or areas as recognised by the government. They are used to determine electoral units, the allocation of government resources, geographic jurisdictions, and more.

- **Operational units**: Non-administrative geographical units that delineate a given area for the functional distribution of resources, humanitarian services, or other interventions.

- **Statistical areas**: Delineation of areas for statistical purposes, such as enumeration areas, metropolitan/micropolitan statistical areas, urban areas, and census-designated places.

**Structure of this paper**

This paper describes GRID3’s unique approach to supporting the delineation and mapping of boundaries. Section one describes GRID3’s work with stakeholders to harmonise operational units in Nigeria and the Democratic Republic of the Congo (DRC). Section two describes GRID3’s work in facilitating inter-institutional dialogue among government agencies to address discrepancies in Zambia’s boundary data. Section three discusses GRID3’s work on pre-enumeration areas in DRC. The paper concludes with a discussion of ongoing challenges and future plans for GRID3’s boundaries efforts.

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Working with stakeholders to harmonise operational units

One form of GRID3’s support centres on the improvement and harmonisation of operational units, which are used to guide the distribution of resources, humanitarian services, and other aid. GRID3’s approach to operational units harmonisation is adjusted for individual contexts, but will often use existing data taken from service provision campaigns (for example, routine vaccination campaigns). GRID3 then works with stakeholders to augment the existing data, correct errors, and store the new (often digitised) data in an easily navigable, accessible format. The outcome of this type of support is not only improved and standardised boundaries, but increased capacity among stakeholders that enables them to take ownership over both the data and the methods used to manage them.

Data for vaccination campaign planning in Nigeria

Wards are the smallest administrative units in Nigeria. They aggregate to Local Government Areas (LGAs) and then to states. To date, no government-accepted and nationally complete ward boundary dataset exists in the country. Consequently, a primary goal of GRID3 has been to facilitate government production of a publicly accessible, high quality, validated, and complete dataset of administrative ward boundaries.

In Nigeria, digitised microplans consist of a map of each ward, as well as the locations of settlements, important POIs, and the population that is to be vaccinated. These microplan ward maps improve the logistics of vaccination campaigns by helping to predetermine how many vaccines are needed and also to enable teams in the field to more easily locate the target population. A complete and accurate ward boundary dataset is therefore extremely valuable.

One facet of GRID3’s ward delineation work in Nigeria has centred on the country’s polio eradication efforts. Since 2012, eHealth Africa has been contracted by the Bill & Melinda Gates Foundation to compile and maintain a database of operational datasets in support of polio vaccination campaigns (initially working in the country’s northern states, the campaign eventually expanded to all 36 states). This database was designed to store settlement, point of interest (POI), and spatial ward boundary data collected by eHealth Africa and in-country vaccination teams. These data feed the Vaccination Tracking System (VTS), which helps to identify the location of settlements and target populations for planning vaccination campaigns. The VTS has been an essential tool for vaccination teams to track the delivery of medicines, as well as to identify which settlements were missed in the field and which should be revisited for a more focused vaccination effort.

7. The government agencies responsible for the production of administrative units include the National Boundary Commission (NBC), Office of the Surveyor General of the Federation (OSGoF), and the Independent National Electoral Commission (INEC).
8. A settled area of permanently inhabited structures and compounds that can range from small to expansive urban zones.
9. Points of interest (POI) refer to point features, or geo-referenced points, that depict infrastructure, buildings, and landmarks.
In addition to the VTS, microplans are utilised to more efficiently and accurately prepare for and conduct vaccination campaigns. In Nigeria, digitised microplans consist of a map of each ward, as well as the locations of settlements, important POIs, and the population that is to be vaccinated. These microplan ward maps improve the logistics of vaccination campaigns by helping to predetermine how many vaccines are needed and also to enable teams in the field to more easily locate the target population. A complete and accurate ward boundary dataset is therefore extremely valuable.

**Sorting through the data: quality checks**

GRID3 conducted quality assurance/quality control (via a set of custom scripts) for all POIs, settlement data, and operational ward boundaries in the eHealth Nigeria database. Ward boundaries were evaluated using a set of data integrity checks that tracked and identified ward count per LGA and state unique operational ward IDs; valid geometries and topology; erroneous ward codes (e.g. XYZ123); identification of any multipart polygons (see Figure 1); and ward boundaries extending past the Nigerian country boundary. Additional effort was made to improve ward boundaries that passed through urban areas. The team at geoBoundaries, a project at the College of William & Mary’s Geospatial Evaluation and Observation Lab (GeoLab), visually inspected urban ward boundaries to ensure that they followed urban and/or natural features (e.g. roads, rivers) and did not cross built structures. Boundaries were also compared with POIs and settlements to check for inconsistencies. For example, GRID3 checked to ensure that each POI and settlement feature was located within the spatial limits of the ward and LGA that were specified in the point attribute table. Error reports were sent back to eHealth Africa to address, and subsequent boundary re-checks were conducted.

**Figures 1 and 2:** Data quality checks (QA/QC results) in Nigeria from April 2019 to May 2020

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10. Settlement data provide vital information on the location of potentially inhabited structures and are used as input data to produce accurate high-resolution population estimates. Settlement data can be derived from high-resolution aerial or satellite imagery or other building maps and can take different forms: settlement boundaries, individual building shapes, or point locations.

11. The data integrity checks for Nigeria consist of the quality assurance/quality control scripts plus visual inspection of the ward boundaries. It is important to note that this process occurred every time eHealth Africa updated the geodatabase, so that data quality progress could be tracked. By keeping track of the number of wards, GRID3 could tell if eHealth Africa was adding new wards to the geodatabase. This also gave GRID3 a sense of the completeness of the dataset.


13. The point attribute table is a “database or tabular file containing information about a set of geographic features, usually arranged so that each row represents a feature and each column represents one feature attribute” (see Esri reference above). For POIs, it identifies the type of point, latitude, longitude, and any other information, such as the name of the ward and the name of the LGA where the point is located. Even though the name of the ward and LGA were identified, GRID3 needed to check that the point actually fell within that ward/LGA boundary. GRID3 ran scripts that ensured that the point was actually located within the boundary that was assigned to it in the POIs dataset.
Figures 3 and 4: Ward boundary typology errors in Nigeria

**‘No Error’**
The boundary follows urban/natural features (e.g. roads, rails, rivers, etc.) when present.

**‘Error Type - ‘Minor’**
The boundary crosses one or two features but most of the boundary follows urban/natural features.

**‘Error Type - ‘Shift’**
The boundary looks like it could follow a road or natural feature but it has shifted by several feet.

**‘Error Type - ‘Significant’**
The boundary does not follow a road or natural feature at all. It is a straight line that cuts across many features.
eHealth uses five categories to evaluate the status of ward boundaries: authorized, operational validated, operational not validated, placeholder, and invalid geometry. The status of ward boundaries as of May 2020 were found to be as follows: 4,143 (44.19 percent) authorized; 3,450 (36.80 percent) operational validated; 1,298 (13.84 percent) operational not validated; 377 (4.02 percent) placeholder; and 110 (1.17 percent) invalid geometry.

Map demonstrates ward boundary topology errors that were found through routine data quality checks. Such errors can include gaps and/or overlaps in the boundaries.

**Outcomes**

GRID3 facilitated the production of a more accurate and useable ward dataset. In the latest iteration of the geodatabase (May 2020), only 110 out of a total of 9,376 wards (1.17 percent) were found to have invalid boundaries, an improvement of 4.25 percent (406 wards) over the prior version.\(^{14}\) This dataset is instrumental for a wide range of interventions. It can facilitate improved microplans for not just polio vaccination, but vaccinations for all types of diseases. It could likewise be used to track the local-level implementation of projects in the education and financial sectors.

In 2019, eHealth transferred the database to GRID3 in order for GRID3 to coordinate the validation and approval process of ward boundaries by the three government ministries responsible for the production of administrative units. It was then decided that the database should be transferred to the National Space Research and Development Agency (NASRDA), which is mandated to manage Nigeria's National Spatial Data Infrastructure (NSDI). NASRDA has the geospatial and political capabilities to convene various government ministries in order to examine, alter, and collectively agree upon a single ward boundary dataset. Although the database has not yet been transferred to NASRDA, significant progress has been made and NASRDA has already begun engaging with the relevant government agencies.

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14. eHealth uses five categories to evaluate the status of ward boundaries: authorized, operational validated, operational not validated, placeholder, and invalid geometry. The status of ward boundaries as of May 2020 were found to be as follows: 4,143 (44.19 percent) authorized; 3,450 (36.80 percent) operational validated; 1,298 (13.84 percent) operational not validated; 377 (4.02 percent) placeholder; and 110 (1.17 percent) invalid geometry.
A participatory mapping approach in DRC

Similar to the Nigerian case, GRID3’s work in DRC’s Haut-Lomami and Tanganyika provinces was based on data gathered for polio vaccination campaign planning. However, in DRC the focus was on generating a dataset of health catchment boundaries.

A health catchment area is a region served by a healthcare facility or health plan. In DRC, these are referred to as “health areas” and are defined as containing one or more health facilities responsible for providing healthcare services to between 5,000 and 15,000 people. Health areas aggregate to health zones, which are made up of 15 to 25 health areas and have a general referral hospital offering more comprehensive healthcare services. GRID3’s involvement was in response to strong demand from different groups in the health sector (including the Ministry of Public Health through its various directorates) to generate health area boundaries; it was also a response to the fact that the National Institute of Statistics (INS) and Central Bureau of Census (BCR) were already actively working on digitising administrative units.

Most of the existing maps of health areas and health zones in Haut-Lomami and Tanganyika were hand-drawn and consequently did not have high spatial accuracy. Health area maps were usually created and kept at local health facilities; with no easy way to access or transfer the data, discrepancies (including gaps and overlaps in the boundaries) often existed, especially between neighbouring health areas. This format made reporting accurate boundary information to the health zone or provincial-level health officials cumbersome. Consequently, GRID3’s goal was to produce a high quality (and agreed-upon) dataset of health area and health zone boundaries that could be officially accepted and used by DRC’s Ministry of Public Health and NGOs.

Approach

To create the health boundaries, GRID3 leveraged existing boundary and settlement point data that included information gathered by the BCR, UCLA, and polio vaccination teams (i.e. a dataset that provides settlement points or polygons and their names to spatially locate, identify, and visualise settlement features) in order to establish baseline data layers. Subsequently, GRID3 engaged with the Ministry of Public Health; health workers were directly involved in mapping the health area boundaries at a participatory event coordinated with in-country provincial coordinators and Geographic Information System (GIS) technicians in the summer of 2019. The baseline settlement layer was used to guide the digitising of health area boundaries during the mapping event, ensuring boundaries encompassed all settlements listed in official microplans, as well as any additional settlements known by the health workers to be in their assigned areas. The health workers were trained to collect supplemental data (using an ODK-based application developed by GRID3’s partner, Novel-T) in the respective health areas where they worked in the Haut-Lomami and Tanganyika provinces.

15. Health areas are the functional units used by the Ministry of Public Health and non-government organizations. Health areas aggregate to health zones and then to provinces.
16. Over the years, boundary data had been collected by various governmental and non-governmental bodies working in the health sector; but this data was always limited to a given project or programme’s geographic area of interest. As a result, only approximately one-third of the country’s health area boundaries had been delineated, and even those boundaries were of differing quality (e.g. some had no metadata). A separate issue was that the health areas did not properly nest into the boundaries of health zones or health districts.
17. Previously, the UCLA-DRC Health Research and Training Program conducted extensive mapping of the former Bandundu Province health zones, using high-resolution satellite imagery, remotely sensed settlement data, and the detailed geographic knowledge of local health zone staff.
18. Many of these technicians were recent university graduates who received additional training from GRID3.
20. These data all had an attribute for a health area and health zone names and thus could be used to refine the boundaries delineated during the mapping event. The involvement of local health workers throughout the mapping process ensured that the resulting data were highly accurate and relevant, since these workers are intimately familiar with their respective health areas and are ultimately the end users of the data.
Figure 5: Creating health catchment area boundaries

Baseline Boundary Data
The pre-existing health area boundary data were often incomplete or inaccurate.

Intermediary Results
An example of the intermediary boundaries that were delineated during the participatory mapping meeting.

Final Health Area Boundaries
The resulting health area boundaries (after additional data were collected in the field) are harmonised with national systems, free of topology errors, and validated by the relevant DRC Ministry of Public Health officials.


Figure 6: Comparing Thiessen polygon approach to GRID3’s participatory mapping approach

The figure on the left shows the results of one approach to creating health catchment boundaries: by generating Theissen polygons from settlement points with health area attributes. The figure on the right shows the results of the approach GRID3 took involving the participatory mapping process. The resulting boundaries of the participatory mapping approach are much more precise, follow natural features, and include all settlements within a catchment area instead of just those that are georeferenced and have a health area attribute.
The mapping event was followed by the field data collection of additional settlement, health facility, and POI data by each health worker. Each point collected included the associated health area and health zone attribute information as known by the local health worker. GRID3 then cleaned the boundaries, coordinating with GIS technicians in the field to resolve discrepancies, including any gaps or overlaps, misalignments, and inconsistencies between point data attributes and boundaries. The resulting boundaries were further improved through collaboration with GeoLab researchers who ensured that the health area boundaries encompassed all the appropriate point data based on its health area attribute and also ensured that, when possible, the boundaries followed natural or artificial features (such as rivers or roads). Finally, the resulting data were validated by the respective health zone-level officials.

**Outcomes**

A set of comprehensive, accurate, and nested health area and health zone data layers were produced in the two provinces. In total, this work improved 590 health areas in 27 different health zones across a 234,825 km² area. The new delineations revealed that there were some significant discrepancies between the old layers (when they existed) and the new, improved layers. For instance, the Kitenge health zone was twice as large as suggested by the extant boundaries, which had important implications for planning and service delivery.21

Improved health areas and health zone maps (in PDF format) will now be used by health workers in the provinces to plan for routine immunisation, as well as for polio and/or measles campaigns. At the health zone and provincial level, boundary data (in shapefile format) are available for download.22 In addition, GRID3 is working closely with the recently-established Agence Nationale d’Ingénierie Clinique d’Information et d’Informatique de Santé (ANICiiS) to propose a sustainable data governance pathway in support of the second National Strategy for Digital Health Plan.

**Figures 7 and 8: Comparing maps in Kayamba health zone**

Compare the hand-drawn operational map used by health workers in Kayamba health zone (without health area boundaries) to a new digital operational map created with the data collected and digitised in Summer 2019.

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21. OpenStreetMap’s health zone boundary for Kitenge was half the size of the health zone according to the distribution of settlements (existing and field collected point data) recorded as being in Kitenge. See OpenStreetMap. https://www.openstreetmap.org/about.

Facilitating inter-institutional dialogue among government agencies to address discrepancies in boundary data

A second type of GRID3 boundaries delineation support centres on cases where authority over boundaries is distributed among different agencies; in this scenario, GRID3 works to bring these authorities together to collaborate on boundary harmonisation. Boundaries can be physically walked using this approach; but in cases where walking is not practical, local managers can make decisions while using a common set of maps. This approach is most effective when blended with additional, carefully targeted technical work.

Participatory mapping in Zambia

In Zambia, GRID3 has supported boundary delineation by facilitating coordinated and integrated participation across government institutions that have formal authority for managing boundaries. These institutions are found in several different agencies: the Office of the Surveyor General (OSG) is responsible for national, provincial, and district boundaries, along with the Ministry of Local Government (MLG); meanwhile, the Electoral Commission of Zambia (ECZ) is responsible for mapping wards and constituencies countrywide, while the Zambia Statistics Agency (ZamStats) is responsible for delineating EAs for census enumeration. Each agency creates administrative units under a different mandate and at a different mapping scale than those used by other agencies.

Given that the land disputes occur at various levels of zoning (such as the city, farm plot, or property level), it is important to have high-resolution district boundaries that follow topological features precisely.

This structure has resulted in boundary discrepancies that make it difficult to calculate and aggregate accurate statistics at different administrative levels, and have led to inaccurate boundaries that make it unclear who has jurisdiction over/ownership of a given area. For example, most district councils in Zambia had little or no capacity to interpret their area of jurisdiction, which often resulted in councils occupying land beyond the boundaries under their authority. In such instances, the team from OSG was called upon to assist local councils with resolving land disputes and did so by referring to the district maps (as well as district narratives) in order to determine to which district the property belonged.

Given that the land disputes occur at various levels of zoning (such as the city, farm plot, or property level), it is important to have high-resolution district boundaries that follow topological features precisely. And yet insufficient mechanisms were in place for the agencies to coordinate their efforts to make boundaries both more accurate and standardised. To address this, GRID3 supported stakeholders by providing concrete suggestions for improved mechanisms via boundary harmonisation workshops (i.e. participatory mapping).

23. *The creation of maps by local communities, often with the involvement of supporting organisations (including governments, NGOs, or other actors engaged in development or land-related planning). Data resulting from this process can be made openly available or can be closed, depending on a community’s wishes.*
Approach

Prior to the harmonisation workshops, GRID3 analysed the topology of districts and wards to identify gaps and overlaps between the two levels of administrative division.

GRID3 then worked with the relevant agencies to develop a workshop methodology to validate and harmonise wards and district boundaries at the same mapping scale. The chairmanship of the harmonisation process and data hosting are under Zambia’s NSDI Technical Committee.24 GRID3 worked hand-in-hand with the NSDI Chair, the Surveyor General, and GIS technicians from ZamStats and ECZ to strategically design, plan, and conduct the workshops. The collaboration with NSDI was not only key to nationalising the data, but also to ensuring a Zambian agency was spearheading the sharing of the respective data on an open platform.

The boundary harmonisation workshop took place in two parts in Chongwe District, Zambia. The workshop was attended by representatives from the ECZ, OSG, MLG, ZamStats, and the University of Zambia. Over the course of the two workshops, GIS technicians from participating ministries aimed to harmonise ward and district boundaries by referring to official district narratives, topographic maps, and aerial imagery. In advance of the workshop, GRID3 prepared map documents and a workflow for the editing sessions. A pre-workshop practice session was held the day before the start of the workshop, allowing GIS technicians from each ministry to review the workshop methodology and practise the editing workflow.

At the start of the first session, participants were divided into groups in which at least one participant from each organisation was present; each group was then given one map document to use to edit the boundaries. A GIS technician from each group connected their laptop to a projector to visualise the editing session, allowing all group participants to see and discuss the edits. The map document included a layer of ward and district boundaries; polygons representing gaps and overlaps; an imagery basemap; topographic maps at a scale of 1:50,000 and 1:250,000; cadastral maps; as well as geospatial files representing rivers, roads, towns, and beacons. In each group, a representative from MLG would read the district narrative while a GIS technician panned around the district polygon, using topographic maps and other reference layers to follow the narrative description. Each significant boundary misalignment was discussed by the given group before an edit was made; this ensured that the boundaries’ custodians were in agreement regarding how the boundary was to be edited. In order to align district boundaries to topographic features described in the narrative, the gap or overlap polygon was either merged to the correct unit or retraced. Imagery was turned on when the boundary needed to be aligned and switched on and off to make sure the revised boundary was consistent with both topographic maps and the natural features on the ground. GRID3 staff assisted the GIS technicians when support with editing tools was needed.

After the completion of the workshop, district boundaries were validated by GIS technicians from the Ministry of Lands, endorsed by the OSG, and shared with provincial and local planners. District and province codes have been adapted from the ZamStats coding schema and added to the district shapefile attributes. The harmonised ward shapefile is currently being validated by the ECZ.

24. This body is led by the Surveyor General’s Office. All government officials working with Geographic Information Systems (GIS) participate in its activities.
25. GIS is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.
Administrative boundaries created by distinct institutions at different mapping scales (boundaries are often not aligned, resulting in gaps and overlaps between two levels of administrative divisions). Misaligned boundaries create inaccuracies during the integration of datasets from various institutions, pose difficulty in calculating and aggregating accurate statistics, and also hinder data-sharing and utilisation among stakeholders. The goal of GRID3 in Zambia was to work with boundary custodians and provide a mechanism to eliminate gaps and overlaps in order to produce an aligned set of geographies.
Outcomes

Through participatory mapping, all 116 district boundaries were aligned to topography and harmonised with wards at the same mapping scale. Within five months, district shapefiles were endorsed and shared with government ministries, as well as with provincial and district planners stationed at the local level. The district shapefiles have also been uploaded to Zambia’s NSDI data platform. Errors in the district narratives were identified for correction.

GRID3 successfully facilitated coordination among all government agencies responsible for boundaries in Zambia. This achievement can potentially provide a path for codifying how these agencies collaborate in the future. In addition, officers from multiple ministries were trained and involved in the mapping process. Should changes to boundaries arise in the future (e.g. due to the creation of new districts and wards), the officers have the required knowledge to make the necessary updates, even when no longer receiving support from GRID3. As a next step, GRID3 will transfer the topology model builder tool created in ArcGIS to the boundaries custodians (OSG and ECZ) so they can identify misalignments, build topology rules, make a schedule to check on topologies and misalignments, and develop a strategy to keep boundaries harmonised.

Figure 10: Before boundary harmonisation workshop

Figure 11: After boundary harmonisation workshop

Livingstone District Boundaries
- District boundary
- Wards within District

Livingstone District Boundaries
- District boundary
- Wards within District

District source: Office of the Surveyor General, Ministry of Lands and Natural Resources
Wards source: Electoral Commission of Zambia
Semi-automatic delineation of pre-Enumeration Areas (pre-EAs)

For interviewer-based censuses, census takers (“enumerators”) cover assigned enumeration areas (EAs), which include all households and persons in an officially designated geographic area during a specified (and usually short) period of time in order to meet the requirements of universality and simultaneity. An EA is the smallest geographical statistical area by which a country is divided. The size of EAs varies among rural and urban sites, with rural EAs containing between 150 and 200 households and urban EAs containing between 200 and 250 households. Census mapping aims to provide the cartographic basis for the actual process of census enumeration. For enumeration, unique maps covering the entire country with accurately defined boundaries are necessary to guide each enumerator’s work during the enumeration phase. In the pre-census stage, maps ensure coverage consistency and facilitate pre-enumeration operations. Where maps with accurate boundaries clearly define small areas (EAs), lists of households can supplement these maps. The design and delineation of EAs and other census management areas for the field enumeration is the geographic foundation for census datasets and a vital component of the national census.

Creating and updating EA boundaries is a challenging yet essential task in the preparation for a census, which (despite technological developments in recent census rounds) still requires significant time and labour investments.

The use and application of geospatial technology and geographic databases have significantly improved census mapping and the collection of more accurate data in a timely manner. Technological advances during the last few census rounds include personal computers; hand-held devices and personal digital assistants (PDAs); global positioning systems (GPS); GIS software, and aerial and satellite imagery. Countries evaluate which mapping options match their national context, mindful of existing geographic resources, technology resources, qualified staff, available funds, and the timeframe allocated to complete the geographic tasks for the census. These developments have led to widespread need for EA boundary datasets and basemaps to be in digital formats. New digital datasets may be created, and existing datasets updated, through digitising small geographic units on high-resolution satellite imagery using GIS software, followed by field verification.

Creating and updating EA boundaries is a challenging yet essential task in the preparation for a census, which (despite technological developments in recent census rounds) still requires significant time and labour investments. In countries such as DRC, where a census has not been conducted for several decades, creating appropriately sized EAs is more difficult given the lack of recent population estimates or an existing EA dataset (as a baseline that can be updated).

To respond to this challenge, GRID3 is developing a semi-automated delineation approach to create small geographic units in preparation for census cartography, referred to as “pre-EAs.”

26. United Nations Department of Economic and Social Affairs Statistics Division. Principles and Recommendations for Population and Housing Censuses: Revision 3. 2017. These figures may vary according to the household size and also depending on the duration of the enumeration period.

27. The term “pre-EA” refers to small areal units created in preparation for census cartography that conform to the specification of an EA (in terms of estimated population, area, etc.) but are considered to be approximate and should be validated during census cartography.
Creating pre-EAs for the Democratic Republic of the Congo

Approach

Considerable work is required to ensure that the necessary mapping of boundaries and statistical units are in place during the pre-census stage. In the context of DRC, the magnitude of this work is amplified by the fact that over three decades have elapsed since the last census was conducted (1984). As a result, a recent, national, digital EA dataset that can be used for census cartography planning does not exist; considering the large population and area of DRC, as many as 200,000 EAs may be needed nationwide.

The GRID3 semi-automated approach utilises geospatial processing tools to produce pre-EA boundaries using geospatial datasets on features such as roads, buildings, rivers, and high-resolution gridded population data.

GRID3 is supporting the realisation of the 2nd National Population and Housing Census in DRC in the 2020 round. GRID3 has been working closely with the INS and BCR to provide technical guidance regarding options for potential ways to incorporate geospatial methodologies into census planning and census cartography. As part of this work, the feasibility of using a semi-automated approach for the delineation of pre-EA boundaries is being investigated.

The GRID3 semi-automated approach utilises geospatial processing tools to produce pre-EA boundaries using geospatial datasets on features such as roads, buildings, rivers, and high-resolution gridded population data. Gridded population data take the form of a raster dataset composed of grid cells and provides population estimates associated with each grid cell (as opposed to a more typical areal unit). The grid cell size is determined by the spatial resolution of the gridded population data; GRID3 gridded population estimates typically have a grid cell size of approximately 100m x 100m. The gridded nature of the data provides flexibility in aggregation such that estimated population can be calculated within a defined boundary.

Linear features (both natural and man-made, such as roads and rivers) taken from existing digitised geospatial sources (e.g. OpenStreetMap) are combined with existing administrative units to subdivide regions into small geographic units. The estimated population for each small unit is then calculated from high-resolution gridded population data, with units subsequently merged to meet the criteria specified in terms of population size, geographic area, and any other constraints. The result is a complete set of boundaries (for small units nested within the existing administrative boundary hierarchy without gaps or overlaps) that can be used for census planning. In the context of a national census, the output can be considered an initial set of pre-EA boundaries, which then need to be validated and updated during census cartography. The method could also be relevant to updating EAs or to deriving national sampling frames.
Pilot study

To test this approach in DRC, outputs have been produced for three test sites in Kongo-Central and Kinshasa provinces: Quartier Kingu, Kinshasa (urban); Quartier Dumi, Kinshasa (suburban); and Secteur Kasangulu, Kongo-Central (rural). These sites were selected because they include a range of rural and urban contexts. A field test was conducted by the BCR under the supervision of a GRID3 team over four days in December 2019; the intention was to assess whether the outputs from the semi-automated approach to creating pre-EA boundaries would be useful in preparing for the 2nd National Population and Housing Census, as well as for providing deeper insights into the advantages and limitations of the approach and areas for further development.
The geographic area covered by the three sites totalled 1,190 km² and was subdivided into approximately 310 pre-EAs using the semi-automated approach. A visual assessment was carried out by comparing the pre-EA boundaries generated with recent high-resolution satellite imagery. In the field, a subset of the pre-EAs was assessed to check how the boundaries related to ground features and their feasibility as units for population enumeration. The estimated population for each pre-EA was calculated from the GRID3 high-resolution gridded population data and were also assessed via a household enumeration exercise. The field teams used GPS-enabled tablets with the pre-EA boundaries overlaid onto satellite imagery, which enabled the field teams to know their location in relation to the pre-EA boundaries and to successfully navigate and identify where they needed to enumerate.

**Figure 12:** Assessment of generated urban and rural pre-EA boundaries in relation to ground features during DRC field test

**Urban areas**

![Urban area assessment](image1)

**Rural areas**

![Rural area assessment](image2)

In the field, a subset of the pre-EAs was assessed to understand how boundaries related to ground features and determine their feasibility as units for population enumeration. To conduct this assessment, the field teams used GPS-enabled tablets with pre-EA boundaries overlaid onto satellite imagery to track their movements.

The GPS tracks, depicting the field team’s movements, helped indicate which parts of the pre-EA boundaries and settlements were assessed. In some cases, the field team also had to step outside of the pre-EAs to ensure that all the necessary sides of pre-EAs were assessed, report if any houses were cut by pre-EA boundaries and ensure that all the households within pre-EAs are accessible and can be enumerated without barriers. The field test enabled cartographers to understand their location in relation to the pre-EA boundaries and to successfully navigate and identify where they needed to enumerate.

The findings from the field test showed that the pre-EA boundaries created using the semi-automated approach could be used successfully by field teams with GPS-enabled tablets in both urban and rural contexts. It is expected, therefore, that this approach could be scaled to create a national dataset of pre-EA boundaries. In the context of preparing for census cartography, without the semi-automated pre-EA approach the creation of a national boundary dataset would most likely require extensive manual digitisation from satellite imagery by a team of GIS experts (a task that is both highly resource-intensive and challenging, particularly creating boundaries that take into account estimated population size and area and that are free from topological errors). The semi-automated approach described here helps address all these issues: area and population constraints are considered in generating the pre-EAs; the boundaries follow features as much as possible and avoid splitting up rural settlements; topological errors are avoided; and the overall resource requirements are less onerous.

Outcomes and next steps

Based on the findings of the field test in DRC, the approach has been found to have applicability in the context of DRC census cartography preparations. Further work is needed to develop the approach for use in a national census (scale-up); for example, ensuring that a wider range of factors determining EA size, shape, and extent can be incorporated. The current workflow involves processing via a Python script, alongside data integration in GIS software and manual checking of outputs. Ultimately, GRID3 will aim to package this in an application where users can adjust parameters via an interface and familiarity with Python is not a prerequisite for implementation. GRID3 would expect that this approach would have applicability in other, similar contexts where a census has not recently been conducted and consequently there are no extant national EAs. In addition, GRID3 expects that the approach could be employed to update outdated digital EA boundaries; but this should be explored through further testing in this context.
The output of the approach takes the form of a set of polygons that meet specified criteria around population size and area (pre-EA boundaries), which can then be validated during census cartography.

**Figure 13**: An overview of the semi-automated pre-EA approach, showing the input vector and raster datasets that feed into the “splitting” and “merging” steps.
The impact of boundaries is far-reaching—boundaries can ultimately determine a household’s access to resources, a town’s distribution of vaccines, or the development trajectory of entire countries. Garikai Membele, a Technical Coordinator for GRID3 and a Lecturer at the University of Zambia, explains that misaligned boundaries can result in incorrect decisions by policymakers: “Say that you want to know the number of people in a particular locality—for example, ward. But because the boundaries are wrong, you may end up sending fewer drugs than you actually need on the ground. So you end up in a situation where there is an inadequate amount of drugs because the boundaries are wrong and the spatial analysis was not properly conducted.”

"With the development of digital microplans, I could independently look at a health area or a health zone, get a realistic picture of how the area looks, and see where highly populated areas are located. This helps to support informed decision-making to choose, for instance, where the next fridge should be installed, or how many vaccines should be allocated to a specific area."

- Jean Pierre Makala, Chef de Division de la DPS de Kwilu in DRC

The positive effects of harmonised, digitised boundaries, on the other hand, can ramify widely, helping to improve the decision-making abilities of stakeholders. For example, correct digital boundaries can inform impactful digital microplanning in DRC. As Jean Pierre Makala, Chef de Division de la DPS de Kwilu in DRC, says: “With the development of digital microplans, I could independently look at a health area or a health zone, get a realistic picture of how the area looks, and see where highly populated areas are located. This helps to support informed decision-making to choose, for instance, where the next fridge should be installed, or how many vaccines should be allocated to a specific area.”

These kinds of real-world implications drive GRID3’s efforts to innovate in the field of boundaries harmonisation, and the programme has already supported important improvements in its partner countries’ boundaries data and related capacities. But there are also significant shortcomings in GRID3’s approach and execution that remain to be addressed: many district narratives that were relied upon in the mapping process often contained topographical errors and inconsistencies; EA boundary alignment was not a part of the Nigeria, DRC, and Zambia work, and should be incorporated in order to make boundary alignment in those countries more comprehensive; and traditional boundaries and health facility catchment areas were not aligned in these countries, but should be eventually.

GRID3 will continue to collaborate with its partners both within and outside government to address these shortcomings and to continue seeking effective and innovative approaches to linking boundary harmonisation with broader campaigns to make development more sustainable. More broadly, GRID3’s boundaries work will continue to dovetail with its work on its other core data layers—mapping comprehensive settlement locations, locating critical infrastructure, and creating high-resolution population estimates—so that each data layer increases the power of the other layers, combining to provide comprehensive data support to development goals throughout sub-Saharan Africa.
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Works Cited


OpenStreetMap. https://www.openstreetmap.org/about.
GRID3 (Geo-Referenced Infrastructure and Demographic Data for Development) works with countries to generate, validate and use geospatial data on population, settlements, infrastructure, and subnational boundaries. GRID3 combines the expertise of partners in government, United Nations, academia, and the private sector to design adaptable and relevant geospatial solutions based on capacity and development needs of each country.

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