Assessment of GIS for the population and housing census and agricultural census in the Sudan

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Economic and Social Commission for Western Asia

Assessment of GIS for the population and housing census and agricultural census in the Sudan

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Key messages

- *Geospatial information technologies have greatly improved and become more accessible and affordable, making hand-drawn maps less used.*

- *In the 2010 census round and even more in this current 2020 round, countries adopted these new technologies with varying levels of success.*

- *With the right mix of resources and skills, countries can greatly improve their map production and field monitoring to collect precise and quality data on population, housing and agriculture holdings to build a well-structured geographic database.*

- *For a successful mapping exercise, it is recommended that the Sudan Central Bureau of Statistics (CBS) build a strong team skilled in imagery and remote sensing and equipped with the appropriate tools for imagery processing.*

- *Capacity-building in imagery processing and external technical assistance have to be considered.*

- *For the mapping activities in its upcoming census, CBS plans to adopt an integrated electronic system composed of geographic information system tools (GIS) and tablets for updating the boundaries of enumeration area and the numbering of buildings.*

Executive summary

Geospatial information methodologies and technologies have been adopted by national statistics offices (NSOs), including in many developing countries, with the recognition that the appropriate use and application of these technologies is beneficial to the efficient preparation, enumeration, processing and dissemination of population and housing censuses, and ultimately their overall quality. Today, virtually every NSO uses a geographic information system (GIS) to create digital maps, create and maintain databases, disseminate geostatistical products and provide a wide range of services. Statistical-geospatial infrastructure supporting censuses and statistical activities is particularly recognized as an enabler for facilitating data sharing and improving the availability and access of country information in support of evidence-based decision making and sustainable development.

The United Nations has indeed recommended that countries build, develop and strengthen their geospatial information infrastructures in support of census and statistical activities, and recognize that the adoption of a geographic-based approach with full integration of statistical and geospatial information offers an opportunity for countries to modernize their national statistical systems and official statistics[1] and build their capacities to manage the challenges of the 2030 Agenda for Sustainable Development.

It is in this vein that the Central Bureau of Statistics (CBS) in the Sudan aims to use innovative geospatial information technologies in support of its upcoming census, in accordance with United Nations recommendations and taking into account its specific national circumstances. In this regard, the Economic and Social Commission for Western Asia (ESCWA) has commissioned this assessment report that identifies the scope and gaps of the existing geospatial infrastructure within CBS, with guidelines on how to use geospatial information technologies at every stage of the census, and identify the resources and capacities for their implementation and monitoring.

1 Cf. In-depth review of developing geospatial information services based on official statistics, Note by the United Kingdom Office for National Statistics, CES, 2016, ECE/CES/2016/7.

Contents

List of tables

List of figures

List of boxes

Abbreviations and acronyms

CAPI	computer-assisted personal interviewing
CBS	Central Bureau of Statistics
DESA	Department of Economic and Social Affairs
ESA	European Space Agency
ESCWA	Economic and Social Commission for Western Asia
FAO	Food and Agriculture Organization
GIS	geographic information system
GPS	global positioning system
GNSS	global navigation satellite system
ISO/TC211	International Organization for Standardization (ISO) Technical Committee 211 Geographic information/Geomatics
NMA	national mapping agency/authority
NSDI	National Spatial Data Infrastructure
NSO	national statistical office (organization)
OGC	Open Geospatial Consortium
PES	post-enumeration survey
SDGs	Sustainable Development Goals
UN-HABITAT	United Nations Human Settlements Programme
UNFPA	United Nations Population Fund
UNITAR	United Nations Institute for Training and Research
UNSD	United Nations Statistics Division
WGS84	World Geodetic System 1984

Introduction

The Central Bureau of Statistics (CBS) of the Sudan is planning to conduct its upcoming population and housing census as well as its agricultural census in compliance with United Nations recommendations and principles encouraging countries to keep abreast with technological developments since the previous 2010 round, especially the use of geographic information system (GIS) and other geospatial information technologies such as global positioning system (GPS), satellite/aerial imagery and spatial analysis in census activities, from preparation to the dissemination of census results[2] and beyond.

Since the strategic decision of CBS is to use GIS-based mapping and the computer-assisted personal interviewing (CAPI) method for data collection with handheld devices equipped with global navigation satellite system (GNSS)/GPS receivers, some required activities need to be carried out in order to develop a digital census mapping programme using geospatial technologies throughout the three stages of the census. Specific guidelines with regard to the demarcation of enumeration areas and the establishment of an enumeration area-based geographic database will be outlined, as well as the detailed operations on the use of GIS and other geospatial technology throughout all stages of the census, and particularly the technical solution that allows the integration of the GIS enumeration area maps with CAPI applications for field operations (including the data preparation and collection workflow). In addition, emphasis will be put on the technical and human resources needed to conduct a full digital census mapping exercise that supports both censuses. Some specific recommendations will be outlined about what benefits the agricultural census could draw from the geospatial information activities carried out for the population and housing census.

The present study reports on the geospatial infrastructure situation, through an inventory of the existing geospatial and mapping data, hardware/software and skilled labour available within CBS. It evaluates the challenges and recommends the best way to use existing resources, identifies the new resources that need to be acquired and produced and determines the best technical solutions to conduct the upcoming GIS-based census mapping for both censuses. More specifically, the report includes guidelines on the enumeration area delineation process, how to build a geographic database at the smallest statistical unit, the procedures to conduct a pilot GIS mapping exercise and a road map of geospatial information activities to be carried out at all stages of the census, including recommendations on capacity development and resources needed to accomplish a successful full GIS-based census mapping exercise.

2 As stated in the "Principles and Recommendations for Population and Housing Censuses – Revision 3", 2017. https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf.

1. Inventory of the existing situation (and needs assessment)

Based on good practices in line with United Nations principles and recommendations, a GIS-based census mapping programme should be developed at an early stage of census planning to allow sufficient time to produce enumeration maps with full national coverage well before the census date, as this is a time-bound operation with a critical date when all enumeration-related maps and map services must be made available to the census field enumeration.

At the institutional level, this requires the identification of the technical and organizational/institutional tasks to be carried out through the planning process. Our diagnosis of the institutional situation reveals that there is a single national authority for geospatial information in the Sudan, the Sudan Survey Authority (SSA), which is in charge of surveying, mapping and charting in the Sudan. SSA provides mapping services for all ministries, but there is a lack of coordination with other national organizations in need of geospatial information. To overcome this gap in coordination, a technical committee was established by CBS and SSA, in 2018, to coordinate the work in the field of mapping and GIS.

At the technical level, a GIS-based census mapping programme requires the evaluation of available geographic and technological resources and the critical design issues involved, with focus on its core geospatial database and the range of applications that it will support. Of particular importance is the inventory of existing maps and other geographic data sources, and the data conversion and integration processes, all of which depend on a well-designed institutional environment and a well-planned operational strategy.[3]

A comprehensive inventory of all existing maps and imagery in the country, in analogue or digital formats, covering the whole country in various scales, is needed to identify those which meet the requirements of enumeration demarcation. This would include rural and urban base maps covering the whole country, at small scale; topographic maps; large scale base maps at town and city levels showing land parcels, details about important physical features such as streets and roads, parks, water features, city buildings and important landmarks (city and cadastral maps); maps of administrative units at all levels; thematic maps showing population distributions from previous censuses, or any features that may be useful for census mapping; and even sketch maps; relevant high-resolution satellite images and

3 See details in the Handbook on Geospatial Infrastructure in Support of Census Activities, 2009. United Nations, DESA – Statistical Division. https://unstats.un.org/unsd/demographic/standmeth/handbooks/series_f103en.pdf.

digital aerial photos, and GPS data.[4] The inventory may show that existing maps do not fully provide all needed data, requiring some additional traditional work in the field or additional search in various data sources. The final outcome is a mapping/geospatial infrastructure available to carry out the census mapping.

As part of the inventory, the consultant prepared a questionnaire (annex 1) that was filled out by the CBS centre for GIS, providing information on the current situation, with additional information gleaned from the responses by CBS to the ESCWA questionnaire (annex 2), as well as online interviews with the director of the CBS centre for GIS.

The inventory shows that: (a) There are no updated base maps, and the existing maps at CBS are mainly administrative maps showing the boundaries of the country's six provinces and 18 states; (b) CBS has no aerial or satellite imagery covering the whole country; (c) The datum for the national geodetic/spatial reference system is based on WGS84;[5] (d) The GIS software available is ArcGIS 9.3[6] (an old version of Esri ArcGIS), with a central geographic database (a database at the enumeration area level created for the 2008 census); (e) CBS has a centre for GIS with around seven people, with hardware including desktops, laptops, printers, plotters and scanners, most of which is not functional. CBS does possess 60 GPS units, and its staff do know how to use GPS in the field.

The inventory shows that the CBS centre for GIS has a limited number of GIS and mapping staff who are mostly young; still, they can provide the needed support to CBS during all stages of the census, provided they are trained and keep abreast with recent technological developments, and that CBS acquires a recent GIS software package (enterprise-oriented GIS software appropriate for a census) and related appropriate technological equipment. This means CBS has to develop and strengthen its GIS capacities for the use of geospatial information technologies during the census mapping process at all stages and beyond, with the view that geospatial technologies may be costly at first, but they will have a return on investment if they are used for the census and beyond. Moreover, resources will be needed to acquire handheld devices (thousands of tablets with built-in GPS/GNSS receivers), communication equipment and systems (such as VPN to ensure efficiency, security and confidentiality of data acquisition and transmission) and probably the outsourcing of the development of apps and integration of CAPI and GIS maps. Since recent satellite imagery is of utmost importance to serve as the basis for delineating enumeration areas and to be used on handheld devices, resources should be allocated to acquire and process such imagery.

4 "GIS and the 2020 Census – Modernizing Official Statistics", 2019, Esri Press. https://www.amazon.com/GIS-2020-Census-Modernizing-Statistics/dp/1589485041.

5 The World Geodetic System (WGS) is a standard for use in cartography, geodesy and satellite navigation including GPS. The latest revision is WGS 84.

6 On 26 June 2008, Esri released ArcGIS 9.3.

2. Geospatial activities in the pre-enumeration stage

The pre-enumeration stage is crucial, as CBS needs to not only prepare for the population and housing census and the common geographic frame with the agricultural census,7 but also plan all of the technology and other requirements for the enumeration and post-enumeration phases. In the following section, we lay out the activities needed for the pre-enumeration phase, and the technical solution that would help to carry out all the census activities.

A. Census geography – Mapping infrastructure

Census geography refers basically to how the country is geographically divided prior to the actual census enumeration in order to facilitate field operations, data processing and analysis, and ultimately reporting and dissemination of census results. One of the early key actions in the development of a census mapping programme is to determine the geographical units for census enumeration, as the definition of "geography on which the census is collected will determine the geography on which the census data can be disseminated".[8]

The inventory of the sources of the geographic data helps determine how we construct the census enumeration areas for collection (census blocks, buildings and dwellings), which constitute the basic features of the census GIS database. In the case of the Sudan, with the absence of base maps, which generally constitute the main sources of data for the delineation of enumeration areas, emerging data sources such as satellite imagery and other imagery when possible or available (such as aerial and drone imagery, though aerial and drone imagery are very costly for the Sudan) should be used to support the delineation of enumeration areas.

In this regard, we need to start to review and update the existing coding scheme to have a geocoding system which constitutes the reference that gives all the census units (census blocks/enumeration areas, buildings, household dwellings/units) their geographic dimension, in providing a unique identifier

7 "A census of agriculture is a statistical operation for collecting, processing and disseminating data on the structure of agriculture, covering the whole or a significant part of a country. Typical structural data collected in a census of agriculture are size of holding, land tenure, land use, crop area, irrigation, livestock numbers, labour and other agricultural inputs. In an agricultural census, data are collected at the holding level, but some community-level data may also be collected". Cf. "Handbook on remote sensing for agricultural statistics". http://www.fao.org/3/ca6394en/ca6394en.pdf.

8 As stated in the "Principles and Recommendations for Population and Housing Censuses – Revision 3", 2017. (ST/ESA/STAT/SER.M/67/Rev.3). https://unstats.un.org/unsd/demographic-social/?aspxerrorpath=/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf.

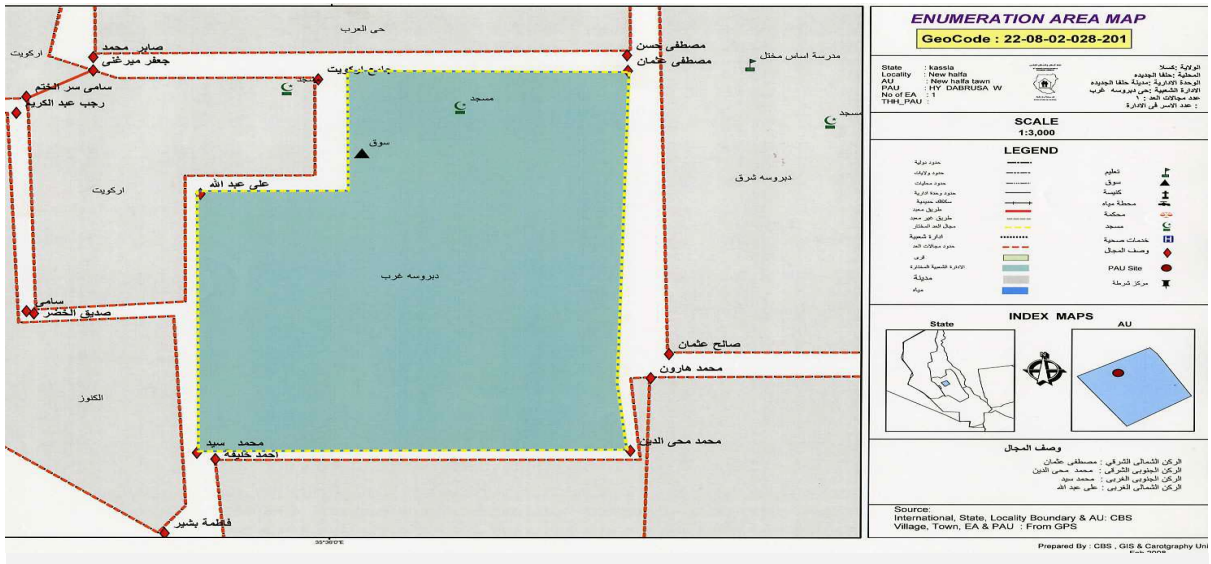
(code) which links between GIS boundaries and tabular census data. To sustain this link, the geocoding system is generally designed to be flexible enough and well-structured to incorporate new and any future administrative divisions. The concept of nested codes is considered one of the best approaches and should be respected where possible.

1. Proposed coding scheme

The existing administrative hierarchy needs to be revisited in order to create an accurate geographic frame, with enumeration areas (with buildings and dwellings) forming the smallest geographic units and falling within certain regions, states, localities, administrative units and popular units, with boundaries that are as accurate as possible. The geographic frame should specify the smallest statistical units, but also incorporate other reference information, such as topography, elevation, land parcels, transport networks, etc. It should also take into account fundamental features needed for the agriculture census, such as household and commercial holdings (including livestock and poultry), land cover and land use, forests, sites of existing or possible migratory/nomadic population, etc. Only once the geographic frame has been created can the re-demarcation and updating of enumeration area boundaries begin (next section).

In this regard, a review of the coding system has been discussed with the CBS team, and there is agreement on the following coding scheme:

Figure 1. An enumeration area map used for the 2008 census



Source: Adapted from UNSD.

(a) Proposed geocoding scheme at the building level (to be discussed and agreed upon):

2 digits	2 digits	2 digits	3 digits	3 digits	3 digits	2 digits

"Region/State", "Locality", "Admin, Unit", "Popular Unit" (A/C) EA(U/R/N/A...) Blocks Buildings

(b) Proposed geocoding scheme at the household level (to be discussed and agreed upon):

"Region/State", "Locality", "AU", "PU" (Admin.) EA(U/R/A) Blocks Buildings Floor Entrance HH Code

(c) Gazetteer (Settlements)

"Region/State", "Locality", "Admin. Unit", "Popular Unit" (A/C) EA(U/R/N/A…) Settlements

The above coding scheme was discussed with CBS and reflected their needs. Even so, CBS can adjust the scheme if some units are left over or include additional ones. Figure 1 demonstrates the principles to be followed in any coding scheme.

2. An integrated approach

CBS is initiating the Sudan Comprehensive Agricultural Census (SUDCAC), to be conducted gradually over three years. However, since there has been no agriculture census for the last 50 years, there is no geographic frame for the smallest statistical units (agriculture holdings), and one needs to be built for the upcoming agriculture census, based on the preparatory work being carried out for the population and housing census. For the agriculture census, the nested administrative hierarchy of the population and housing census coding scheme should be used at least until the enumeration area level, as any data collection of enumeration areas from the population and housing census will provide inputs that help demarcate the operational agriculture holdings[9] (the enumeration areas for the agriculture census) and adapt them to the specific needs of the agriculture census. In other words, the population and housing census will help build the frame for the agriculture census,[10] and a geocoding scheme built for the population and housing census but taking into account the needs of the agriculture census will serve as a common ground between the two censuses.

For its agricultural census, and in line with FAO principles and recommendations, CBS is considering two types of agricultural holdings: family holdings (similar to the population and housing census households) and commercial holdings. Accordingly, the coding scheme for the agriculture census would be as follows:

9 "An agricultural holding is an economic unit of agricultural production under single management comprising all livestock kept and all land used wholly or partly for agricultural production purposes, without regard to title, legal form or size". FAO "World Census of Agriculture programme 2020, vol. 1: Programme, concepts and definitions, para. 6.2": http://www.fao.org/3/i4913e/i4913e.pdf.

10 "In a statistical collection, the frame is the means by which the statistical units to be enumerated in the collection are identified – in this case, the agricultural holdings". Cf. "Handbook on remote sensing for agricultural statistics". http://www.fao.org/3/ca6394en/ca6394en.pdf.

(a) For household agriculture holdings:

"Region/State", "Locality", "AU", "PU"(Admin.) EA(U/R/N/A) Blocks Buildings Floor Entrance Holding Code.

(b) For commercial agriculture holdings:

"Region/State", "Locality", "Admin. Unit", "Popular Unit" (A/C) EA(U/R/N/A…) Commercial Holding code

The same remark of adjustment applies to this agricultural census coding scheme, as CBS may need to add more units for the agriculture census.

3. GIS/data collection software

With regards to the types of GIS software used at the global level, free/open source software such as QGIS (formerly known as Quantum GIS), PostgreSQL and GRASS is increasingly generating interest, with some applications for surveys, but has still not reached mainstream use in the census GIS process.

For the CAPI method used in combination with GIS mapping, there is Survey Solutions, a free program for data collection and survey management developed by the World Bank. Survey Solutions has powerful CAPI capabilities, guiding interviewers to the point of interviewing offline using high resolution satellite images and built-in GPS receivers, but still with limited mapping and GIS functionalities.

The most widely used commercial GIS software is ArcGIS, developed by Esri; with its additional apps for CAPI-based field data collection, such as Survey123 and Collector, it constitutes an integrated suite for census field operations. The Esri package is completely configured and does not require any further major development. Compared to free/open source software, Esri products have better technical support, more reliable documentation and a more vibrant community. Other commercial GIS and associated software such as MapInfo or AutoCAD can be used in conjunction with Esri products.

While the Census and Survey Processing System (CSPro)[11] is a powerful public domain software package used in many countries for entering, editing, tabulating and disseminating data from censuses and surveys, "it is not intended to provide database management capabilities; however, the data generated and/or manipulated by a CSPro application may be imported into a database system. Even though

11 CSPro was developed jointly by the U.S. Census Bureau, Macro International and Serpro, SA, with major funding from the U.S. Agency for International Development.

CSPro includes a module for generating thematic maps, it cannot be considered a geographical information system [GIS], as the maps cannot show the multiple layers available in a true geographical information system".[12] This means that when we opt to use CSPro, we need to develop a lot of programming (which is tedious and costly) to integrate CSPro-based CAPI with true GIS/mapping software or GIS/mapping applications.

B. Enumeration area design/maps

The primary aim of a census mapping exercise is to facilitate the preparation and production of census blocks/enumeration area maps used for the location and enumeration of households at a national level during the data collection phase of the population and housing census. With the use of contemporary technologies, the approach develops a census GIS infrastructure for map production and incorporates and uses available data (e.g. base maps, road and water bodies datasets) so that enumeration area boundaries are clearly delineated and correspond to physical ground features to ensure that there are no omissions or duplications of territory coverage.

Based on the inventory, CBS has a geodatabase composed of multiple geographic data layers, except at the enumeration area level of 2008, which means CBS needs to build its database at the updated enumeration area/building level, where the enumeration areas covers the whole country, with its urban and rural settlements alike. CBS has identified around 50,000 enumeration areas throughout the country. Delineating and identifying the total number of enumeration areas that cover the whole country is a prerequisite for all census activities, to inform the number of enumerators/supervisors to be hired for fieldwork and the handheld devices and other equipment needed. Since CBS has decided on enumeration areas of approximately 200 households each, the enumeration area delineation process would consist of three main steps as follows:[13]

Box 1. 3-step method of the enumeration area delineation process

(a) The first step is an initial in-office demarcation or re-demarcation phase using satellite imagery as a backdrop. It consists of demarcating new and existing enumeration areas through on-screen digitizing, editing and GIS functionality, superimposing the vector data such as administrative boundaries, roads, water bodies, place names, cadastral/parcel boundaries and other point-based features (dwellings/buildings, schools, health facilities, landmarks, etc.) on top of recent imagery[a] with resolution of less than 5 m, preferably less than 2 m, obtained within a year of the census (details on imagery in subsection 3.3). A dataset of demarcated enumeration areas is created and maps produced and printed for field verification.

(b) The second step is the field verification process where field visits are conducted across the country to correct and update the data and maps created in the office. The enumeration area boundary, size and shape are verified: enumeration area boundaries should change as little as possible so data can be compared between consecutive censuses at the lowest level of geography possible. However, in the event that enumeration areas are too large for a single enumerator, they can be split, and splits should follow reference features such as roads

12 https://www.who.int/healthinfo/tools_data_analysis/WHO-DQR-Data-Verification-v1-0-Collection-Tools-CSPro-Manual.pdf.

13 This methodology is reported in the Book ("GIS and the 2020 Census – Modernizing Official Statistics", 2019, Esri Press), expanded and used in other similar reports prepared by the Consultant.

or water bodies where possible to minimize future changes. If enumeration areas are too small due to population decrease, they can be merged, though an alternative would be to simply have an enumerator work on two small enumeration areas and keep the boundaries consistent. Any new features on the ground are captured, and any suggested changes to enumeration areas should be highlighted/annotated on the map. Point-based data such as house units/dwellings/buildings and other points of interest are verified and captured by GNSS/GPS handheld devices, and any changes annotated.

(c) The third step consists of a return to the office to capture the field-verified data, and thus create the final enumeration area/supervisory area maps to be used for the actual enumeration. The changes made to the enumeration areas can only be confirmed once all the updated data have been loaded, and together with the annotated fieldwork maps an informed decision is made in the GIS office (the updated information must be included in the GIS database). The production of enumeration area maps can then commence, in this case in the form of digital maps that can be uploaded onto the tablets.

Note: The spatial resolution of a satellite image is measured by the size of a pixel on the ground which varies from the sub-1 m of the most popular high-resolution systems to 100 m for low resolution systems. For most census applications, 5 m or better spatial resolution is needed to identify housing units, roads, etc.

C. Satellite imagery: A necessity in the Sudan

The advent of satellite imagery with high (1 m or better) spatial resolution has revolutionized mapping. Satellite imagery can save countless person-hours by allowing the NSO to focus attention on critical areas. Using satellite imagery, analysts and census planners can identify areas that require additional fieldwork, for instance to account for new growth in areas surrounding cities. For planning and logistical purposes, it makes sense to identify these priority areas ahead of time to locate areas of rapid change since the last census and focus on them; this is what is meant by the "change-detection" approach.

A satellite image has the advantage to cover large areas, particularly remote areas that are otherwise inaccessible. High-resolution satellite images show a level of geographic detail that is almost comparable to digital Ortho-photo maps created from aerial imagery, sufficient for EA delineation, provided population estimates exist for the areas delineated. Satellite imagery has an advantage over other means of data collection, since there are usually no restrictions on its acquisition. However, to be fully suitable for census mapping operations, particularly the need to identify individual housing units to help delineate enumeration areas, the satellite imagery should meet some criteria. There are some generally agreed criteria for selecting the appropriate satellite imagery for census activities, though these criteria can vary depending on the country situation: (a) they should be recent, preferably less than one year; (b) their resolution should preferably be less than 1 m and 2.5 m for urban and rural respectively; (c) for the maximum allowable interference, images that contain less than 20 per cent cloud coverage should be used; and (d) their cost should be reasonable, relative to the total cost of the census. This multi-criteria selection could speed up the decision-making process of procuring and using satellite imagery.[14]

14 Excerpts, with some additions, from the book "GIS and the 2020 Census – Modernizing Official Statistics", 2019, Esri Press. https://www.amazon.com/GIS-2020-Census-Modernizing-Statistics/dp/1589485041.

GPS is a satellite-based navigation system, operated by the United States Department of Defense. There are other GNSSs such as the Russian GLONASS, the European Galileo or the Chinese BeiDou. The satellites give out signals that can be picked up by GNSS/GPS receivers for positioning and navigation. GNSS/GPS devices are useful for capturing the coordinates or location of point-based features like physical addresses, housing units and dwellings, buildings, landmarks and other points of interest. They are particularly used for navigational and tracking purposes to ensure that the right enumeration area on the ground is visited and that the field team is actually in the appropriate assigned areas.

The main reason NSOs use GNSS/GPS and remotely sensed data at the pre-enumeration stage is to field-validate the enumeration area boundaries that were created in the NSO's GIS lab from the prior census. Or, when accurate maps are not available, it is done as a basis for delineating enumeration areas in the census main office using recent satellite or aerial imagery, before fieldwork for completion and validation. With the provisional enumeration area boundaries superimposed atop an imagery, the areas most in need of updating can be distinguished from areas requiring minimal updating, and with population settlements quickly located, priority areas are thus identified. Simply put, the basic use of GPS and satellite imagery is to verify boundaries and identify new buildings and housing locations.

Satellite/aerial imagery is needed for both censuses, as it makes up for the lack of base maps, and the imagery should be recent and with relatively high resolution for the population and housing census, while the imagery required for the agricultural census may be of a little bit lower spatial resolution. Imagery is the most realistic and cost-effective option to capture multiple geographic features in a large country such as the Sudan. However, CBS may opt for two types of satellite imagery acquisition: one high resolution imagery (<4 m) for small and urban areas, and one with a spatial resolution of a 4-10 m range for large and rural areas that would serve for both censuses.[15] While the two categories are not available for free from open source providers, entailing some costs if acquired from commercial providers, a spatial resolution imagery may be less expensive and might be acquired through donors (United Nations agencies like UN-HABITAT, UNITAR or ESA, etc.). For example, if 10 m satellite images are needed for a certain purpose, they can be provided for free from ESA Sentinel-2. This means we have to develop and strengthen the **Imagery Processing Unit** and allocate significant human and financial resources and equipment when using satellite imagery. Also, increasing the use of Earth observation data in many censuses and statistical activities will pave the way for progress.

D. GIS and enumeration area-based geographic database

At the core of a census GIS is the geographic database that is used primarily to create map products. However, a cost-effective geographic database also aims to cater to the present and

15 "The ESA [European Space Agency] denomination relies upon the practical < 4 m, 4-10 m, 10-30 m, 30-300 m and > 300 m resolution ranges to group families of sensors. In addition to the difference in resolution, the 10-30 m range also demarcates the division between sensor data that are (predominantly) available under free and open licenses and those categories (<10m) that fall within the commercial realm". Cf. "Handbook on remote sensing for agricultural statistics". http://www.fao.org/3/ca6394en/ca6394en.pdf.

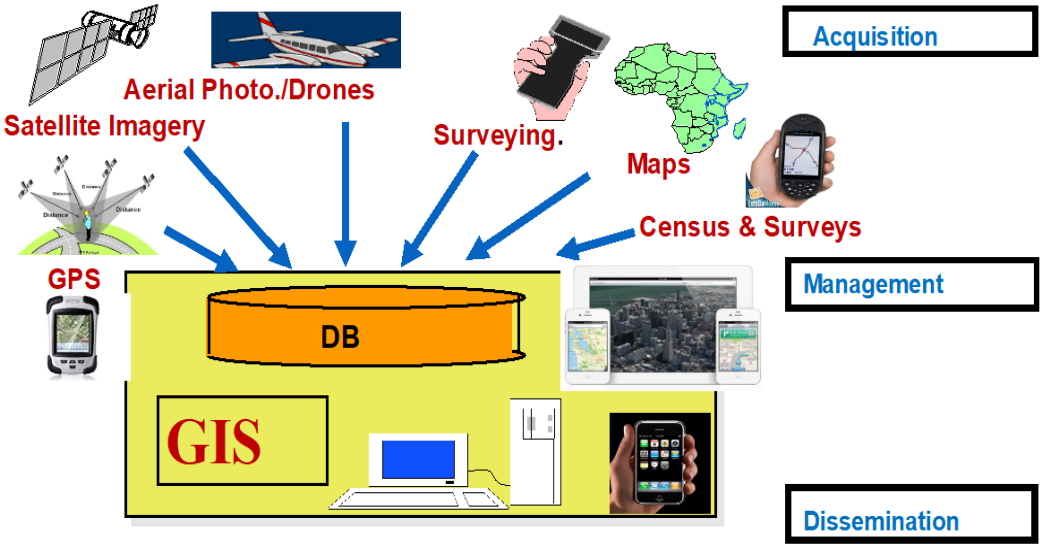
future needs of the census and national stakeholders with an interest in geospatial information. In some countries, agencies that collect different types of geographic data that complement the census GIS participate in its development in order to further build upon this database after the census, including for spatial analysis and evidence-based decision-making.

The integrative role of GIS is central. As illustrated in the graphic below, satellite imagery and GNSS/GPS receivers, among other traditional tools like censuses and surveys, maps, etc., are used for geographic data acquisition. Once data are collected, they are processed and analysed using GIS, in order to provide sound information to users and the general public at large.

The census database contains the various statistical attributes, in addition to the geographic features defined in the GIS, and can be designed on an evolving basis. Any other spatial information collected in subsequent phases can also be added to the database. In a population and housing census for example, besides the geographic location of the building, dwelling and/or household unit, demographic statistics captured before, during and after the census are also stored in the database for the benefit of the end user. CBS needs a GIS capability **to build an enumeration area database at the smallest statistical units** (enumeration area and building levels); this requires a comprehensive database to address issues related to the database modelling/design, data conversion and integration and all other phases of geospatial data production, including field verification and the capture of updates and corrections, and populating the geographic database with the updated enumeration areas.

The trend is to build a national dwelling frame (a geo-referenced census) that relies on a point-based data collection approach, dealing with the highest spatial resolution of any possible statistical data collection. This is done through the direct capture by GPS/GNSS of the coordinates (latitude and longitude) of point-based features such as house units/dwellings, buildings, parcels or other features of interest. This means that the locations of dwellings or buildings are specified using unique identifiers (geocode) and geographic coordinates, giving the exact location of each statistical unit. The adoption of unique identifiers at the point level (e.g. building centroids and addresses) and map coordinates for buildings and addresses can also pave the way for a more flexible determination of small spatial units for municipalities or at the level of villages for local development purposes. While collecting data at the individual level is highly recommended, confidentiality and privacy issues must be taken into account and security measures should be implemented.

Figure 2. Geospatial information technologies that can be used in census activities



Source: Adapted from UNSD.

Map creation consists of drafting census enumeration maps as well as all other maps associated with the management of the actual census. Census enumeration map standards must be put in place to stipulate what features must be included and how maps should be designed for efficiency and ease of use by enumerators, bearing in mind that the enumeration area maps created will be uploaded on handheld devices and used electronically.

Developing a timetable for the GIS and mapping activities is crucial, as they are time-sensitive activities, with the critical date being the date on which all enumeration-related maps and map services must be made available to the census field enumeration. This task is even harder if CAPI is used with an electronic questionnaire, integrated with a digital enumeration area map on handheld devices (subsection F).

E. Data quality/metadata

The digitally created enumeration area map is generally the result of the integration of data from existing (base) maps and from imagery, complemented by data captured from the field, and structured and organized in the geospatial database. While the enumeration area data are generally accurate, they must mesh with other

data (e.g. topographic, built environment, transportation data) and then be integrated into the database. Since geospatial data are captured from various sources, the map metadata should be well documented to be part of the data dictionary. This includes the geographic referencing information and other cartographic/imagery parameters such as the scale/resolution, projection and geographic datum, map compilation date or satellite imagery capture, compiling agency, legend, etc. that should be appropriate for use by the GIS. In this regard, it is advisable to adopt geo-standards in line with the international standards developed by the International Organization for Standardization Technical Committee 211 Geographic information/Geomatics (ISO/TC 211), the Open Geospatial Consortium (OGC), the International Hydrographic Organization (IHO) and FAO.

As already mentioned, the development of a GIS database at the enumeration area level (or point-based level) requires the use of technology and data conversion and integration from multiple sources, and the database can be used for purposes at the national level other than the census itself, thus making data quality crucial. Hence, the reliability and accuracy of the data must be verified prior to inclusion into the geospatial data infrastructure of the NSO to support the census.

Geospatial data accuracy, as generally recognized, refers to both positional accuracy and logical accuracy. The United Nations has encouraged and recommended that each country have a quality assurance and improvement system developed as part of the overall census programme and integrated with other census plans, schedules and procedures.[16] A quality assurance programme that puts the census staff in a good position to identify problems and suggest improvements should include geospatial data issues. CBS may also use administrative data to conduct the census and perform quality checks. The quality control and assurance checks are a continuous process across all stages of the census.

F. Use of CAPI/handheld devices

In a 2012 survey conducted by the United Nations Statistics Division (UNSD) on national experiences with population and housing censuses in the 2010 round, **56 per cent** of countries reported that the implementation of new technologies was the most successful aspect of that round.[17] Innovative technologies included the use of mobile technology (handheld devices) and Internet for data collection; scanning technology; integrated systems for field management; geospatial technologies for mapping; and other web-based and mobile telephony applications for dissemination.

More specifically, the CAPI method has been recommended as a viable alternative to traditional paper-based methods for census data collection.[18] CAPI for census data

16 "Principles and Recommendations for Population and Housing Censuses, Revision 3", Paras. 2.169-2.170. (ST/ESA/STAT/SER.M/67/Rev.3) – 2017. https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf.

17 "Overview of national experiences for population and housing censuses of the 2010 round" (June 2013), prepared by the Statistics Division, available from https://unstats.un.org/unsd/censuskb20/KnowledgebaseArticle10706.aspx.

18 "CAPI is the face-to-face interviewing mode in which a computer displays the questions onscreen, the interviewer reads then to the respondent, and enters the respondent's answers into the computer".

collection is basically carried out through a small handheld electronic device with an on-screen keyboard. It allows for census data to be captured and stored electronically, replacing the traditional census form with a series of questions, with the enumerator entering answers by either selecting from a predefined list or entering a variable on the spot. Handheld devices such as handheld computers, smart phones and particularly tablets are emerging as powerful tools, increasing the quality of the data collected, improving the timeliness of census releases and reducing the costs of field operations.[19] Some recent good practices in the use of mobile technology in developing countries are commended and ought to be emulated by other countries planning for their censuses or surveys.[20] Particularly, lessons can be learned from the recent Egyptian, Jordan and Palestinian censuses, as they addressed and coped with many issues similar to those that will be encountered in the Sudan.

Most mobile devices can be equipped with GNSS/GPS, Wi-Fi and Bluetooth to allow connections to the Internet and other Bluetooth-capable devices; many can also access the Internet over-the-air using a mobile service provider. Handheld devices have a number of other technical options that can aid the enumerator and census process, including the cameras and the ability to make telephone calls and transmit data. The CAPI data collection integrated with GIS has manifold benefits but also presents some challenges, chiefly: (a) the need to test the integration of the electronic questionnaire, enumeration areas maps, GPS,[21] transmission of data functionalities, battery, etc., before making use of the devices in census data collection; (b) the need to provide a thorough training prior to the deployment of mobile devices on not only the forms and data collection, but also the basics of the device, what to do during trouble shooting and how to manage its battery life, and other issues related to the fieldwork; (c) the need for plans to redeploy and/or reuse the equipment after the census, in order to not waste the large number of devices with long useful lives extending well beyond the relatively short census exercise. More details on the operational side of CAPI will be provided in Section 3.

In summary, in using electronic devices instead of paper maps in the upcoming Sudanese census, CBS has to ensure that the process of data collection goes as planned and has to fulfil the responsibilities and the requirements for census activities. CAPI is meant to reduce the time and costs involved in traditional data entry, editing and processing. CBS particularly needs to immediately update geospatial data from fieldwork, in order to support enumerators in the field in geocoding buildings and other features of interest.

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19 United Nations. (2012) Report of the United States of America on the 2010 World Program on Population and Housing Censuses. E/CN.3/2012/2. https://unstats.un.org/unsd/statcom/.

20 For example, a 2017 study showed that 57 per cent of countries in Africa were in the various stages of using CAPI in census taking during the 2020 round. "2020 Census Preparedness", African Centre for Statistics, UNECA. https://archive.uneca.org/publications/african-centre-for-statistics.

21 For example, if the handheld device has integrated GPS and this is going to be used to capture the latitude and longitude of each housing unit, accuracy tests may need to be performed. We will use in the following text the word GPS, just as to indicate a satellite receiver.

G. Preparation of geospatial data for the pilot census

The pilot census serves to test in real conditions the adequacy of the entire census plan, including the cartography, the methodology, the technology applied such as the CAPI system and mobile devices, the census organization in general and the interaction between all planned resources to be used in the actual census. The pilot census is recommended to be conducted a year before the main census, to better simulate expected weather and organizational conditions.[22]

One of the major tasks to do during the upcoming pilot census is to test the integrated use of GIS with CAPI. With regards to the preparation of geospatial data for the pilot, the pilot/sample areas need to be selected to represent the diversity of socioeconomic and geographical conditions in the country, while ensuring some balance between urban and rural areas, to observe the management and supervision of the field operation in real situations. CBS may consider around 500 enumeration area maps (1 per cent of all enumeration areas) to be prepared and made available for navigation, and uploaded on the handheld devices (tablets) for offline/semi-online field work (this is to be decided by CBS, particularly after testing through the pilot census, as Internet connectivity may be an issue for any real-time data collection).[23] The GIS team has to prepare and provide each enumeration area map at the enumeration area/building level with its related coding system and with the format required by the CAPI app.

The evaluation instruments for the pilot census need to be developed to include performance indicators related to planning, field operations management, the quality and efficiency of the questionnaires, the performance of the tablets as working tools, their endurance in the field, the transmission of data, etc. The pilot census will then generate insights and lessons learned to inform CBS in determining any modifications for the actual census, including the appropriate CAPI to be selected and its integration with GIS.

H. Technical solution

To cater to the needs of the census mapping programme, we propose a mobile GIS solution to be implemented by the GIS/IT team. This solution allows for the integration of the different GIS data layers for the enumeration/counting areas, the choice from existing CAPI applications (CSPro, Survey Solutions or Survey123) and the transmission of the data collected to the central system. Box 2 provides a general view of the workflow through five major components, covering data preparation and data collection but not extending to data analysis and dissemination. Figure 3 likewise presents this information in a visual format.

22 "Principles and Recommendations for Population and Housing Censuses, Revision 3". 2017. https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf.

23 Based on the ITU database (as ITU is the custodian of this indicator: INDICATOR 9.C.1: PROPORTION OF POPULATION COVERED BY A MOBILE NETWORK), at Least 3G Mobile Network 46.6 per cent (2018) – Source: Telecommunication and Post Regulatory Authority.

Box 2. Detailed data preparation and collection workflow

1. Pre-enumeration geospatial data collection, organization and structuring in a geospatial database at the enumeration area/building levels

   As stated in sections 2 and 3, at the pre-enumeration stage, CBS needs to conduct an inventory of the existing data and collect the additional needed data from multiple sources. Once data are collected, they should be integrated and organized to create the enumeration area-based database.

2. Production of the enumeration area maps

   GIS will be used to delineate the administrative and enumeration area units with the greatest degree of completeness and accuracy and produce the highest possible quality enumeration area maps. All enumeration area maps should be simple and clear and easy for enumerators and field supervisors to use. Enumeration area maps typically contain: (a) geographic features on base maps, such as streets and roads, buildings, major water bodies, topographic and other hydrologic features and any map annotations; (b) enumeration area boundaries; and (c) points of interest for orientation with symbols (e.g. mosques, schools, hospitals, landmarks).

3. Integration of CAPI with GIS-based enumeration area maps

   Since CBS has already planned to use tablets for the field map updating, a computer-based application has to be developed or selected and then loaded onto handheld devices, offering tools to edit the geometrical and other descriptive data of the enumeration areas, buildings and dwellings, in addition to providing GIS functionalities for the capture and editing of the various GIS layers, notably buildings, streets and other features of reference.

   Enumeration area maps and electronic questionnaires then need to be uploaded onto the tablets, subject to any adjustments based on the results of the pilot census.

4. Field operations management

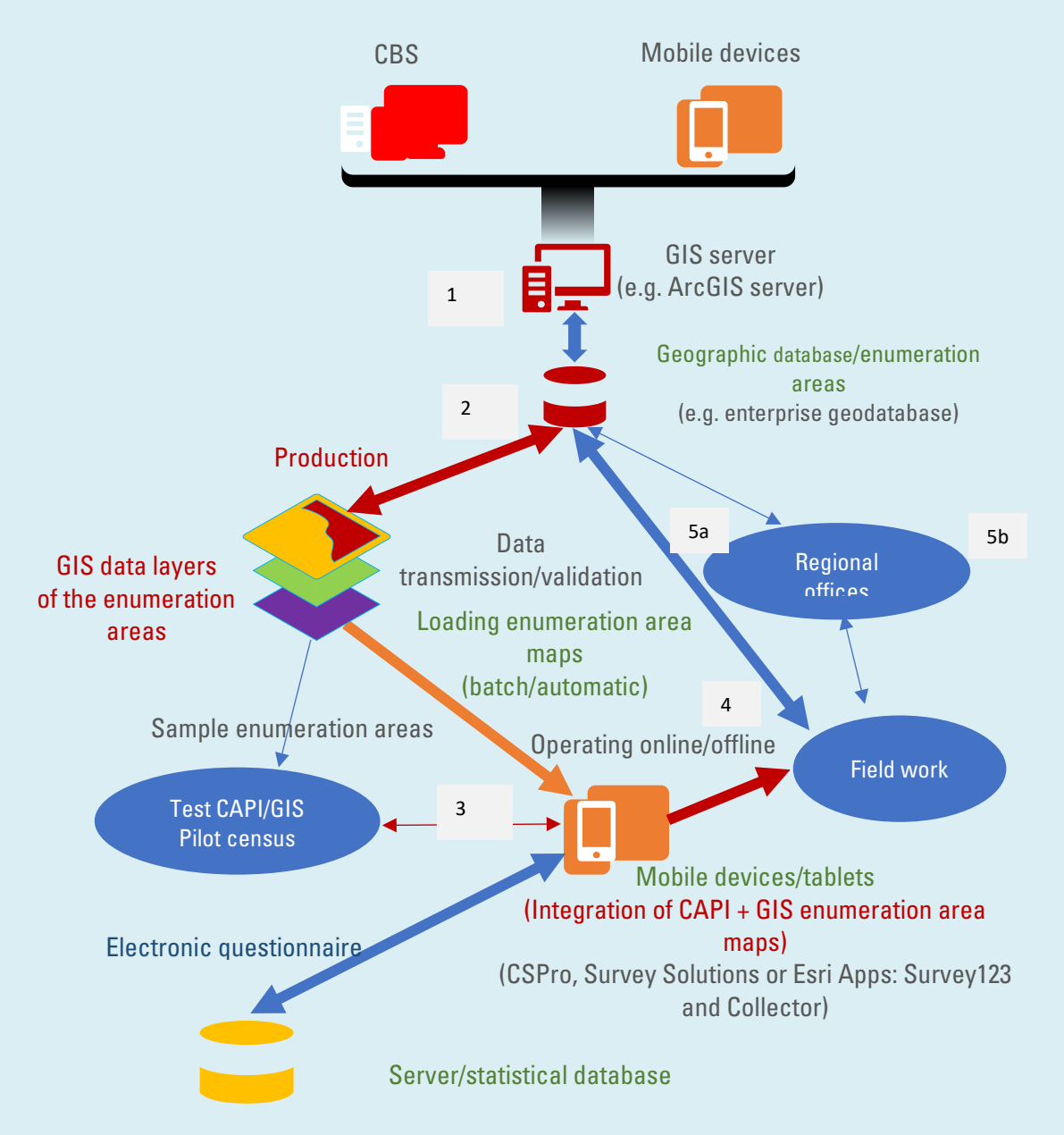
   Once CAPI and the GIS-based maps are integrated and ready to operate, fieldwork commences.

5. Data transmission and validation

   This step consists of the transmission of data to the central system. There are two options for the flow of data: either directly from the field to the central system (5-a), or through regional offices as intermediary data centres before transmission to the central system (5-b).

Steps 4 and 5 are described in greater detail in the following section 4.

Figure 3. Diagram of the Technical Solution



Source: Prepared by consultant

3. Supporting and implementing data collection and helping to monitor census activities for the enumeration phase

As CBS has opted for the CAPI method in enumeration, the process will rely on map services and mobile map packages more than printed maps. Such mobile map packages will allow enumerators to download maps when they have a connection and then view the maps in the field to find the correct housing units within their assigned enumeration areas. With a simple tap on a feature (dwelling or housing unit), they can add information and accurately capture statistical data on the household by filling out the electronic questionnaire related to that household. Then, enumerators can transmit the data to feed directly into the GIS or save it until the end of the day or until they are back to a connection to send to the central office. Using the enumeration area maps and the electronic questionnaires filled out by enumerators, along with GPS points collected on devices, CBS staff can check the data and verify that the enumeration areas were fully covered.

Mobile technology has the advantage of being able to feed data collected from each device to the central database in real time (or near real time). Census managers can locate and track the location of enumerators, monitor their progress, identify gaps and determine which households the enumerators may need to revisit or where enumeration is not meeting quality standards. These capabilities allow CBS to streamline and automate field operations through dashboards and thus improve its management and the quality of the census itself. GIS-based analysis of the enumeration areas also helps optimize workloads and provides tools for solving complex routing problems to best direct fieldworkers.

Since CBS is considering capturing point-based features such as the buildings, the computer application for updating the maps will be used not only for the 2021 census, but also in future activities, for instance to support the preparation of sample-based surveys, and for the creation or updating of the register of buildings and dwellings. Ideally, fieldworkers should be able to select different GIS layers to edit (layer of buildings, streets, landmarks), with different spatial features within each layer.

4. Contributing to statistical analyses and dissemination for the post-enumeration phase

A census is a major undertaking, but it will not bear fruit and impact policy decisions unless census data is made available in a suitable format to various users. To maximize the use of census results, a dissemination strategy should be prepared, with the objective of reaching a wider audience, including the media and the public.

With the rise of information technology capabilities, digital products are replacing traditional publications, meaning the dissemination strategy should consider diversifying the types of outputs to cater to the needs of a wide range of users, including government agencies and major users, as well as citizens, civil society, researchers, academia, developers and more.

The strategy should also include key elements such as determining the level of geography at which census data will be disseminated, identifying the census and geography products and services to be delivered and providing a timeline of the main dissemination activities with their estimated costs and the human and technological resources that will be needed to carry them out. Census products should be of sufficient quality to meet user needs, and safeguards should be put in place to ensure individual information is kept private and confidential.

Since CBS will use GIS from the pre-enumeration stage, it will benefit from greater ease in putting census data on maps to better convey information and enable users to visualize statistical information. Moreover, GIS enables the presentation of census results in different forms – charts, graphs, dashboards, thematic maps, map applications and smart and story maps. In addition, GIS enables maps to be easily exchanged in digital format on the Internet and allows for web-based applications.

With a geospatial census database built out at the enumeration area and building levels, GIS provides powerful tools for spatial analysis, allowing users to create various census and geographic products to be disseminated in a compelling manner. In addition, with the use of mobile technology and the WebGIS applications, the census data dissemination will put CBS census data at the fingertips of major users and even the public in general. Thematic maps are generally produced not only for major census data users and census reports but also for a wider, non-specialist audience. Moreover, for the Sudan, thematic maps in an electronic (interactive) atlas can present census data and many indicators at the level of the whole country, administrative units and any human settlements.

5. Guidelines and capacity development

A. Guidelines on the use of GIS and other geospatial technology at all stages of the census

The benefits of GIS in the census process are manifold as its use spans all the stages of the census. In the pre-enumeration stage, GIS is used to delineate enumeration areas and build the census geographic database.
The GIS-based enumeration area maps are prepared to be integrated with the (electronic) questionnaire on a handheld device and used for the pilot census, and eventually for field enumeration. In the enumeration stage, GIS is used to support field work in managing field operations, including optimizing workloads and routes. At the post-enumeration stage, GIS allows for spatial analysis and assists in the creation of products for dissemination with advanced tools of visualization, dashboards and other smart/story maps (Annex 3).

Table 1 summarizes all of the steps that should be followed in using GIS, some of which can be performed simultaneously. These exact steps are not necessarily required, and CBS can make adjustments depending on national conditions in terms of infrastructure, capacities and institutional arrangements.

Table 1. Guidelines on the use of geospatial and mapping activities at all stages of the census

Phase	Activity	Procedures
1. Supporting and implementing geospatial activities for the pre-enumeration phase	Delineation of enumeration areas	The enumeration area delineation process, using GIS and other geospatial information technologies, is carried out in three main steps as described in chapter 2, section B.
	Building the GIS/enumeration area-based census geographic database	This is the process of building a geographic database, the foundation of any GIS. In the case of the Sudan, this is a census GIS database at the enumeration area level and point-based (building and household) levels. In creating the census GIS database, we start by identifying the database components (i.e. the data layers to be created) and stress the different stages in its development (some of them in parallel), including geographic data inventory for enumeration area delineation; geographic data conversion through scanning, digitizing or use of earth observation data; construction and maintenance of topology; geo-referencing and geocoding of geographic features, integration of various digital data; developing conceptual database design and data models; identifying accuracy requirements and standards; implementation of the enumeration

Phase	Activity	Procedures
		area database; developing the data dictionary and metadata guidelines (including data dictionary) for quality control/quality assurance. The census GIS database can be designed on an evolving basis. The foundational features are established first, with any other spatial information collected in subsequent phases then added to the database. For example, besides the geographic location of buildings, dwellings and/or household units, demographic statistics captured before, during and after the census are also stored in the database for the benefit of end users. The changes made to the enumeration areas in the third step of the delineation of enumeration areas above can only be confirmed once all data have been uploaded together with the annotated fieldwork maps and an informed decision has been made by the GIS office. The updated information is included in the GIS database and the map production can then commence.
	Integration of GIS with CAPI	Integrating GIS with CAPI is a very complex technical operation, which is not a core function of CBS and is advisable to be carried out through partnership. The combination of CAPI with a handheld GNSS/GPS-equipped device and GIS-based enumeration area maps requires the following: • Developing or selecting a CAPI app. • Preparing mobile GIS-based enumeration area maps. • Uploading the enumeration area maps on handheld devices (mobile map packages to be used online, offline or semi-online). • Administering tests of the integration of the electronic questionnaire, enumeration area maps, GPS, data transmission, battery, etc., before actual use of handheld devices in the census. • Proceeding with a thorough training prior to the deployment of mobile devices not only on the use of forms and data collection, but also on the basics of the device, troubleshooting and how to manage the battery life.
	Pilot GIS mapping exercise	The pilot census serves to test the adequacy of the entire census plan in real conditions, including the cartography and technology such as the CAPI system and mobile devices. The pilot GIS mapping exercise includes the following steps: • Selecting pilot areas for preparation of geospatial data to represent the diversity of the socioeconomic and geographical conditions of the population in the country and for observation

Phase	Activity	Procedures
		of the management and supervision of the field operation in real situations. • Preparing and providing each pilot enumeration area map at the enumeration area/building level with its related coding system in the format required by the CAPI app. • Testing the integration of GIS with CAPI. The results of the pilot GIS mapping exercise need to be carefully analysed by CBS to determine the potential modifications for the successful conduct of the actual census, including the appropriate CAPI app to be selected and its integration with GIS.
	Other planning activities with GIS	Additional activities using GIS to optimize the enumeration areas in terms of spatial analysis, placement of field offices and asset distribution.
2.Supporting and implementing data collection and helping to monitor census activities for the enumeration phase	Mobile GIS for field data collection	This task consists of the use of handheld devices for field data collection, where in support of the CAPI enumeration process GIS-based enumeration area maps are uploaded onto devices and combined with satellite or aerial images as backdrops. This helps enumerators orient themselves and find the correct housing units within their areas. Using the enumeration area maps and the electronic questionnaires filled out by enumerators, along with GPS points collected on the device, CBS can check the data and verify that enumeration areas were fully covered. Ideally, once the data are transmitted to the CBS central data centre, the data including geocodes will be entered into the GIS census database, providing information about the census progress. Tools may include the open-source Survey Solutions, developed under the auspices of the World Bank, or commercial tools such as Esri's Survey123 for ArcGIS and Collector.
	Monitoring census activities	This task consists of the use of GIS on mobile devices to support field management in streamlining and automating operations, such as monitoring the flow of timely information to and from the field allowing census managers to be informed of the progress of data collection while providing enumerators with updates; tracking the location of enumerators and identifying gaps; optimizing the workload assignment and routes (guiding enumerators on where to go and the best route to take); and particularly in monitoring the progress of census activities, including identifying trouble spots.
	Updating enumeration area maps/Updating	This task consists of the use of GIS/GPS and imagery during field work for a final update of enumeration areas, as there may still be some updates and corrections needed to the master database. Traditionally, the census cartographic staff would collect the enumeration area maps after the census and incorporate the edits

Phase	Activity	Procedures
	Geographic Database	into the master database; however, this task can be tedious and, in some instances, can slow the release of census results. However, with digital methods to capture field edits, this operation can be automated. Updates captured in this manner can be simply verified and then incorporated into the database in a much more streamlined fashion. The updated GIS census database is then used for post-enumeration and inter-census activities.
3.Contributing to statistical analyses and dissemination for the post-enumeration phase	Interactive Maps/Atlases/Geo-Portals	To maximize the use of census results, a dissemination strategy should be prepared, with the objective of reaching a wider audience, including the media and the public, as the United Nations has recommended. CBS needs to take advantage of new information technology capabilities to enhance the dissemination and sharing of census data/information to reach a wider audience, including government agencies and major users, as well as citizens, civil society, researchers, academia, developers and more. GIS has been initially used by NSOs for the dissemination of their geographic products, mainly through maps. However, in addition to the GIS mapping capacities, CBS can use it for the following: • Thematic maps and interactive atlases: Thematic maps are generally produced not only for major census data users, but also for a wider, non-specialist audience. Thematic maps in an (electronic) interactive atlas can present census data and many indicators at the level of the country, regions, large cities, municipalities and human settlements. (Geo)-Portals are a cost-effective mechanism for marketing and continued delivery of useful census and geography products and services to a diverse user base that can go far beyond the first years after the census. • Web mapping/WebGIS/story maps/smart maps: Web mapping is more than traditional mapping, as it is more a service by which users can choose and customize what a map will show. The automated creation of maps accommodates users who are not necessarily familiar with GIS, often to create interactive web maps that communicate meaningful and compelling stories. Overall, instead of web GIS systems that try to cover everything, a better approach would be to build a “story map” that answers one particular data-related question. • Spatial analysis: With a geospatial census database built out at the enumeration area level, GIS provides powerful tools for spatial analysis, allowing users to create various census and geographic products to be disseminated in accordance with cartographic and metadata standards.

Phase	Activity	Procedures
		• Supporting surveys and sampling frame: Geospatial information is also instrumental for other statistical activities, such as the creation of a geo-referenced national dwelling frame to identify and provide the geographic coordinates of all structures on the ground (the national register of buildings and dwellings), the development of business frames for use in an economic census, the improvement of the coverage in parcel units and the building of the National Spatial Data Infrastructure (NSDI). Geospatial information supports the maintenance of these frames which are required as the basis for the statistical sampling frame for intercensal surveys and future censuses.

B. Manuals and training/capacity-building

The guidelines on how to use geospatial information technologies at every stage of the census require identification of the needed resources and capacities for implementation and monitoring. More specifically, since census mapping is specific and different from regular cartographic activities which are not generally a core function of most national statistical organizations, mapping staff have to undergo training. A very important component for enumerators is to learn how to use the survey application and forms on mobile devices as well as the entire process of data collection, including the basics of the device and troubleshooting. For the use of GPS to obtain point feature locations, mapping staff need to be trained on the procedure for collection and storage of these locations. Likewise, since a list of buildings/dwellings is to be compiled alongside the mapping, field staff need to be trained on identification and location of buildings/dwellings.

The field and census mapping work requires manual support. Indeed, guidelines and reference manuals are to be put in place, including requirements for accuracy and census enumeration map standards, the data dictionary and metadata, the procedures for uploading enumeration area maps and the use of handheld devices with built-in GPS receivers and the final outputs. If the decision is made to use commercial products, a help line and vendor support should be provided.

Building the technical and human capacities needed for a GIS-based census requires training of census cartography staff on GIS and all mapping needs. It also requires training of trainers on census mapping and geospatial information technology, who in turn will conduct trainings when needed.

Well-trained staff are a key factor for the success of GIS-based census mapping projects, but in order to **retain** them, CBS needs to provide significant **incentives** and ensure continuous training to keep them abreast of advances in technology. For this upcoming census, beside the specific trainings (table 1), one or more study visits should be organized to a country with good practices in the use of GIS and handheld devices for data collection, including at the point-based level. The destination country should be broadly similar to the Sudan, with a good experience in its last census in recent years.

6. Road map of geospatial information activities to be carried out at all stages of the census

A full digital GIS-based census requires a detailed road map outlining the activities to be carried at all the stages of the census. In table 2, the planned census mapping activities are presented in detail by main phases: activities for the pre-enumeration, enumeration and post-enumeration phases. These activities are crucial in order to succeed in a full digital and GIS-based census mapping exercise, the most important of which are: (a) being aware that building a long-term digital census mapping programme is a strategic decision that requires commitment from high-level decision makers in the country; (b) building technical and human capacities required for sustaining the census mapping programme and establishing well-equipped teams for cartography/GIS activities within CBS to maintain the GIS database and mapping infrastructure and keep abreast with advances in technology; (c) developing a partnership for cooperation with other organizations involved in geospatial information activities to build a national statistical-geospatial information infrastructure in support of decision-making and sustainable development. These recommendations are mainly derived from lessons learned from country experiences during the last 2010 round of censuses.[24]

Table 2. List of census mapping and geospatial activities for pre-enumeration, enumeration and post-enumeration

Activity code	Activity description
1	Geospatial activities to ensure coverage and facilitate the pre-enumeration phase.
1.1	Inventory of existing maps and geospatial data in all its forms.
1.2	Define census geography and update boundaries and coding, including the hierarchical structure of administrative, statistical and geographic units.
1.3	Delineate/update enumeration area boundaries and coding of spatial units/geocoding.
1.4	Build/update the census enumeration area-based geographic database.
1.5	Strengthen/build IT infrastructure for geospatial activities (update software and/or make new acquisitions; and upgrade hardware and/or make new acquisitions).

24 "United Nations Population Fund (UNFPA) Strategy for the 2020 Round of Population and Housing Censuses (2015-2024), 2019". https://www.unfpa.org/publications/unfpa-strategy-2020-round-population-housing-censuses-2015-2024.

Activity code	Activity description
1.6	Identify the mapping requirements for the CAPI app in order to integrate GIS-based enumeration area maps for use on mobile devices (mobile map packages) on a (very likely) offline mode.
1.7	Prepare for map updating activities (field organization, staff, training, manuals, tablets).
1.8	Update maps in the field (surveyors).
1.9	Update enumeration area boundaries and coding of spatial units/geocoding.
1.10	Edit and conduct quality checks of the census geodatabase and delineation of supervisory areas.
1.11	Prepare enumeration area maps to be made available for use by CAPI app on mobile devices, including for the pilot census.
1.12	Update maps in selected areas by CBS/GIS team.
2	Data collection and monitoring of census activities for the enumeration phase.
2.1	Select (or develop) apps for the field management, monitoring and tracking system, including evaluation and testing.
2.2	Prepare digital enumeration area maps and upload them onto tablets for enumeration.
2.3	Select training activities (trainers) for assistants on field mapping.
2.4	Provide field support and update maps during data collection.
3	Mapping activities for the post-enumeration phase – Contribution to statistical analyses and dissemination.
3.1	Prepare a strategy for the dissemination of geospatial data/information (a component of the overall census dissemination strategy).
3.2	Prepare geospatial data for the post-enumeration survey (PES) – Link census and PES data with geospatial data for the census evaluation.
3.3	Link census data with geospatial data and update the census geodatabase.
3.4	Prepare new sample frames.
3.5	Use geospatial information for census dissemination and analysis.
3.6	Create thematic maps for data dissemination in census reports, including an electronic (interactive) atlas.
3.7	Prepare a Geo-Portal/WebGIS with story/smart maps.
3.8	Develop a metadata system at CBS on metadata standards in line with international standards.
3.9	Train (major) census users on the use of geospatial information at the central and local levels.

7. Conclusions and recommendations

Geospatial information technologies have greatly improved and become more accessible and affordable, rendering hand-drawn maps less used, and GIS, GPS, satellite/drone imagery and automated digital field map creation have become the norm. In the 2010 and 2020 round, countries adopted these new technologies with varying levels of success. There are a few considerations which need to be taken into account for a GIS-based census to be truly successful. With the right mix of resources and skills, countries can greatly improve their map production and field monitoring for greater precision and quality in their collection of population and housing data, and agriculture holdings for the censuses, and for other applications such as precision agriculture and food security, and disaster preparedness and management.

For success in the mapping exercise, CBS needs to build a strong team skilled in imagery and remote sensing and equipped with the right tools for imagery processing. An **imagery processing unit** is required to make up for the base maps and assist in uploading the images as backdrops on tablets. This unit needs experts in imagery as well as external technical assistance.

For the mapping activities in its upcoming census, CBS plans to adopt an integrated electronic system approach composed of GIS tools, and tablets for enumeration area boundaries updating and numbering of buildings. The system is also intended to be linked with the **CAPI** applications to be used for the enumeration process, and to support the field management and monitoring activities. The system will also support the preparation and implementation of the PES and the dissemination of census results and geographic products.

The integration of CAPI with GIS is not an easy task. It requires specific skills and capacities that few NSOs have in-house. At the institutional and organizational levels, NSO requires GIS and IT units with staff working closely together, and well trained to use the panoply of technologies (GIS, GPS, imagery and IT), or else CBS may need to outsource some portions of the process of preparing census maps,[25] as it needs to process satellite imagery to create them and it needs them to be integrated with CAPI. If CBS finds that its GIS capacities are not strong enough and the support they can offer is limited, it should seek an external partnership, bearing in mind that CBS should define the terms of reference for external consultancies and develop mechanisms to control and evaluate the various activities to be outsourced, most important of them being the security of the data to be collected.

Finally, we summarize the findings, issues and potential solutions in the following table:

25 "Principles and Recommendations for Population and Housing Censuses, Revision 3", pp. 94-95. (ST/ESA/STAT/SER.M/67/Rev.3) – 2017. https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Principles_and_Recommendations/Population-and-Housing-Censuses/Series_M67rev3-E.pdf.

Table 3. Main findings, obstacles, potential solutions and the way forward

	Task/observation	Issue	Potential solution	Way forward
1	Base map	Lack of updated base maps/information available at the urban level.	Update by: Satellite imagery • Using an optimal solution: High resolution (<4 m) vs Intermediate resolution (4-10 m). • Enable an imagery processing unit and use satellite imagery to make base maps for the delineation of enumeration areas.	Develop the use of imagery, including UAV/drones.
2	Enumeration areas and coding	What are the common geographic frames for the population and housing census and agricultural census, and how to proceed with the delineation of enumeration areas covering the whole country?	Agree on a common geographic frame with the agricultural census: Adopt a geocoding scheme for the population and housing census that can cater to the needs of the agricultural census. Use satellite imagery and any existing administrative maps and GIS to delineate enumeration areas covering the whole country. Most of the work takes place in the office, with validation in the field. (3-step method – guidelines in the report).	Adapt the coding scheme with future changes and developments.
3	Geographic database	What geographic layers do we include in the enumeration area-level database?	Update the enumeration area-level geographic database with the population of enumeration areas into the database.	A continuous process

	Task/observation	Issue	Potential solution	Way forward
			(CBS has identified around 50,000 enumeration areas throughout the country). Fundamental.	
4	GIS/software	What kind of GIS software to be used: Commercial vs. open source.	Capitalize on what is existing, but formally: ArcGIS enterprise and ArcGIS online.	An interoperable system with various ministries and national organizations.
5	Linkages of IT and GIS software	Integration of CAPI and GIS enumeration area maps.	Technical solution (box 2 and figure 3).	To be adjusted after the pilot census.
6	Pilot census GIS exercise	How many enumeration areas and what apps need to be selected for the pilot?	Pilot the use of CAPI and GIS in the field, to test the technical solution (including Survey Solutions and Esri Suite).	The pilot will inform the final apps to be used and the technical solution.
7	Capacity development	Need to train GIS/IT staff and to keep them abreast with the last technological developments.	Train GIS staff and acquire needed equipment.	Maintain training/incentives to GIS staff to retain them at CBS.
8	Technical assistance	The integration of CAPI with GIS is arduous and needs various skills.	Resort to technical assistance and possible outsourcing of some technical tasks.	Take all measures for security and privacy/confidentiality of data and systems, particularly if outsourcing.

Annex 1. Brief questionnaire: A request for CBS GIS & Mapping/IT Department

Please respond to the following questions designed to help develop an inventory of the mapping and geospatial infrastructure in Sudan, as CBS is a main user of geospatial data for the census. Thank you in advance for your valuable contribution![26]

Steps to follow in checking a box:

1. Left double-click on the box
2. Select "Checked" for default value
3. Click "OK"

A. Do you have these categories of maps?

☐ **Small scale maps (national map overview)**:

Showing the major administrative area boundaries, the location of major features, large settlements and places, important transportation networks, bodies of water and important points of reference and other landmarks. (we have them all)

☐ **Topographic maps**:

Showing elevation contours and other major topographic features. (we have them within the base map above)

☐ **City and cadastral maps**:

Showing land parcels, details about important features such as transportation networks, parks, water features, points of interest such as schools, hospitals and police stations as well as important city buildings and landmarks. (we have them from 2008 population census shapefile map)

☐ **Maps of administrative units**:

Showing administrative unit boundaries at all levels of civil divisions. (due to last war in Darfur some will be full work the available 90%)

26 Prepared by Amor Laaribi, Consultant.

☐ **Thematic maps**:

Showing population distribution for previous census dates, or any features that may be useful for census mapping. (if needed)
For each category, please provide the scale, date, source, projection, etc.
Could you please provide as requested the scale of the existing maps and the dates of their production? Their sources?

B. Do you have imagery:

☐ Aerial photography
☐ Orthophotos/Orthophoto maps
☐ Satellite imagery

Please indicate the resolution/scale of these satellite images/digital aerial photos, the source/mode/date of their acquisition and their coverage. We don't have any

---

C. How are the map products delivered?

☐ in hard copy
☐ in digital form
☐ online
☐ online by web services

During field updating we delivered A2 hard copy with image overlapping and detail of base maps we have in the office before reaching the field for detailed blocks and building for each pause to define all what inside even enterprise and agriculture. Also inside tablet shape file of it if tracking and way point will be shown on it during the field is better because enumerator cannot make digitization in the field. During population census field work digital EA map for each enumerator will be in his tablet as shape file. online and by Web this in tracking and monitoring.

D. Is mapping and map updating done in-house or by outsourcing?

Updating door to door because we need waypoint of each household/housing unit and building with delineation of EA boundary using GPS tracking in tablet outsourcing comes from image before the field on base map.

E. What Datum and National Geodetic/Spatial Reference System?

In 2008 we used standard and international datum but we know national survey used special one we will deliver it to you later.

F.Software

Please name the GIS software used in your organization
1- Esri Products:
- ☐ ArcGIS Desktop
- ☐ ArcGIS Enterprise
- ☐ ArcGIS Online
- ☐ ArcGIS Pro

2- Other (please specify)
Crack ArcGIS 9-4
A crack format is not legal? There is no ArcGIS 9.4? It would be ArcGIS 9.3/9.3.1 or ArcGIS 10.0?

_____

3- Please indicate whether you have a geographic database. If yes, was it at the EA level?
Yes, at EA level but in 2008
Could you please specify the Layers in the geographic database?

_____

G. Infrastructure/equipment

☐ Does your organization have a GIS Unit, and with how many people?

Yes, 15

_____

☐ What kind of hardware (desktops, workstations, plotters, scanners, printers, etc.)?

All detail of each will reach you
Please send them as soon as possible

_____

☐ Do you have and use GPS devices? Please specify.

Yes, 60cs we used it in the two ways waypoint and tracking after making setup for each detail of setup will reach you
Please provide me with the information as soon as possible

_____

☐ Is there a digital elevation model (DTN) available?SEPSEPPlease specify.

No

_____

H. Do you have GIS-based applications and/or GeoPortal/Web-based mapping tools?

No

_____

I. Other geospatial data such as gazetteers-place/geographical names…

No

_____

J.Are you using ISO/TC 211 Geo-standards and/or OGC standards?

No

_____

K. Any other mapping/geospatial services?

No_____

Annex 2. ESCWA questionnaire for the Thirteenth session of the ESCWA Statistical Commission "Technology for Statistics"

Questionnaire on the experiences and practices of Arab countries regarding the use of geospatial methodologies and technologies, and the dissemination of statistical data.

A. Background information

Please provide the following information on the person filling the questionnaire:

Name of person filling the questionnaire: Tarig Hassan Hashim Osman
Functional title: GIS & Mapping Director
Institution, department or unit: CBS- IT Department
Country: SUDAN
E-mail: Tarigho@hotmail.com
Persons/Institutions consulted: D. Karam Alla Ali, DG

Please indicate the date of the population and housing census (dd/mm/yyyy) on which you are providing information:

01/05/2008

B. National statistical geospatial information capability

1. Describe the organizational structure of geospatial information capability in your country. For example, is there a single National Geospatial Information Authority (NGIA)? Do other areas of government also have geospatial information capabilities and/or responsibilities?
   The National Survey Authority prepares the mapping for all Ministries.

2. Is the primary national geospatial agency supporting/advancing the geospatial enablement of government information – statistics and/or administrative data?

   ☐ Yes

   ☒ No

If yes, can you briefly describe how?

If not, can you briefly explain why?

There is a gap in coordination.

---

a. Does your National Statistics Office (NSO) have any relationships and/or collaborative activities with the NGIA?

☒ Yes

☐ No

Describe what collaboration occurs?

In 2018 a technical committee was established with the Federal Survey Authority to coordinate the work in the field of maps and GIS.

---

b. Does your NSO take a leadership role in geospatially enabling national administrative and statistical data?

☒ Yes

☐ No

If yes, do you get support and assistance from the NGIA or other geospatial/mapping agency?

There is no support provided by the Survey Processing Authority.

UNFPA, UNICEF, Support the GIS UNIT.

If no, what organization in your country undertakes this role?

---

c. What geospatial capability and capacity does your NSO have?

Do you have a specific geography or geospatial unit?

☒ Yes

☐ No (please proceed to (d) below)

i. If yes, does this group produce only maps or does it undertake other geospatial activities to support the NSO?

The unit produces maps for census and field surveys currently, we are striving to equip a framework to keep up with modern technology.

---

ii. If yes, does it support organizations and activities outside the NSO?

☒ Yes, namely

UNFPA, UNICEF, World Bank.

☐ No

d. Could you describe the geospatial framework that you use in the Organization's activities?
The framework is based on the data of the fifth census. Since 2016, the Department is in the process of updating and equipping a new statistical framework.

Do you use different levels (scales) of geographies?

☐ Yes

☒ No

If yes, how does each level relate to each other?

---

e. Do you have geospatial attributes linked to the statistical information (unit level records and statistical outputs) in your organization's data management systems?

☒ Yes

☐ No (please proceed to (f) below)

If yes, could you explain what types of geospatial attributes you attach to the unit record and statistical aggregation?

Population data, different survey.

What approach (and what systems) do you use to geo-code your unit level data?

Geographic system.

Do you apply any specific geographic administrative boundaries to your statistical information – such as suburb, local government or other boundaries?

Yes.

Do these geographic boundaries ever change and if they do, do you track these changes over time?

Yes, there is a change in the geographical boundaries of the states, and the administration follows and borders with the ministry concerned.

---

f. Do you produce any geospatial map-based outputs?

☒ Yes

☐ No

If yes, briefly describe these:

---

g. Do you produce any other type of output that could be considered geospatial?

☒ Yes

☐ No

If yes, briefly describe these:

We produce GDP, Poverty, social services map.

---

h. Is any form of geospatial capability used in relation to creating statistics, or in their analysis?

☒ Yes

☐ No

If yes, briefly describe these:

We produce Pop Density.

C. Technological tools

1. What technological tools has the national statistics office/census office used for the dissemination of census results? (Check all that is applicable):

   ☒ CD-ROM/DVD
   ☒ Static web pages (html, PDF, excel)
   ☐ Census Atlas (Static)/Thematic Maps
   ☐ Interactive Census Atlas
   ☐ Query-able database(s)
   ☐ Online database(s)
   ☐ Dynamic web pages
   ☐ GIS web-based mapping tools
   ☐ Cloud Computing
   ☐ IHSN[27] Toolkit
   ☐ Others (please specify)

2. Does the national statistics office/census office employ interactive tools for mapping, tabulating, analysing and presenting data in graphs or other visual formats in the dissemination of census data?

   Yes ☐ No ☒

   If yes, provide the link (website) to the tools.

---

3. Does the national statistics office/census office employ mobile technology applications and the new social media (Twitter, Facebook, SMS, etc.) in reaching users?

   Yes ☐ No ☒

   If yes, describe the technologies and social media employed.

---

27 IHSN: International Household Survey Network.

D. Geographic Information System (GIS)

1. Does the national statistics office/census office have GIS infrastructure to capture, manage, analyse and disseminate geo-referenced data?

   Yes ☐ No ☒

   If yes, describe the geographic information system used, including the geographic database

   _____

2. Does the national statistics office/census office have a geographic/cartographic unit (with trained human resources and the requisite IT infrastructure) dedicated for managing the geographic information system?

   Yes ☐ No ☒

3. Indicate the census activities towards which the geographic information system is used (check all that is applicable):

   ☒ Cartography/census mapping in the initial stages of census operation (pre-enumeration stage)
   ☒ Census data collection (enumeration stage)
   ☐ Analysis and dissemination of geo-referenced census data (post-enumeration stage)

4. Does the national statistics office/census office disseminate geo-referenced data?

   Yes ☒ No ☐

   If yes, what is the smallest geographical level at which geo-referenced data are disseminated?

   PAU Popular Administer Unit.

   _____

E. Dissemination and archiving strategy

1. Has the national statistics office/census office developed a written plan/strategy for the dissemination of census data?

   Yes ☐ No ☒

   If yes, please provide specific components of the dissemination plan/strategy.

   _____

2. Did the national statistics office/census office develop a dissemination schedule (a comprehensive list of census outputs with accompanying timetable)?

   Yes ☐ No ☒

   If yes, please provide the schedule in a table below (or alternatively as an annex to the questionnaire)

   _____

3. Does your country have a law/regulation for archiving census micro-data?

   Yes ☐ No ☒

   If yes, describe the law/regulation

   _____

If the law/regulation is available on the internet, please provide the web-link:

_____

F. Data confidentiality and anonymization

Does the statistical law of your country include clause(s) to ensure confidentiality of census micro-data?

Yes ☐ No ☒

If yes, please describe the clause(s):

_____

Describe what procedures have been implemented or plan to be implemented for anonymization of census micro-data:

_____

G. Meta-data and documentation

Does the national statistics office/census office provide metadata (information about census data and census methods) with census products?

Yes ☒ No ☐

If yes, what kinds of metadata are provided? (Check all that is applicable):

☒ Data source (census methodology)
☒ Variables and definitions
☒ Structure and formatting of the dataset
☒ Coding instructions and classifications
☒ Data processing procedures
☒ Evaluation of data quality
☒ Confidentiality and anonymization[28] procedures
☒ Sampling methodology and weighting
☐ Other-Specify

_____

H. Challenges

What are the main challenges faced by the national statistics office/census office in the dissemination of census data?

Staffs' training.

No who of using the new technology compatibilities.

_____

28 Anonymization of data refers to the procedures of removing and modifying all individual identifiers (such as the name of the person, address and so forth) from digitized census micro-data.

Geospatial information methodologies and technologies have been adopted by national statistical organizations (NSOs), including in many developing countries, with the recognition that the appropriate use and application of these technologies is beneficial to efficiency in the preparatory, enumeration, processing and dissemination phases of the population and housing census, and ultimately in its overall quality. Today, virtually every NSO uses a geographic information system (GIS) to create digital maps, create and maintain databases, disseminate geostatistical products and provide a wide range of services. Building a statistical-geospatial infrastructure in support of censuses and statistical activities is particularly recognized as an enabler for facilitating data sharing and improving the availability and access of country information in support of evidence-based decision-making and sustainable development.

It is against this mandate that the Central Bureau of Statistics (CBS) in the Sudan aims to use innovative geospatial information technologies in support of its upcoming census, and to adopt and implement them in accordance with United Nations recommendations, taking into account national circumstances. In this regard, the Economic and Social Commission for Western Asia (ESCWA) has commissioned the present report to identify the scope and the gaps of the existing geospatial infrastructure within the statistical office in the Sudan, with guidelines on how to use geospatial information technologies at every stage of the census, and identify the resources and capacities needed for their implementation and monitoring.

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