Designing and Implementing Gridded Population Surveys

Acknowledgements

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Acronyms

CAPI	Computer-Assisted Personal Interviewing
CIESIN	Center for International Earth Science Information Network
CSPro	Census and Survey Processing System
DEFF	Design effect
DEFT	Square root of design effect
DHS	Demographic and Health Survey
EA	Enumeration area
EC-JRC	European Commission Joint Research Centre
EPI	Expanded Programme on Immunization
GADM	Global Administrative dataset
GHS-FUA	Global Human Settlement - Functional Urban Areas
GHS-POP	Global Human Settlement - Population
GHS-SMOD	Global Human Settlement - Settlement Model
GHS-UCDB	Global Human Settlement - Urban Centres Database
GIS	Geographic information system
GPS	Global positioning system
GPWv4	Gridded Population of the World, Version 4
GRID3	Geo-Referenced Infrastructure and Demographic Data for Development
GridEZ	Gridded enumeration zones
HH	Household
HRSL	High Resolution Settlement Layer
ISWGHS	Intersecretariat Working Group on Household Surveys
LMIC	Low- or middle-income country
LSMS	Living Standards Measurement Study
MICS	Multiple Indicator Cluster Survey

Acronyms (cont'd)

NGO	Non-governmental organization
NNHS	National Nutrition and Health Surveys
NSO	National statistical organization
ODK	Open Data Kit
OSM	OpenStreetMap
PPS	Probability proportional to (population) size
PSU	Primary sampling unit
RMSE	Root mean squared error
SALB	Second Administrative Level Boundaries
SES	Socioeconomic status
SMART	Standardized Monitoring and Assessment of Relief and Transition
SRS	Simple random sample
SSU	Secondary sampling unit
SUE	Surveys for Urban Equity
UNFPA	United Nations Population Fund
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations Children's Fund
UNSD	United Nations Statistics Division
WPG-C	WorldPop Global-Constrained
WPG-U	WorldPop Global-Unconstrained

Section 1.

Introduction

1 Introduction

“Gridded population sampling” refers to a sampling approach in which the survey sample frame is derived from modelled estimates of the population in grid cells (i.e., gridded population data) rather than field counts (i.e., a population census). Gridded population sampling emerged only within the last decade, so its practitioners are still settling on a common vocabulary. Other terms for this practice include “grid-based sampling” and “geo-sampling”. We avoid these terms in this manual because they can also apply to spatial sampling and our focus is exclusively on population-representative household surveys. Gridded population sampling is simply a population sample derived from a modelled, gridded population dataset rather than from a census.

This manual is designed for survey practitioners who already have experience conducting face-to-face household surveys using traditional census-based sampling methods and tools, particularly in low- and middle-income countries (LMICs). Therefore, the target audience for this manual includes survey practitioners in national statistical organizations (NSOs), development organizations, polling firms, demographic research institutes, and community-based organizations. Readers who are less experienced at designing and implementing traditional household surveys may benefit from reviewing **Supplement A** where we link to a number of additional survey resources. This manual is not sufficient for survey novices to learn and apply survey methods from scratch.

The purpose of this manual is threefold:

1

To provide a general overview of gridded population sampling

2

To enable you, the reader, to decide whether this sampling approach is appropriate for your survey

3

To easily plan and implement your own gridded population survey using a subset of the step-by-step tutorials listed in **Section 3**

This manual was developed in 2021–22 for survey practitioners in NSOs and other organizations to fill an information gap about the emerging field of gridded population sampling. At the time of writing the tools, methods, and datasets available to implement gridded population surveys were evolving rapidly. In addition, many face-to-face surveys were being postponed, performed with modified field protocols, or partially or fully replaced with phone surveys due to the COVID-19 pandemic. Given that gridded population survey techniques, and possibly all face-to-face survey techniques, are expected to evolve rapidly in the near future, we emphasize our rationale for recommendations and provide cautionary notes when evidence is still limited, so that you are able to make informed judgements as they arise about new gridded population survey tools, methods, datasets, and evidence.

1.1 What this manual is, and what it isn't

This manual only discusses population/household probability survey samples that are selected to make representative inferences about human populations. This manual does not address spatial sampling methods (which are sometimes referred to as "gridded sampling"), nor does it cover sampling of farms, businesses, or plant or animal populations. This manual is designed for survey practitioners already well versed in survey methodology, and is thus not intended to give detailed information about the steps of doing a survey.

The manual is organized as follows:

This Introduction (Section 1) provides enough information for you to decide whether or not gridded population sampling (and this manual) is an appropriate choice for you.

Section 2 details the specific ways that gridded population sampling is similar to, and different from, traditional census-based sampling. For a brief overview of traditional census-based household survey concepts and practices, see Supplement A. Section 2 also includes background on gridded population datasets, and provides several decision trees to help your team find an appropriate sample design, sample frame, and suite of tools to match your needs, skillsets, and survey setting.

Section 3 links to a series of tutorials for each step of a gridded population survey workflow. Each tutorial provides step-by-step instructions with illustrations to aid survey practitioners to achieve a specific task in a specific software tool based on one of four example surveys. These tutorials are designed as separate online Microsoft Word documents which can be mixed and matched, and updated if desired, to create a bespoke manual to implement your specific gridded population survey. Tutorials are also hosted online so that the collection can be expanded and updated as the household survey landscape evolves, and to facilitate contributions from a broad community of practice. The website serves as a platform for practitioners like you to share your experiences of implementing gridded population surveys so that we might learn from each other.

Supplement A provides a brief overview of traditional household survey concepts with links to external resources. It is provided to help survey practitioners from multiple disciplines understand how the concepts and tools discussed in this manual are similar to, and different from, traditional household survey methodology. Supplement A includes a summary of:

- Types of survey samples, including probability samples and non-probability samples.
- Concepts of accuracy, precision, and resource usage – and their trade-offs – which must be balanced during survey design.
- Probability survey concepts and vocabulary that we use throughout this manual, including common terms (e.g., stratification) and less-common terms (e.g., area-microcensus). This section also includes a review of sample probability weight calculations.
- End-to-end decision points throughout phases of survey design, fieldwork, data processing, analysis, and reporting. This section links to multiple manuals, guides, and templates from major household survey implementers.

Supplement B includes the URL addresses for all linked resources for the benefit of readers using a printed version of this manual.

1.2 Gridded population sampling concerns and myths

By the end of Section 1.2, you will be familiar with common concerns and myths about gridded population sampling.

Gridded *population* sampling versus gridded *spatial* sampling.

These are two very different sampling approaches, though they are sometimes conflated. As stated earlier, gridded population sampling should result in a sample that is representative of the underlying population, while spatial sampling is equivalent to tossing darts at a map. There is a substantially different probability that a person or household is selected in a spatial sample than in a population-based sample, because people are not uniformly distributed across space. A strictly spatial sample will oversample people in sparsely settled areas (e.g., rural areas), and those who live in larger structures (e.g., richer households). Note that it is possible to draw a gridded population sample, and then supplement that population sample with a spatial oversample to fill any "holes" in the map. This might be useful if survey results will be used to produce small area estimates by applying sample weight adjustments to ensure that the sample remains representative of the underlying population (Thomson et al., 2020).

Navigating to gridded population survey clusters.

In some traditional census-based surveys, clusters (i.e., sampling units) may be identified only by a series of nested administrative unit names that field teams locate by asking residents for directions. Clusters derived from gridded population data, however, have precise geographic boundaries, and generally can only be identified by higher level administrative unit names (e.g., province and district) because detailed administrative spatial datasets (e.g. village or neighborhood boundaries) rarely exist in settings where gridded population sampling is used. A lack of local place names should not be a problem for navigation to clusters, as navigation to any geographic point or area is relatively easy with basic map-reading skills and tools.

Cluster boundaries that intersect a building/property.

Often, the clusters derived from gridded population data have a square, rectangular, or block-shaped boundary that does not conform to roads, rivers, or other natural features, and which might intersect buildings or properties. A simple protocol can be used to decide whether intersected features should be included or excluded from the cluster. For example, a common protocol is to include buildings/properties intersected by a northern or eastern cell boundary, and exclude buildings/properties intersected by a southern or western cell boundary. This simple protocol ensures that a building/property will only ever be counted in one cluster.

Cost of a gridded population survey versus a census-based survey.

Few cost comparisons have been made between gridded population and census-based surveys, but the comparisons that do exist (e.g., Thomson, Bhattarai et al., 2021), as well as anecdotal evidence, suggest that gridded population surveys cost the same or are less expensive than census-based surveys. Gridded population surveys often cost less, because it takes less time to complete the household listing and/or because the need for a household listing is removed altogether (see Section 2.2.1 for a description of existing and new sample designs supported by gridded population sample frames).

Accuracy of gridded population sample frames.

The accuracy of available gridded population datasets should be the team's main concern when considering gridded population sampling. While the tools to select and implement a gridded population survey might be further improved and streamlined, there are enough options that teams of all skill levels can implement most gridded population survey designs as outlined in this manual. However, gridded population datasets vary substantially at the local level, and local accuracy (e.g., at the level of grid cells or clusters) is largely unevaluated. The accuracy of gridded population datasets is of particular concern in data-sparse settings where gridded population sampling is most likely to be used.

In **Section 2.3.1** we provide an overview of publicly available gridded population datasets, how they are produced, and what we know about their local accuracy. **Section 2.3.1** also recommends gridded population datasets that should – and should not – be used for gridded population sampling (and other local-level fieldwork). For example, gridded population datasets that are made without building footprint data (the standard until recently) have a tendency to smooth out estimates within and around settlements, increasing the probability of selecting uninhabited clusters, and should be avoided. We are clear that these recommendations are subject to adjustments as new accuracy assessments are performed and as gridded population modeling methods evolve.

Accuracy of gridded population samples versus census samples.

Despite variation and local inaccuracies in gridded population datasets, early evidence suggests that gridded population sampling is more desirable than census-based sampling in settings with an outdated or inaccurate census. This conclusion is supported by a series of analyses performed on simulated, realistic population datasets that are modified to reflect realistic levels of census outdatedness and inaccuracy (Thomson, Kools, and Jochem, 2018; Thomson et al., 2022). In these studies, a gridded population dataset derived from an outdated, inaccurate census more accurately reflected the fine-scale distribution of the population than the underlying census data because model auxiliary datasets such as building footprints ensured the allocation of imperfect census population counts to areas where people actually lived, including informal settlements and new housing developments (Thomson, 2020). As a result, gridded population sampling (in a simulated environment) produced more accurate estimates of the "true" population than samples drawn from the underlying simulated (outdated, inaccurate) census. This is another area for further research using both simulated populations and real-world evaluations.

1.3 When is/isn't gridded population sampling appropriate?

By the end of Section 1.3, you will be clear whether or not gridded population sampling is advisable for your survey, and why. Use the decision tree in **Figure 1.1** to identify whether your survey includes one or more common reasons to use a gridded population survey.

The survey is in a conflict zone (or other dangerous area) where the amount of time spent in the field needs to be limited for the security of data collectors. This might also apply to surveys in areas experiencing high rates of COVID-19 or other public health emergency, where the number of face-to-face contacts and/or length of time during each face-to-face contact needs to be minimized for the safety of both the public and data collectors. The small size of grid cells in gridded population estimates means that gridded population sampling can use new sample designs unavailable in traditional census-based surveys. These new gridded population survey designs both enable robust probability sampling with just one field visit (unlike most field-based sampling methods), and require fewer face-to-face contacts than traditional census-based sampling.

The only available sample frame is outdated or inaccurate, for example, a census that is more than 10 years old or a census that is hotly contested on the grounds of deliberate misreporting or poor data-quality protocols. At the time of writing, 1 in 10 LMICs had not held a census in the last 15 years (UNSD, 2019), and census delays due to COVID-19 were exacerbating this situation. Countries with the oldest official censuses include Afghanistan (1979), D.R. Congo (1984), Lebanon (1932), Somalia (1987), and Uzbekistan (1989), and Eritrea has never conducted an official census. All would be good candidates for a gridded population survey.

The setting is highly dynamic and complex, such that a census-based sample frame would become rapidly outdated. Rapid urbanization, for example growth in informal settlements, (re)development of housing and business districts, and general urban expansion all contribute to rapid urbanization, and together can render a census-based survey sample frame inadequate after just a few years. Other forces, such as natural or human-made disasters, can lead to large-scale population movement and resettlement. The gridded population datasets that we recommend for use with gridded population sampling reflect recent (e.g., 2020) locations and concentrations of human populations. With relatively more accurate fine-scale population distribution data, more accurate samples can be drawn (even when the population totals are sourced from an outdated or inaccurate census).

The survey design team wishes to stratify on environmental or geographic characteristics. While any sample frame that is georeferenced, including census enumeration areas, can be stratified with external spatial data, many census sample frames are still not spatially referenced and thus have limited stratification options beyond administrative boundaries and urban/rural delineations. Sample frames derived from gridded population data are always georeferenced, and usually at fine geographic scale, enabling stratification on spatial characteristics such as pollution level, land-cover type, distance to waterways, etcetera.

A potential fifth reason to choose gridded population sampling is to perform spatial oversampling after population-representative sampling in order to improve small area estimates modelled from survey results. This is discussed in Thomson et al. (2020), but not emphasized in this manual because we are unaware of any survey teams who performed spatial oversampling in a real-world gridded population survey to explicitly improve small area estimates. More research is needed to evaluate whether, and to what extent, this approach makes sense.

There are a number of situations in which gridded population sampling is less ideal than alternative sampling approaches.

These include settings where:

- The survey coverage area is very small (e.g., one village or neighborhood).
- The survey planning team does not have reliable electricity or internet access (because many gridded population survey tools require digital maps to be downloaded, even if they are used offline).
- The survey planning team is unfamiliar with basic mapping tools such as Google Maps or Google Earth (because our recommended “basic” toolkits require these proficiencies).
- A national census was recently conducted, is publicly available, and widely trusted (because recent field-referenced population counts are always preferred to modelled population estimates).

1.4 Who uses gridded population sampling and for what?

The methods and tools used in surveys of human populations vary widely depending on the purpose of the survey, needs of data users, and best practices as defined in specific sectors. Although we outlined above common reasons why survey practitioners choose gridded population sampling, the added value of gridded population sampling (versus current methods) will vary by type of survey and sector. In this section, we describe **four common use cases** (i.e., sector and survey purpose) for gridded population sampling, and the advantages of gridded population sampling for each use case. Each use case is detailed in Section 2 with examples of real-world gridded population surveys.

Routine multi-topic surveys

National statistical organizations (NSOs) use gridded population sampling for **routine multi-topic surveys.** Compared to census-based sampling, gridded population sampling improves sample accuracy when (a) the last census was 10+ years ago, (b) the census quality was disputed, and/or (c) the census undercounted vulnerable or mobile populations. This is because sample frames are created from models that project and redistribute the census population counts to small areas based on recent satellite imagery and GIS evidence of population settlement and density.

Evaluation and research

Non-governmental organizations (NGOs), government development teams, and academic teams use gridded population sampling for program **evaluation and research.** That is, compared to the amount of time and resources it takes to conduct the classic two-stage sample design often used by these types of survey teams (see Supplement A, Section SA.3), gridded population sampling offers several equally accurate but less expensive and faster alternative designs. This is because new sample designs leverage the small cells in gridded population datasets (e.g., 100×100 m) as sampling units, requiring just one visit to the field instead of two, while still allowing the calculation of robust sampling weights. An additional benefit of listing and interviewing on the same day in small sampling units is that interviewers more accurately identify hidden, vulnerable neighbors of respondents *after* an interview during which rapport was established than *before* an interview during a household listing or field sampling exercise.

Opinion polls

Private or government polling teams use gridded population sampling for **opinion polls.** Compared to random-walk (or other field-based sampling) methods, gridded population sampling offers several more accurate sample designs that require just one field visit per cluster and little, if any, additional resources. This is because new sample designs leverage the small cells in gridded population datasets (e.g., 100×100 m) as "microcensus" sampling units, which also enables calculation of robust sampling weights.

Rapid needs assessments

Humanitarian response teams use gridded population surveys for **rapid needs assessments.** Compared to random-walk surveys, gridded population sampling offers several sample designs that more accurately identify vulnerable, hidden populations while costing little, if any, additional time and resources in the field. As with other use cases, this is because new sample designs leverage the small cells in gridded population datasets (e.g., 100×100 m) as "microcensus" sampling units. This enables interviewers to more accurately identify hidden, vulnerable neighbors of respondents *after* an interview during which rapport was established rather than *before* an interview during a household listing or skipping exercise.

Throughout this manual, we refer to these four common survey use cases, and tailor our suggestions about tools and approaches to meet the needs of diverse survey teams. At this point, you have enough context to use Figure 1.1 to decide whether or not gridded population sampling is appropriate for your survey.

Figure 1.1. When to use (or not use) gridded population sampling

KEY:
- Gridded population sample frame suggested
- Other sample frame suggested

Is your study area very small (e.g., one village or neighbourhood?)

YES: **Consider a simple random sample (e.g., EpiCentre's Geo-sampler).**

(or) **NO:** *Does your country or region face days without internet access?*

YES: Most gridded sampling tools or protocols require basic internet access to view Google Earth. **Use a census or other sample frame.**

(or) **NO:** *Does the planning team have limited or no experience with Google Earth or Google Maps?*

YES: At a minimum, the planning team should be able to use Google Earth to implement a gridded population survey. **Use a census or other sample frame.**

(or) **NO:** *Is the survey stratified on spatial characteristics?*

YES: Any georeferenced frame might be stratified on spatial characteristics. **Gridded population sample frames** are always a decent option because they are derived from fine-scale spatial data.

(or) **NO:** *Is the survey occurring during an infectious disease outbreak or pandemic?*

YES: **Consider a gridded population survey, or consider recruiting a representative population cohort** via a face-to-face gridded population sample with phone-based follow-up.

(or) **NO:** *Is the survey in a conflict zone where fieldworkers will only make one visit to the field for their safety?*

YES: **Consider a gridded population sample frame.**

(or) **NO:** *Is the census (or other available sample frame) outdated (>10 years old) or inaccurate?*

YES: **Consider a gridded population sample frame.**

(or) **NO:** *Is the target population urban or highly dynamic?*

YES: **Consider a gridded population sample frame.**

NO: **Use a census or other sample frame.**

Section 2.

Planning your gridded population survey

2 Planning your gridded population survey

This section describes how gridded population surveys differ from census-based surveys, and will help you make key decisions about your own gridded population survey. **Section 2.2** introduces two new survey designs that are uniquely enabled by gridded population survey frames (one-stage and two-stage, area-microcensus sampling). The remaining sections guide you through four decisions about the most appropriate (1) sample design (**Figure 2.2**), (2) sample frame (**Figure 2.5**), (3) gridded population sampling tool (**Figure 2.7**), and (4) survey implementation toolkit (**Figure 2.8**).

2.1 Survey phases and steps

Figure 2.1 includes all of the phases and steps of a traditional population survey, but those steps that potentially differ in gridded population surveys are highlighted. **Table 2.1** further details how each step differs by sample design. If you plan to use a multi-stage sample design or random-walk (or similar field-based sampling) methodology, you will find that fewer steps differ in your gridded population survey. The following sub-sections detail each phase and its corresponding steps in a gridded population survey. See **Supplement A** for descriptions of each phase and step in a standard census-based survey, and for links to widely used survey planning and implementation resources.

Before detailing the differences between gridded population and census-based surveys, we briefly review common census-based survey designs. *See **Supplement A** for a refresher on traditional census-based survey concepts and practices.* NSOs and evaluation/research teams favor robust two-stage surveys that involve first sampling small geographic units such as census enumeration areas (EAs) or villages with probability proportional to population size (PPS). These small areas serve as the primary sampling units (PSUs) and are commonly referred to as clusters. A team of mapper-listers visits each selected PSU and manually enumerates all households (or eligible respondents). In a second stage of sampling, the household/individual lists are sampled systematically or at random, resulting in secondary sampling units (SSUs). Interviewers generally perform a second visit to the field to collect data from the selected households/individuals, though this is sometimes performed on the same day as the listing, with data collectors trained to use a table of random numbers to sample from the household/individual listing. Sample probability weights are calculated and applied during analysis to adjust for different probabilities of selection due to stratification, oversampling in sub-populations, and differences in EA (PSU) population size. Polling agencies and needs assessment teams often implement faster, less robust two-stage survey sampling designs that can be implemented with one field visit using field-based random-walk or similar methods to select households/individuals (SSUs).

2.1 Survey phases and steps (cont'd)

Figure 2.1.

Steps in a gridded population survey that differ from a census-based survey

In Section 2.2 we detail six survey designs that are possible with gridded population sampling. These designs fall into three categories:

1 . Multi-stage samples with a household listing

2. Less robust multi-stage samples with field-based sampling of households (e.g., random-walk)

3. New area-microcensus designs that are uniquely supported by gridded population data

Table 2.1 summarizes the differences between gridded population sampling and census-based sampling at each stage of the survey process. The main differences are in the PSU sample frame construction and the field navigation tools used when performing a household listing.

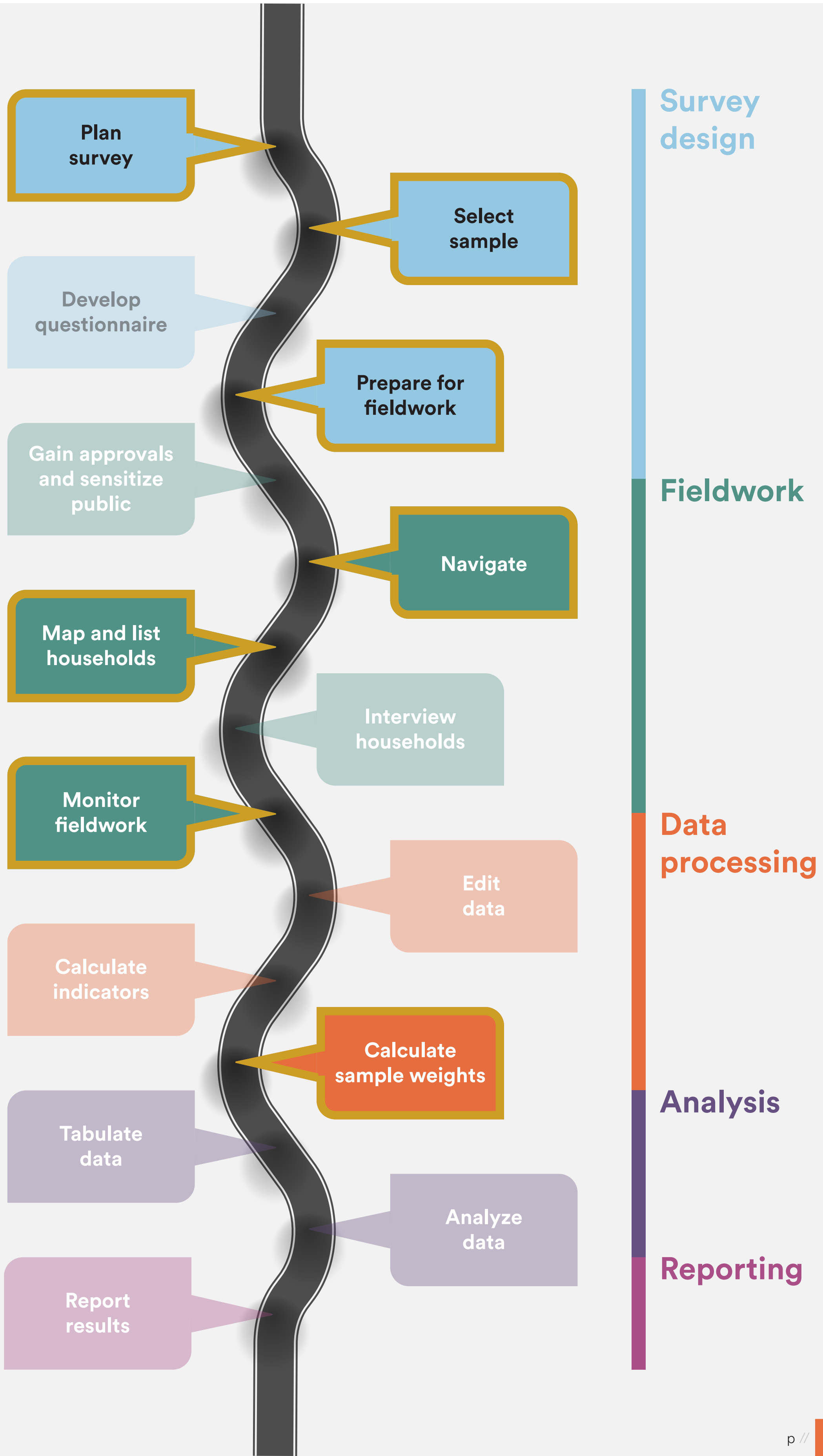
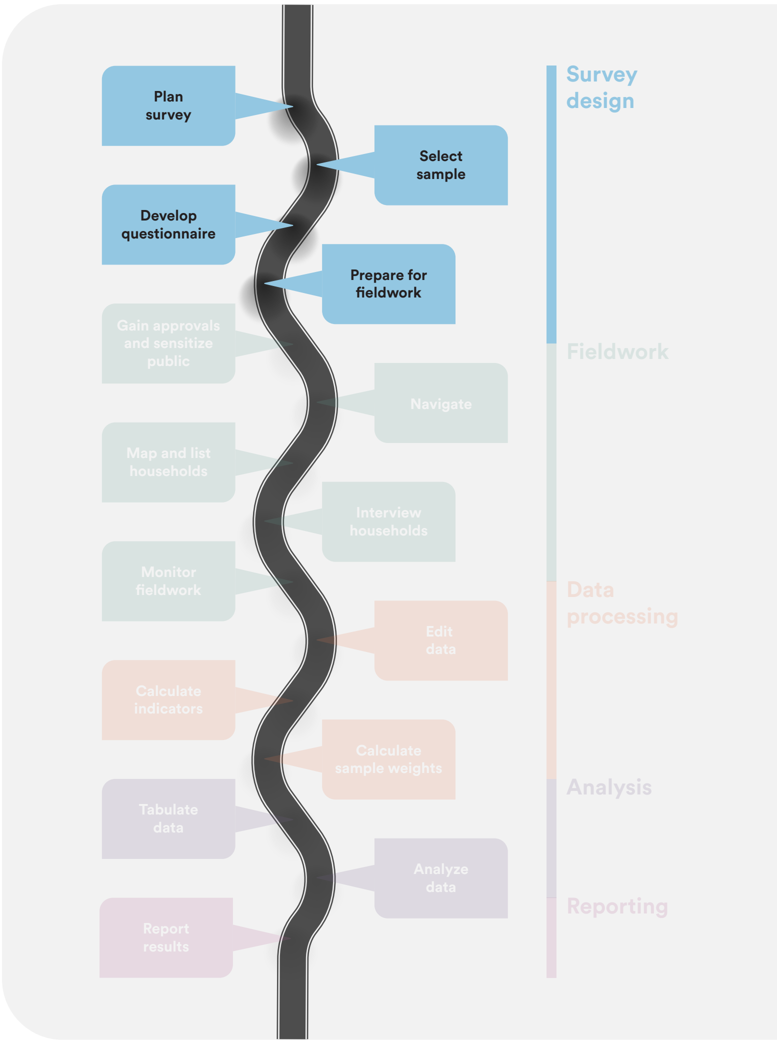


Table 2.1. Details of how gridded population survey steps differ from census-based survey

Step	Component	Multi-stage with household listing	Multi-stage with random-walk	New designs that leverage grid cells
Plan survey	Context	No differences		One field visit is useful for insecure settings.
	Sample size and design	No differences		Limitation is that design effects are largely unknown.
	Budget	Hire staff and/or partners with Intermediate GIS skills.		
Select sample	Sample frame and PSU selection	Create the sample frame from gridded population estimates instead of a census. The tools used to draw gridded population survey PSUs are sometimes different than those used for census-based samples.		
	Prelisting aggregation or back-up sample	Inflate the PSU sample size by 10–20% per strata to create randomized back-up PSUs, or visually inspect PSUs over satellite imagery and aggregate any clearly low-population PSUs with a randomly selected neighbor PSU.		
	Prelisting segmentation	Review each PSU over satellite imagery before fieldwork and segment PSUs that have a population well above your PSU target size.		
Develop questionnaire	Development and testing	No differences		
Prepare for fieldwork	Recruitment and training	Provide practice-based training in navigation for listing and interview staff. Use Intermediate-level GIS specialists to produce maps and manage/monitor spatial data.		
	Field maps preparation	Produce digital and/or paper field maps of PSUs with a satellite imagery or OpenStreetMap base map.		
	Questionnaire preparation	No differences		
	Server set-up	No differences		
	Tablet set-up	Ensure tablets have app(s) for (offline) navigation to PSUs and within PSUs.		
Approvals and sensitize public		No differences		
Navigate	Navigation to PSU	Use an app such as Google Maps because PSU boundaries may not align with local administrative units or place names.		
	Navigation within PSU	Use an app such as SW Maps to display the fieldworker's location and PSU boundary over imagery/OpenStreetMap to ensure accurate PSU coverage.		
Map and list households	Mapping	Mark buildings on paper field map and digital app.	Not applicable	
	Listing	Use a digital app (preferably the same app as used in interviews) rather than a paper form.		
	SSU selection (multi-stage)	No differences		
Interview households		No differences		
Monitor fieldwork	Tabular data	No differences		
	Spatial data	Use a digital spatial tool to monitor, on daily basis, the accuracy of interviewer locations.		
Edit data		No differences		
Calculate indicators		No differences		
Calculate sample weights		Sample weights formula is the same, however apply assumptions to translate estimated gridded population counts into estimated households.		
Tabulate and analyze data	Tabular data	No differences		
	Spatial data	No differences		
Report results		No differences		

2.1.1 Survey design



2.1.1.1 / Plan survey

Survey planning is an iterative process to find a sample design and sample size that balances the team's needs for both indicator accuracy and precision with survey affordability and timeliness. Most **census-based surveys** follow a two-stage design in which census EAs are sampled with PPS, and households are either sampled after a complete household listing or directly in the field using a technique such as random-walk (see Supplement A).

Gridded population surveys provide unique survey design options that are particularly attractive if:

You are working in a **disaster or conflict zone** in which you need to limit fieldwork to one visit for staff safety.

You have **strict resource and/or time constraints** and therefore wish to complete all fieldwork at once.

These new designs include **one-stage, area-microcensus sampling** and **two-stage, area-microcensus sampling** (also called adaptive sampling). Both designs are detailed in Section 2.2.1.

Briefly, one-stage, area-microcensus sampling means that you sample very small PSUs (e.g., 10–15 households each) and interview all households. Two-stage, area-microcensus (adaptive sampling), means that you sample "normal"-sized PSUs (e.g., 100–250 households each), then segment by grid cell and interview all households in a series of randomly selected cells until you have met or exceeded the target household/individual sample size per PSU.

The benefits of both of these designs is that they can be implemented with one field visit, permit calculation of robust sample probability weights, and are more likely to include the "hidden" vulnerable urban households that are often excluded in standard multi-stage and random-walk surveys. However, a limitation of both sample designs is that we **do not yet have good estimates of the design effects** that can be expected for common indicators. Nearby neighbors (e.g., area-microcensus designs) are expected to be more similar on many indicators than distant neighbors (e.g., multi-stage designs), resulting in higher design effects. However, one-stage and two-stage, area-microcensus samples are both more likely to identify "hidden" households (e.g., atypical, unregistered, migrant households)

2.1.1 Survey design (cont'd)

2.1.1.1 / Plan survey (cont'd)

where they exist, which might result in greater heterogeneity among households within the PSU and reduce design effects for certain socio-economic indicators. This was the case in the highly mixed, dynamic city of Kathmandu, Nepal, where comparable one-stage area-microcensus and standard two-stage samples were drawn (Thomson, Bhattarai, et al., 2021).

In all gridded population surveys, survey planners must consider a few **new or different budget items** that relate to the number and type of personnel, number of field visits, and tools that will be used for sample selection and implementation. Generally, gridded population surveys rely on use of satellite imagery and/or vector maps (e.g., outlines of roads and buildings) before and/or during fieldwork. Therefore, it is common for gridded population survey teams to include an Intermediate-level GIS expert or consultant. That said, it is possible to implement a gridded population survey without a GIS expert in the team, and this manual provides details of available tools and protocols for such teams.

Credit: Surveys for Urban Equity, Kathmandu, Nepal

2.1.1 Survey design (cont'd)

2.1.1.2 / Select sample

After the survey team settles on a sample design and sample size, they identify population data to construct a sample frame (see **Supplement A**). Ideally these population data are fine-scale, current, accurate, and mapped. The main difference between a gridded population and a census-based survey is the source of the PSU sample frame population information. A gridded population sample frame is comprised of PSUs that take any shape, such as:

- grid cells;
- contiguous clusters of cells that form gridded EA-like shapes;
- areas that follow natural features; or
- administrative boundaries including census EAs (detailed in **Section 2.3.2**).

The defining characteristic of a gridded population sample frame is that the population count in each PSU is derived from a gridded population dataset.

Not all estimated gridded population datasets are the same, and your choice of gridded population estimate may strongly influence PSU probabilities of selection. Therefore, it is important to become familiar with the pros and cons of available gridded population datasets before choosing which one to use. **Section 2.3.1** details eight multi-country gridded population datasets, and will help you decide which gridded population dataset(s) and sample frame units (PSUs) are appropriate for your survey design and team. Depending on your sample frame requirements and team skills, it will also help you choose a tool to create and draw PSUs for your gridded population survey.

Even when you have used a relatively accurate and current gridded population dataset to derive the sample frame, it is possible that some PSUs will have far more, or far fewer people than are targeted per PSU, due to local uncertainties in gridded population estimates. This can be particularly problematic for multi-stage sample designs in which mapper-listers will enumerate all households (or eligible individuals) in PSUs, and for area-microcensus designs in which all households (or eligible individuals) in PSUs will be interviewed. For this reason, it is important to review each selected PSU over satellite imagery before fieldwork begins, and then either aggregate low-population PSUs with a randomly selected neighbor or drop and replace these PSUs with a randomly selected back-up PSU. Generally, **aggregation** of PSUs requires GIS skills. The alternative approach, particularly if your team does not have GIS skills, is to inflate the PSU sample size by 10–20% per stratum, randomly assign sampled PSUs to the "main" versus **"back-up" sample,** and then randomly draw a PSU from the back-up sample to replace a main PSU that clearly has no, or very few, habitable buildings.

For PSUs that clearly have far too many households upon visual inspection of satellite imagery, the team should consider **segmentation.** Segmentation is done manually over recent satellite imagery by splitting the PSU into two or more units of approximately equal population along roads, rivers, fences, and other physical features. Whether or not your team is skilled in GIS, it is possible to segment large PSUs before fieldwork, and the tutorials linked in **Section 3** provide instructions to do so for all skill levels.

2.1.1 Survey design (cont'd)

2.1.1.3 / Develop questionnaire

The questionnaire development and testing step in gridded population surveys is identical to that in census-based surveys. This is true regardless of the sample design. More details and resources for this step can be found in Supplement A.

2.1.1.4 / Prepare for fieldwork

Fieldwork preparation differs depending on the sample design, skillset of the survey team, and context. In census-based surveys, either the mapping-listing staff hand-draw maps of each PSU in the field, or survey coordinators provide PSU maps to mappers-listers and interviewers before beginning fieldwork. Survey teams may photocopy maps from previous census fieldwork, rather than generate new ones each time (see Supplement A for more detail).

However, unlike census-based surveys, gridded population surveys often do not result in PSU boundaries that are familiar to government officials or local community leaders, and thus require the use of geographically accurate maps to identify PSU boundaries during fieldwork. The main additional tasks when preparing for gridded population survey fieldwork are (a) hiring **staff who can produce maps and manage/ monitor spatial data,** (b) preparing paper and/or digital **geographically accurate maps for fieldworkers and training them on field navigation,** and (c) providing mobile devices equipped with **navigation applications** for fieldworkers. At the time of writing, a number of traditional census-based surveys have gone digital, and already employ these tools and methods.

Whether you are planning a paper-based or tablet-based survey, the questionnaire preparation, server set-up (if applicable), and interviewer training steps will be identical between a gridded population and traditional census-based survey.

Credit: Surveys for Urban Equity, Kathmandu, Nepal

2.1.2 Fieldwork

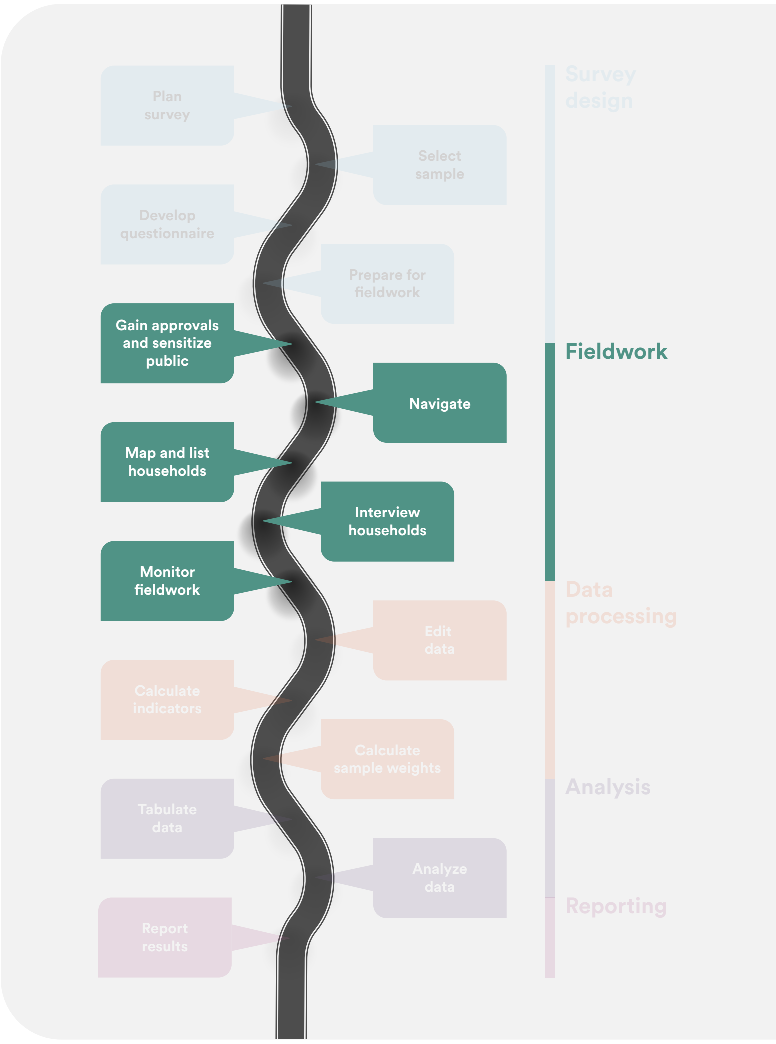
2.1.2.1 / Gain approvals and sensitize public

The processes of seeking official permissions, carrying out an ethics review, and/or sensitizing the public about the survey are the same for a gridded population survey as for a census-based survey.

2.1.2.2 / Navigate

Survey field teams need tools and protocols to, first, navigate to a PSU, and second, navigate within a PSU. While it is not essential for mapper-listers and/or interviewers in a gridded population survey to use a mobile device (paper maps can be exclusively used), a **navigation app is highly recommended,** especially in densely populated areas. In Section 2.4.1 we recommend apps for offline navigation that display PSU boundaries over a base map, and explain how to display the device's location on the map. Together, these features will help fieldworkers to collect accurate information more efficiently.

Regardless of the tools used for data collection and navigation, we recommend that you **provide fieldworkers with a paper-based map of each PSU** showing the PSU boundary over a reference base map (e.g., satellite imagery or OpenStreetMap). Paper PSU maps can be used in many ways in the field. First, they are an additional navigation tool in case the tablet or navigation app stops working. Second, paper maps can be marked-up to generate a household sample frame, and/or to update OpenStreetMap with accurate road and building information before you carry out a second stage of sampling and fieldwork (see Section 2.1.2.3). Third, fieldworkers often find paper maps valuable for building trust with residents, local leaders, officials, and others in the neighborhoods where they are working. This is especially true if fieldworkers are using a tablet for navigation and data collection, because digital devices might feel suspicious or threatening to residents, while a paper map of the neighborhood might feel more approachable and help the fieldworker to explain the purpose of the survey.



Credit: Surveys for Urban Equity, Kathmandu, Nepal

2.1.2 Fieldwork (cont'd)

2.1.2.3 / Map and list households

Mapping, listing, and drawing secondary sampling units (SSUs) (e.g., households) only happens in surveys that follow a multi-stage sample design, such as a routine government survey. When routine government surveys use a census sample frame, mapping can be performed in one of four ways as described in **Supplement A, Section SA.4.1.4**: (a) hand-sketching the PSU on a blank piece of paper, (b) marking up a photocopy of an old census EA map, (c) marking up a bespoke map of the PSU produced in a GIS or other spatial software, or (d) recording a GPS point location for each household (or eligible individual) identified. At the time of writing, the first two options were more common in census-based surveys. For a gridded population survey, only options 3 or 4 are viable, and we recommend you use both, or option (c) at a minimum.

We suggest that mapper-listers in multi-stage gridded population surveys **mark up a bespoke PSU map produced in a GIS or other spatial software** because it (a) is fast and easy from the perspective of the fieldworker, (b) provides a paper trail that ensures data quality of any collected spatial data, and (c) guarantees that mapping-listing fieldwork can continue even when fieldworkers encounter a broken, lost, malfunctioning, or dead device. A paper trail that documents the location of all buildings and roads in each PSU is valuable to supervisors who monitor all collected mapping-listing data, and it also enables the creation of detailed and accurate maps later for interviewers. This is because buildings and roads can be digitized in OpenStreetMap by GIS non-experts (thereby integrating the features into an open, global, crowd-sourced map), or digitized offline by the team's GIS expert(s) using ArcGIS or QGIS (to keep road and building locations private).

Credit: National Bureau of Statistics, Abuja, Nigeria

2.1.2 Fieldwork (cont'd)

2.1.2.3 / Map and list households (cont'd)

Contributing to OpenStreetMap as part of your survey mapping process has lasting societal benefits in terms of providing accurate road and building data that will almost certainly aid future disaster responses and/or development initiatives. However, be careful to maintain the anonymity of PSU locations in OpenStreetMap. If PSUs are located in areas that are already partially mapped in OpenStreetMap, then any contributions by your team will be minimal and undetectable. However, if PSUs are located in areas where virtually no buildings or roads have been mapped in OpenStreetMap, then someone could figure out your survey PSU boundaries. You might conceal PSU locations by digitizing roads and buildings beyond the boundary of your PSUs, and by digitizing some additional fake PSUs, but we do not have specific guidance that can ensure the anonymity of PSUs in this situation, and recommend careful consideration. If you cannot maintain the privacy of PSU locations in OpenStreetMap, you might choose to have a GIS expert digitize roads and buildings within PSUs offline in ArcGIS or QGIS, or simply skip this step and instead produce maps for interviewers using a satellite imagery base map.

In both gridded population- and census-based surveys, the household **listing** can take place on paper forms or digitally. The content of the listing form in a gridded population- and census-based survey is identical, as is the process of compiling the listing for each PSU and **drawing SSUs.** If using a digital listing form, we recommend that you provide mapper-listers with back-up paper forms and basic training on their use in case your fieldworkers encounter problems with their devices in the field.

Credit: National Bureau of Statistics, Kaduna, Nigeria

2.1.2 Fieldwork (cont'd)

2.1.2.4 / Interview households

Interviewer skills, tools, protocols, and training to identify eligible respondents and to administer the questionnaire in a gridded population-based survey are essentially identical to a census-based survey. Whether implementing a multi-stage survey design or random-walk methodology, the interviewers will need to navigate to specific points (either sampled households or the random-walk start location) using familiar tools such as a paper field map and/or navigation app on a mobile device.

Interviewers who implement a one-stage or two-stage, area-microcensus design will be instructed to navigate to a small PSU (or small cell within a larger PSU) and interview all households. They will use the same skills, tools, and training to implement an area-microcensus design as a census-based survey. Optionally, implementers of area-microcensus designs might aim to identify "hidden" populations that might ordinarily be missed by typical multi-stage or random-walk surveys, and thus the protocol might also involve interviewers asking respondents, shopkeepers, security guards, and other people in the PSU about atypical and unregistered households nearby (this can include street-sleepers).

2.1.2.5 / Monitor fieldwork

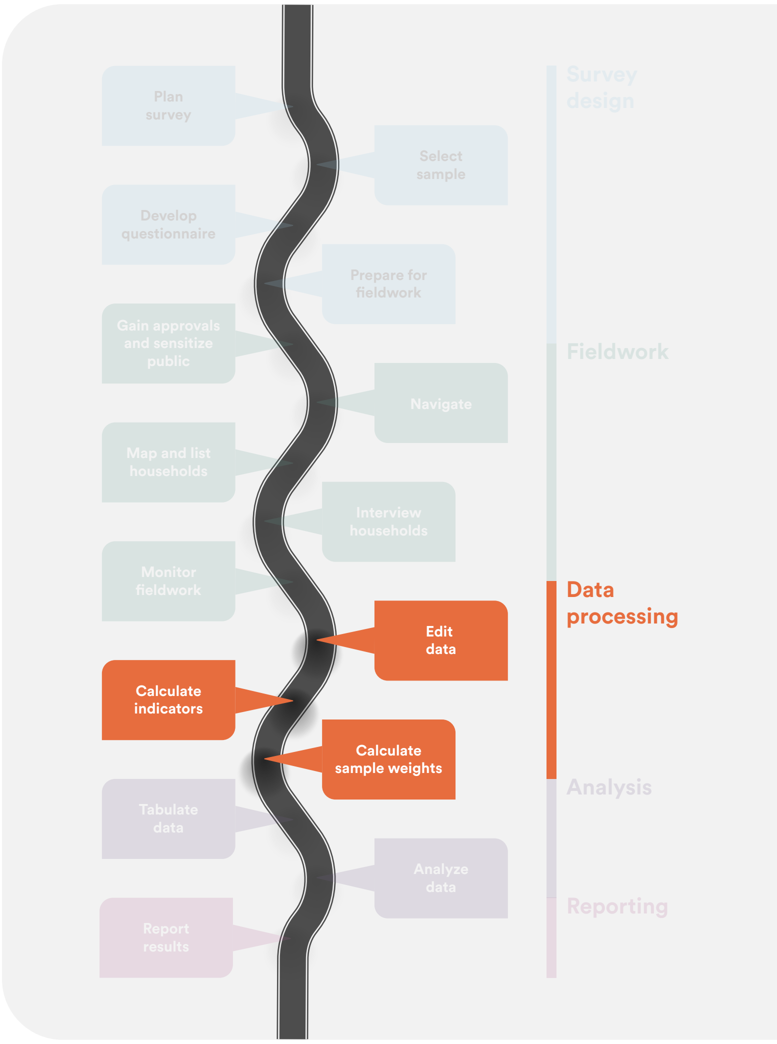
For survey teams who already collect and use spatial data, monitoring data quality in a gridded population-based survey will be identical. Most data collection applications now include graphical dashboards to monitor patterns in survey responses and identify outliers in near real time. For teams that do not currently collect spatial data (i.e., GPS point locations during the listing or interviews) or do not produce bespoke maps for fieldworkers, supervisors will need to familiarize themselves with a few new basic **spatial data-monitoring** protocols.

During mapping-listing, if fieldworkers mark up bespoke paper field maps, they should submit daily photographs of their work to their supervisor, and the supervisor should check that the markings are clear and consistent with survey protocols. If a GIS expert is part of the survey team, they might quickly compare the field map photographs against satellite imagery or OpenStreetMap to gauge the quality of the fieldwork.

If GPS coordinates are collected during the listing or interview steps, it is important that field supervisors plot the GPS points and IDs over satellite imagery or OpenStreetMap to confirm complete and accurate coverage of buildings (listing), or accurate identification of sampled households (interview). This option is now standard in most data collection apps, or can be performed in Google Earth.

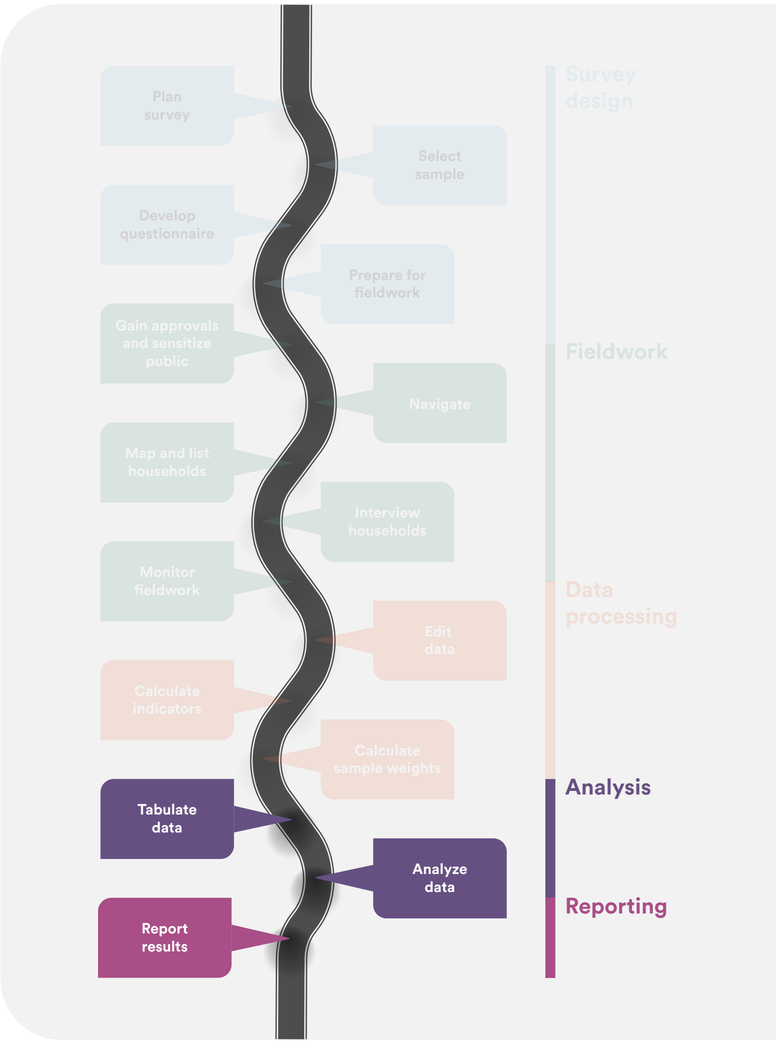
2.1.3 Data processing

After listing or interview data are collected, the data should be cleaned and indicators calculated. In a gridded population-based survey, data editing and the processing of paper or tablet questionnaires is identical to census-based surveys (see **Supplement A, Section SA.4.3**). Sample weights are also calculated in the same way in gridded population- and census-based surveys, with the exception that we use average household size to convert gridded population estimates to estimated households (or eligible individuals). There are slight additional variations of the weight formula for certain sample designs, which we explain below in **Section 2.2.1**.



2.1.4 Analysis and Reporting

There is no difference in the analysis or reporting of gridded population- versus census-based survey results.



2.2 Gridded population survey designs

2.2.1 Available designs

By the end of this section, you will be familiar with six gridded population survey designs, and their key strengths and limitations. Four of the six designs are possible with a standard census sample frame, and two are only possible with a gridded population sample frame. **Table 2.2** summarizes the six gridded population survey designs, as well as their accuracy, precision, and affordability based on a simple subjective scale of least-to-most desirable. (See **Supplement A, Section SA.2** for a refresher on the meanings of accuracy, precision, and affordability.)

In **Table 2.2** we score several of the survey designs as 10 (out of 15) in terms of their balance of accuracy, precision, and affordability, including the most common "two-stage, detailed-listing" design used in most routine national surveys, and the "two-stage, random-walk" design often used for rapid needs assessments and opinion polling. However, the "two-stage, area-microcensus (adaptive)" design is scored 12 (out of 15), indicating a "better" balance of accuracy, precision, and affordability, which we describe on the following page.

Table 2.2. Potential gridded population sample designs

Least desired → Most desired: 1 | 2 | 3 | 4 | 5

Sample design	Frame creation		Field visit 1	During listing	Field visit 2	Design score		Use case
1. Two-stage, detailed-listing	Census or gridded population	Segmentation and aggregation	Detailed listing *All eligible HHs or individuals*	Segmentation	HH sample and interviews	4 Accuracy 5 Precision 1 Affordability	10	• Routine multi-topic surveys • Evaluation and research
2. Two-stage, quick-listing	Census or gridded population	Segmentation and aggregation	Quick listing – dwellings only *Count front doors*	Segmentation	HH sample and interviews	3 Accuracy 5 Precision 2 Affordability	10	• Routine multi-topic surveys • Evaluation and research
3. Two-stage, random-walk	Census or gridded population	Segmentation and aggregation *(optional)*	No listing and interviews *Random walk from point*			1 Accuracy 4 Precision 5 Affordability	10	• Rapid needs assessments • Opinion polls
4. Two-stage, building SRS	Census or gridded population	Segmentation and aggregation *(optional)*	No listing and interviews *Simple random sample of buildings*			3 Accuracy 5 Precision 2 Affordability	10	• Rapid needs assessments • Opinion polls
5. One-stage, area-microcensus	Gridded population	Segmentation and aggregation	Full listing and interviews *HH microcensus*	Segmentation		5 Accuracy 2 Precision 3 Affordability	10	• Evaluation and research • Rapid needs assessments • Opinion polls
6. Two-stage, area-microcensus	Gridded population	Segmentation and aggregation	Partial listing and interviews *Staged HH microcensus*			5 Accuracy 4 Precision 3 Affordability	12	• Routine multi-topic surveys • Evaluation and research • Rapid needs assessments • Opinion polls

2.2.1 Available designs (cont'd)

Table 2.3 summarizes the number of real-world gridded population surveys that have been conducted as of early 2020, based on a research paper by Thomson et al., (2020). While additional gridded population surveys have been conducted since this publication, Table 2.3 provides a sense of who currently uses gridded population surveys and how they use them. See Section 1.4 for a description of each type of survey implementer. Next we review each of the six survey designs in detail.

Table 2.3. Gridded population surveys conducted in low- and middle-income countries before early 2020 by survey design and type of implementer (Thomson et al., 2020)

Survey design	Routine multi-topic surveys	Evaluation and research	Rapid needs assessments	Opinion polls
1. Two-stage, detailed-listing	1	2	-	-
2. Two-stage, quick-listing	-	-	-	-
3. Two-stage, random-walk	-	1	1	19
4. Two-stage, building SRS	-	-	-	-
5. One-stage, area-microcensus	-	5	-	13
6. Two-stage, area-microcensus	-	-	1	-

2.2.1.1 / Design 1: Two-stage, detailed-listing

National statistical organizations (NSOs) and many research and program evaluation experts (e.g., in development organizations) use multi-stage sample designs with detailed listing protocols to randomly sample households (or individuals) and measure demographic, social, economic, and health characteristics. When this design is based on a gridded population sample frame, there are generally two stages of sampling. In this manual, we refer to this design as a "two-stage, detailed-listing."

In the first stage, the planning team draws a sample of PSUs with probability proportional to the gridded population size (PPS). If average household sizes are known in different sub-regions (e.g., from a past survey), the planning team might choose to convert population estimates to household estimates before sampling PSUs. Next, the team reviews each sampled PSU over satellite imagery, and if a PSU clearly has more households than can be feasibly mapped and listed, they manually segment the PSU into approximately equal population segments along roads, rivers, and other physical features based on visual inspection of the satellite image. If the PSU clearly has too few habitable buildings, then the planning team either drops and replaces the PSU with a randomly selected back-up PSU, or aggregates the PSU with a randomly selected neighboring PSU.

2.2.1 Available designs (cont'd)

2.2.1.1 / Design 1: Two-stage, detailed-listing (cont'd)

During the first field visit, mapper-listers knock on the doors of every building and speak with residents, shopkeepers, or guards to generate a detailed listing of all eligible households (or individuals) in each building in the PSU. While segmentation during the creation of the sample frame generally results in sensibly sized PSUs for fieldwork, it is possible that the satellite imagery was outdated, or that the planning team misjudged vertical or high-density housing structures, and that further segmentation of PSUs is necessary by the mapping-listing team during fieldwork. In the second stage, households or individuals are sampled systematically or randomly from each PSU listing, and interviewers are sent to these households to administer the survey questionnaire.

This design is scored as "least desirable" in terms of affordability as it generally requires two field visits to each PSU by separate teams, and listers need to speak to people at every building in a large area, which requires substantial time and resources. Furthermore, results from a "two-stage, detailed-listing" survey are generally published many months after initial fieldwork.

Generating the detailed listing in this way is often thought to lead to highly accurate survey results, thus justifying the higher costs and longer timeframes. However, as populations become more mobile and the share of people living in informal and atypical arrangements increases in cities, detailed listings become less accurate because (a) urban residents are less likely to report informally and atypically housed neighbors to mapper-listers during brief interactions, and (b) urban residents are less likely than rural residents to know their neighbors to be able to describe them. Smaller household sizes and a greater likelihood of being away from home during the day are other reasons that listers are often unable to achieve complete listings in urban PSUs during their relatively short visit.

These challenges during the listing process mean that poor, vulnerable, mobile, and other "hidden" households are systematically omitted from the detailed listing, and are thus under-sampled during the second stage of sampling. For these reasons, we do not score the two-stage, detailed-listing design accuracy as "most desirable." However, we score this design as having the most desirable precision, because the random sample of households selected during the second stage across relatively large PSUs is most likely among the six described survey designs to result in a heterogeneous sample of listed households.

One situation where the "two-stage, detailed-listing" is highly desired and recommended is when the target population is rare, for example a vaccination coverage survey targeting children age 12–23 months, because it is more cost effective and statistically efficient to perform a detailed listing during an initial field visit than have interviewers waste their time and interview varying numbers of households during a second field visit (see, for example, recommendations for **WHO Vaccination Coverage Surveys**).

We are aware of at least three real-world gridded population surveys that have followed a two-stage, detailed-listing design, and these are summarized in **Table 2.3** and described by Thomson et al. (2020). Household sample probability weights (adjusted for non-response) for this design are calculated in the same way as for two-stage census-based surveys, although gridded population estimates (and, optionally, household-size estimates) are substituted for census household counts. Note that if segmentation is performed twice (during both frame creation and the mapping-listing step), then the weights include two segmentation terms.

2.2.1 Available designs (cont'd)

2.2.1.1 / Design 1: Two-stage, detailed-listing (cont'd)

$$w_{ijk} = \frac{P_k \div s_k}{n_k \times p_{jk} \div s_k} \times B1_{jk} \times B2_{jk} \times \frac{M_{jk}}{m_{jk}} \times \frac{n_k}{n_{k^*}} \times \frac{m_{jk}}{m_{jk^*}}$$

Where:

P_k is the estimated population in stratum k according to the sample frame

p_{jk} is the estimated population in PSU j in stratum k according to the sample frame

s_k is the average household size in stratum k according to a census or past survey

$B1_{jk}$ is the number of equal-sized segments created in PSU j in stratum k during frame creation

$B2_{jk}$ is the number of equal-sized segments created in PSU j in stratum k in the field during mapping-listing

n_k is the number of PSUs sampled in stratum k

n_{k^*} is the number of sampled PSUs that were found and visited in stratum k

M_{jk} is the number of households enumerated in PSU j in stratum k during mapping and listing

m_k is the number of sampled households in PSU j in stratum k

m_{jk^*} is the number of sample households that responded in PSU j in stratum k

Box 2.1. 2020 Nutrition and Health Survey in Kaduna, Nigeria

Since 2014, the Nigerian government and its partners have performed routine national nutrition and health surveys (NNHS) to monitor child health (NBS, 2018). Despite using the robust "Standardized Monitoring and Assessment of Relief and Transition" (SMART) methodology, the NNHS surveys used the outdated and disputed 2006 census sample frame for PSU selection. By 2019, an alternative sample frame had emerged – the "bottom-up" gridded population dataset produced by the Government of Nigeria and partners under the Geo-Referenced Infrastructure and Demographic Data for Development (GRID3) program. To evaluate the reliability of the GRID3 gridded population dataset as a survey sample frame, and to gauge the feasibility of gridded population sampling, the National Bureau of Statistics, in collaboration with the National Population Commission, Kaduna Bureau of Statistics, Flowminder Foundation, and other partners, designed and implemented the following study.

Credit: National Bureau of Statistics, Kaduna, Nigeria

Alongside the 2020 NNHS in Kaduna state, a replicate gridded population survey was implemented based on a sample frame of GRID3 gridded population estimates. The same number of PSUs (36) were selected in Kaduna, and household enumeration and interviews were conducted by the same staff back-to-back with the census-based survey. The only difference in Kaduna's gridded NNHS was the use of a gridded population sample frame, satellite imagery PSU paper maps and the SWMaps navigation app to enumerate PSUs during the mapping-listing step. The same questionnaire was administered in both the gridded population survey and the main survey, including collection of anthropometric measurements, and both surveys excluded PSUs in insecure areas.

The implementing team shared the following experiences with gridded population sampling:

- Based on the household listings in 36 PSUs in Kaduna State, the GRID3 gridded population estimates were reasonably accurate.
- Mapper-listers were able to navigate within PSUs with SWMaps and printed paper maps.
- Previously, census-based enumerations of PSUs (Local Government Areas) were performed with local leaders in the field. To use paper maps and map apps in the field, practice-based trainings that included map reading skills were essential.

Skill level: Intermediate-GIS

Toolkit: (see Section 2.4)

- PSU selection: GridSample
- PSU review: ArcGIS
- SSU listing: Kobo Collect
- SSU selection: Stata
- Map production: ArcGIS
- Navigate to PSU: Google Maps and printed paper maps
- Navigate within PSU: SWMaps and printed paper maps
- Data collection: Kobo Collect

2.2.1 Available designs (cont'd)

2.2.1.2 / Design 2: Two-stage, quick-listing

A slight variation on Design 1 is the "two-stage, quick-listing." The main difference between a quick-listing and the detailed-listing of the previous design is that mapper-listers do not interact with residents during the quick-listing field visit, but instead they walk quickly through the PSU recording what appear to be dwelling front doors (e.g., homes, apartments). Mapper-listers, therefore, spend a fraction of the time in each PSU, reducing overall time and costs of the survey, however the completeness of the listing suffers because listers may not notice atypical dwellings (e.g., dwellings in a shop or hostel). A further limitation of this design is that it assumes each dwelling is home to just one household, which might generally be true in rural areas and middle- or upper-class urban neighborhoods, but is increasingly inaccurate among lower income urban households in densely populated cities (Thomson, Bhattarai, et al., 2021). For this reason, we score this design as less desirable on accuracy but more desirable for affordability, compared to Design 1. We are not aware of any real-world gridded population surveys using this design. The same sample probability weights formula is used as for "two-stage, detailed-listing", with number of dwellings enumerated in each PSU serving as a proxy for households enumerated M_{jk}.

2.2.1.3 / Design 3: Two-stage, random-walk

Another common survey design that is used primarily for rapid needs assessments and opinion polls is the "two-stage, random-walk" design. The main strength of this design is that two (or more) stages of sampling can be performed with just one visit to the field, minimizing survey time and cost and enabling analysis of results within days or weeks of fieldwork.

Like the two previous designs, the planning team draws a sample of PSUs with PPS, reviews the sampled PSUs over satellite imagery, then manually segments very large PSUs and replaces or aggregates very small PSUs. However, rather than performing a household listing before the second stage sample, interviewers are hired and trained to perform a random-walk, or similar randomized field-sampling protocol. In a random-walk survey, the planning team selects a starting point in each PSU, such as a recognizable landmark or intersection. From that point, interviewers follow a protocol of randomized turns and a specific skip pattern so that, in principle, households are selected at random.

There are several practical challenges with this design, however, that make accuracy least desirable among the six survey designs. First, interviewers may consciously or subconsciously avoid visiting (sampling) certain dwellings, for example, dwellings inconveniently located far from the road, or dwellings that appear unkempt or uninviting. Without a complete listing of eligible households (or individuals), survey managers have no way to identify or adjust for coverage biases that might be introduced by interviewers in the second-stage sample.

The "two-stage, random-walk" design has additional inaccuracy that is identical to a "two-stage, quick-listing". When interviewers operationalize the random-walk skip pattern and household selection protocol, they observe what appear to be dwelling front doors, and are thus unaware of any multi-household or atypical dwellings, resulting in a systematic under-sample of what are likely vulnerable and mobile households, especially in cities.

2.2.1 Available designs (cont'd)

2.2.1.3 / Design 3: Two-stage, random-walk (cont'd)

Depending on the random-walk route and skip pattern (e.g., sampling every 3rd versus every 10th household), the second-stage sample may not cover the entire PSU, and thus we score precision slightly lower compared to the previous two designs. When Thomson et al. (2020) reviewed existing gridded population surveys, more than 20 surveys – mostly opinion polls – had been conducted with this design (see Table 2.3). By the time this manual is in readers' hands, the number of "two-stage, random-walk" gridded population surveys will likely have multiplied because many of these polls are repeated annually.

In Design 3, a complete enumeration of all households in the PSU is not conducted, and thus the term M_{jk}/m_{jk} – representing the probability of household selection in PSU j – is represented as a simple random sample of m_{jk} of the $(m_{jk} - 1)(o_{jk} + 1) + 1$ households that the team walks past when they skip o_{jk} households between each selected household. Thus, the household sample probability weight (adjusted for non-response) in "two-stage, random-walk" surveys is:

$$w_{ijk} = \frac{P_k \div s_k}{n_k \times p_{jk} \div s_k} \times B_{jk} \frac{(m_{jk} - 1)(o_{jk} + 1) + 1}{n_k \times p_{jk} \div m_{jk}} \times \frac{n_k}{n_{k*}} \times \frac{m_{jk}}{m_{jk*}}$$

Where:

P_k is the estimated population in stratum k according to the sample frame

p_{jk} is the estimated population in PSU j in stratum k according to the sample frame

s_k is the average household size in stratum k according to a census or past survey

B_{jk} is the number of equal-sized segments created in PSU j in stratum k

n_k is the number of PSUs sampled in stratum k

n_{k*} is the number of sampled PSUs that were found and visited in stratum k

m_{jk} is the number of sampled households in PSU j in stratum k

m_{jk*} is the number of sample households that responded in PSU j in stratum k

o_{jk} is the number of households the team skips (walks past) between sampled households in PSU j in stratum k

Box 2.2. 2019 Election survey in Uruguay

The 2019 Uruguay presidential election provided a unique opportunity to evaluate the accuracy of gridded population sampling in an LMIC setting. This is because Uruguay's most recent 2011 census was robustly conducted, Uruguay's population has been relatively stationary between the census and national election, and voter participation is mandatory (with turnout over 90%). Researchers used these conditions to design a real-world experiment during Uruguay's 2019 first-round presidential election by comparing the results of a national gridded population survey versus a national census-based survey, using the election results as a reference (Ford and Kirwin, 2022). Both surveys followed the same stratified two-stage, random-walk design with 100 PSUs and approximately 1000 adult respondents each. To ensure comparability, both surveys were implemented by the same teams simultaneously using comparable protocols.

The study found that both surveys accurately predicted three standard election indicators: (1) the rank order of major candidates, (2) the share of votes for each major candidate, and (3) distance between the first two candidates. The gridded population survey, however, performed slightly better in terms of smaller error (RMSE) around point estimate predictions, and the margin between the first and second candidates.

The study offered the following conclusions and observations:

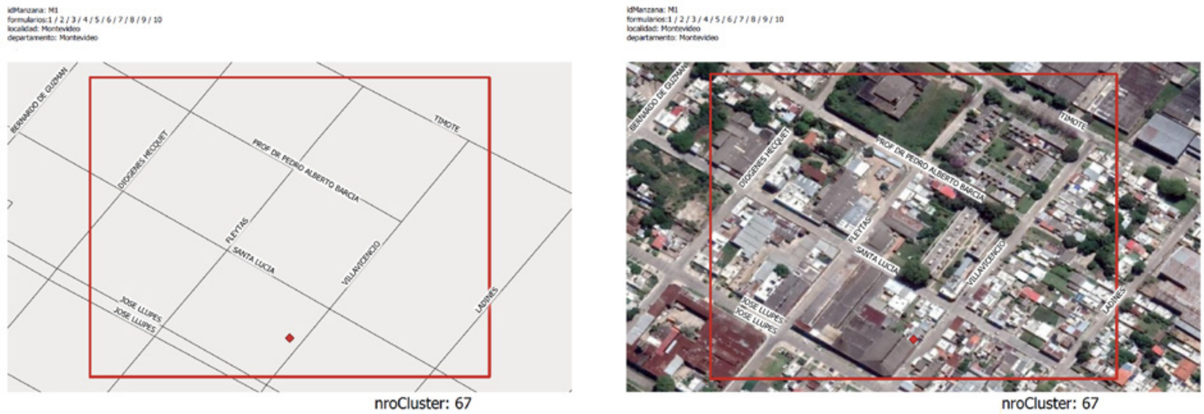
- The gridded population sample was as accurate, if not slightly more accurate, than the census-based sample.
- The implementation team successfully adapted a household field sampling approach which they had used in their census-based random-walk survey to the multi-cell PSUs generated by the GridEZ algorithm.
- Fieldworkers easily identify the boundaries of gridded PSUs based on roads, trees, structures, and other landmarks visible in satellite imagery maps that were uploaded to tablets as a GeoPDF.

Skill level: Intermediate-GIS

Toolkit: (see Section 2.4)

- PSU selection: GridSample
- PSU review: ArcGIS
- SSU selection: Modified random-walk protocol
- Map production: Google Earth and Agesic (GIS software)
- Navigate to PSU: Department, locality, and street names
- Navigate within PSU: GeoPDF in SurveyToGo and printed paper map
- Data collection: SurveyToGo

The survey implementation firm created two custom pdf/printed maps for each PSU. One map showed satellite imagery and the other showed street names with the starting point and indicators of the walking route. Within SurveyToGo, maximum radius geo-fences were set to warn interviewers when they neared the edge of the PSU, but they were instructed to navigate with maps.



Credit: Sarah Staveteig Ford and Matthew Kirwin, Montevideo, Uruguay

2.2.1 Available designs (cont'd)

2.2.1.4 / Design 4: Two-stage, building simple random sample (SRS)

Design 4, "two-stage, building SRS," is a variation on the "two-stage, random-walk" design with distinct advantages in terms of accuracy and precision. In this design, the survey planning team samples PSUs, performs segmentation and aggregation or back-up PSU selection, and then uses a tool like GeoSampler (discussed in **Section 2.4.1**) to manually select a simple random sample (SRS) of buildings within the PSUs based on recent, detailed satellite imagery.

This means that interviewers go to the field with a list of latitude–longitude coordinates that identify specific buildings in which a household (or individual) should be interviewed. This removes the possibility of conscious or subconscious bias during second stage sampling and increases the likelihood of household sampling across the entire PSU. This has the effect of increasing both accuracy and precision, and only slightly increasing time (for the survey planning team to select buildings, and for interviewers to navigate to pre-selected buildings).

A limitation of the GeoSampler tool is that the survey planning team has to select buildings manually, which can become arduous at scale. Although we are not aware of this survey design being implemented explicitly as described, we are aware of these protocols being used successfully in household simple random samples across relatively small study areas (e.g., Miller et al., 2020).

Some households will own multiple buildings, for example a main residence, a latrine, and a shed. If the latrine or shed were sampled, the field team would identify the owner and sample that household. Other buildings, such as offices, places of worship, shops, and schools will not be residential, so for each PSU 20-50% of buildings should be drawn as back-up and used at random to replace any non-residential buildings visited. To calculate accurate sample probability weights for this design, it is important that the questionnaire includes questions about (a) number of households per building, and (b) number of buildings per household.

2.2.1 Available designs (cont'd)

2.2.1.4 / Design 4: Two-stage, building simple random sample (SRS) (cont'd)

This enables the inclusion of additional terms in the household sample weights to adjust for the probability that household i was sampled in building q while ensuring that households that own multiple buildings are not oversampled. In practical terms, this means visually inspecting satellite imagery for each PSU and estimates the count of buildings to include the term G_{jk}/g_{jk} – representing the probability of sampling building q in PSU j. The term t_{ijk}/T_{ijk} represents the fact that households who own multiple structures have a greater probability of selection than those associated with a single building. Finally, the term M_{qjk}/m_{qjk} represents the probability of sampling households from building q in PSU j.

$$w_{iqjk} = \frac{P_k \div s_k}{n_k \times p_{jk} \div s_k} \times B_{jk} \times \frac{G_{jk}}{g_{jk}} \times \frac{t_{ijk}}{T_{ijk}} \times \frac{M_{qjk}}{m_{qjk}} \times \frac{n_k}{n_{k*}} \times \frac{m_{jk}}{m_{jk*}}$$

Where:

P_k is the estimated population in stratum k according to the sample frame

p_{jk} is the estimated population in PSU j in stratum k according to the sample frame

s_k is the average household size in stratum k according to a census or past survey

B_{jk} is the number of equal-sized segments created in PSU j in stratum k

G_{jk} is the number of buildings counted in satellite imagery in PSU j in stratum k

g_{jk} is the number of buildings selected to be visited in PSU j in stratum k

t_{ijk} is the number of buildings belonging to household i that were selected to be visited in PSU j in stratum k (usually 1)

T_{ijk} is the total number of buildings belonging to household i in PSU j in stratum k

M_{qjk} is the total number of households in building q in PSU j in stratum k

m_{qjk} is the number of households visited in building q in PSU j in stratum k

n_k is the total number of sampled PSUs in stratum k

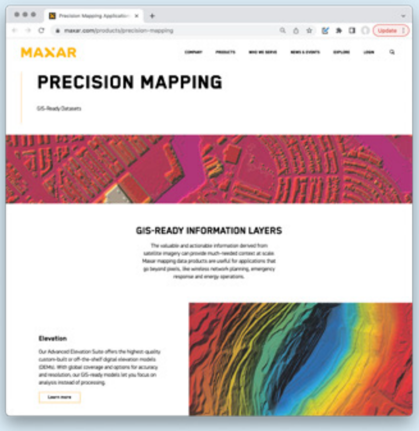
n_{k*} is the total number of sampled PSUs that were found and visited in stratum k

m_{jk} is the number of sampled households in PSU j in stratum k

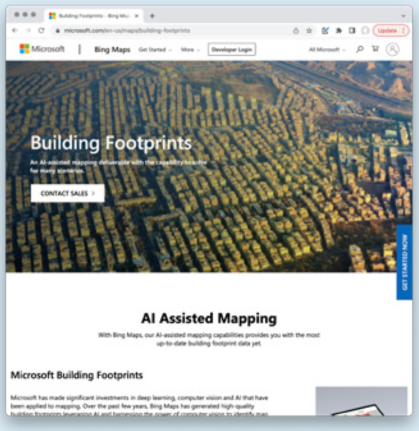
m_{jk*} is the number of sample households that responded in PSU j in stratum k

Box 2.3. Using building footprints as sample frames

Building footprint datasets are increasingly available, generated from satellite imagery with semi-automated feature extraction algorithms (e.g., [Maxar/Ecopia](), and [Bing Maps/Microsoft Building Footprints]()). Some survey researchers might consider using these building datasets in place of a listing as a second-stage sample frame. While both the completeness and accuracy of building footprint datasets are improving, the feature extraction algorithms from which they are derived tend to underperform for rural buildings constructed from natural materials, and in high-density informal settlements where contiguous buildings are merged or small buildings are not detected. This means that use of building footprint datasets instead of satellite imagery could lead to the systematic under-sampling of vulnerable households.



Maxar/Ecopia



Bing Maps/Microsoft Building Footprints

2.2.1 Available designs (cont'd)

2.2.1.5 / Design 5: One-stage, area-microcensus

The "one-stage, area-microcensus" design means that very small PSUs created from grid cells are sampled with PPS, and every household (or eligible individual) in the PSU is included in the sample. Unlike the mapper-listers in the first two sample designs, interviewers in area-microcensus designs spend one or more full days in each PSU, building rapport with residents, shopkeepers, guards, and others. If informal or atypical households reside in the PSU, interviewers are far more likely to learn about them than would mapper-listers during their brief 10- to 15-minute interaction with people at each building. For this reason, we score accuracy as most desirable in this sample design, and affordability as more desirable.

This design also enables mapper-listers to include street-sleepers who had spent the previous night in the PSU into a general population survey, rather than conducting a separate data collection exercise, which is typical. Inclusion of populations who do not reside in usual dwellings is novel and potentially insightful. If you are considering the inclusion of street-sleepers in your survey, consider stratifying cities by areas where street-sleepers typically do and do not stay (e.g., deprived areas and non-deprived areas) to ensure a sufficient number of street-sleeper respondents.

Precision in this design is largely unknown because so few such surveys have been implemented. If we apply common logic that near neighbors are likely to be more similar than distant neighbors, then we would assume that the "one-stage, area-microcensus" design results in homogeneity (similarity) among respondents per PSU, and thus larger design effects (see **Supplement A, Section SA.3** for more about design effects). The size of design effects, however, will depend on the indicators of interest, spatial distribution of the indicators in the population, prevalence of the indicator in the population, and number of respondents per PSU.

A real-world comparison of "one-stage, area-microcensus" versus "two-stage, detailed-listing" sample designs in Kathmandu, Nepal found that area-microcensus sampling resulted in greater heterogeneity (diversity) of respondents per PSU, and thus lower design effects among socio-economic indicators because area-microcensus sampling included a greater number of mobile and vulnerable households that would have been missed during a two-stage listing process (Thomson, Bhattarai, et al., 2021). Demographic and health indicators, however, showed greater homogeneity and higher design effect in area-microcensus designs (Thomson, Bhattarai, et al., 2021). Given that limited information is available about design effects in real-world area-microcensus samples, and the likelihood of there being homogeneity across many indicators among near-neighbors, we assume fairly limited precision with this sample design, though more research is needed.

Another practical challenge of the "one-stage, area-microcensus" design with gridded population data is that imprecision in cell-level gridded population estimates results in variability in PSU actual population size, particularly for smaller PSUs (variance in population estimates are generally "smoothed out" as cells are aggregated into larger areal units). In practical terms, this means that a greater proportion of "one-stage, area-microcensus" PSUs (small target population) will typically require more segmentation and aggregation than "two-stage, area-microcensus" PSUs (larger target population). Even with substantial manual processing of PSUs using satellite imagery before fieldwork, interviewers will inevitably find variable numbers of respondents per PSU because some buildings will be non-residential, while others will have multiple households (or eligible individuals). This variability in number of respondents per PSU increases the statistical variance (e.g., confidence intervals) of indicator estimates during analysis.

2.2.1 Available designs (cont'd)

2.2.1.5 / Design 5: One-stage, area-microcensus (cont'd)

We are aware of at least 18 gridded population surveys that have used this design (see Table 2.3). Most were from opinion polls and the main reason for choosing this design was high accuracy while limiting resources spent on fieldwork. Three of these surveys were to explicitly study "one-stage, area-microcensus" sample designs (see Table 2.3). The standard household sample weight (adjusted for non-response) should be used for this design, though note that M_{jk}/m_{jk} – the probability of sampling a household in PSU j, will always equal 1 and can thus be ignored:

$$w_{ijk} = \frac{P_k \div s_k}{n_k \times p_{jk} \div s_k} \times B_{jk} \times \frac{n_k}{n_{k*}} \times \frac{m_{jk}}{m_{jk*}}$$

Where:

P_k is the estimated population in stratum k according to the sample frame

p_{jk} is the estimated population in PSU j in stratum k according to the sample frame

s_k is the estimated population in PSU j according to the sample frame

B_{jk} is the number of equal-sized segments created in PSU j in stratum k

n_k is the number of PSUs sampled in stratum k

n_{k*} is the number of sampled PSUs that were found and visited in stratum k

m_{jk} is the number of sampled households in PSU j in stratum k

m_{jk*} is the number of sample households that responded in PSU j in stratum k

Box 2.4. 2017 Surveys for Urban Equity (SUE) Study in Kathmandu, Nepal

The Surveys for Urban Equity (SUE) project, funded by the Global Challenges Research Fund, sought to answer a number of practical survey and data-related questions in modern dynamic urban settings (Elsey et al., 2018). One question was whether one-stage, area-microcensus household surveys were more likely to sample vulnerable and mobile populations (including slum dwellers) than the traditional two-stage, detailed-listing survey design (Thomson, Bhattarai et al., 2021). Simultaneous one-stage and two-stage gridded population surveys were drawn from a 2017 WorldPop gridded population dataset in Kathmandu Valley, Nepal, and respondents were compared in terms of demographic and socioeconomic status (SES) characteristics. While the study only resulted in one modestly sized sample of each design (30 one-stage and 30 two-stage PSUs with a combined target of 1200 households), the experiment provided exploratory evidence about one-stage, area-microcensus gridded population surveys.

Credit: Surveys for Urban Equity, Kathmandu, Nepal

The team reported that:

- The one-stage, area-microcensus sample included more mobile and vulnerable households (e.g., 6.3% non-family and 4.9% single mothers) than the two-stage, detailed-listing sample (e.g., 1.9% non-family and 3.2% single mothers).
- PSUs with slum areas were largely absent from both samples because neither sample was stratified within Kathmandu Valley, but slum areas were especially rare in the one-stage, area-microcensus design. Stratification by deprived/non-deprived areas could overcome this problem in both one-stage and two-stage samples.
- Among demographic indicators (e.g., marital status, employment status), design effects were larger in the one-stage, area-microcensus sample, indicating more clustering and less statistical information about the population, while the opposite was true among SES indicators (e.g., urban poverty index, migrant head of household).
- The estimated survey cost per household was US$59 in the two-stage detailed-listing design and US$45 in the one-stage, area-microcensus design, with most of the cost savings attributed to having one field visit instead of two.
- Field staff skills in both of the SUE gridded population surveys were similar to previous conventional census-based surveys implemented by the local partner (HERD International), with the exception of digital map production and use of digital navigation apps in the field.

Skill level: Intermediate-GIS

Toolkit: (see Section 2.4)

- PSU selection: GridSample
- PSU review: ArcGIS
- SSU selection: Excel
- Map production: ArcGIS
- Navigate to PSU: MAPS.ME and Google Maps
- Navigate within PSU: GeoODK and printed paper map
- Data collection: GeoODK

2.2.1 Available designs (cont'd)

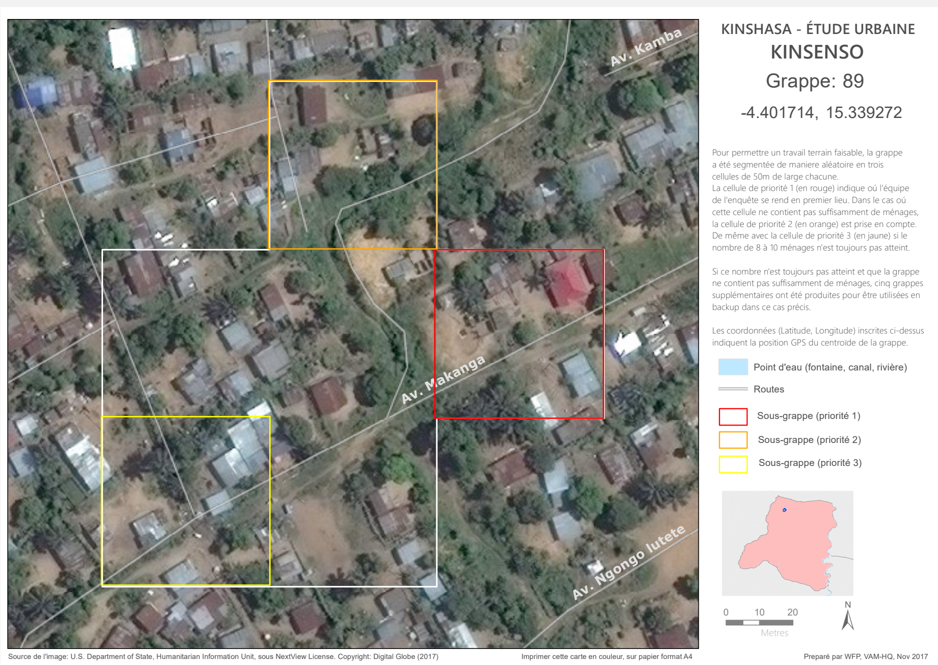
2.2.1.6 / Design 6: Two-stage, area-microcensus

The "two-stage, area-microcensus" design (which follows an adaptive sampling protocol in the field) maximizes accuracy, precision, and affordability, though currently is only feasible if there is a GIS expert in the survey planning team. In this design, typical EA-sized PSUs (e.g., 100–250 households) are sampled with PPS. We specifically recommend use of multi-cell PSUs (described in **Section 2.1.1.1**) because each PSU needs to be segmented into its component grid cells. Finally, the GIS expert randomly orders the component grid cells in the PSU before producing bespoke digital and/or paper PSU maps for interviewers to use in the field.

Interviewers are trained to navigate to the first grid cell in the PSU and interview all households (i.e., conduct an area-microcensus). If the target number of respondents per PSU is achieved or exceeded after this area-microcensus, the interviewer is done interviewing in the PSU. However, if the target number of respondents is not achieved, the interviewer proceeds to the second grid cell and performs another area-microcensus. The interviewer continues performing area-microcensuses of grid cells until they run out of cells (i.e., the entire PSU has been sampled), or the target number of respondents per PSU is achieved.

Compared to "one-stage, area-microcensuses," this design improves precision in two ways: first, by constraining the number of respondents sampled per PSU, and second, by sampling respondents across a larger geographic area and likely increasing the heterogeneity (diversity) of respondents per PSU. The design effects, unfortunately, are difficult to estimate because so few surveys have used this design, however the design effects are likely to be smaller than the "one-stage, area-microcensus" design but larger than the "two-stage, detailed-listing" design (see **Supplement A, Section SA.3** for a review of design effects).

This "two-stage, area-microcensus" design was developed by the World Food Programme to maximize accuracy and precision for a humanitarian needs assessment in an urban area, while limiting fieldwork to one visit due to insecurity (Thomson et al., 2020; WFP-VAM, 2018).



Credit:

World Food Programme Vulnerability Analysis and Mapping Unit, Kinshasa, D.R. Congo

See **Box 2.5** for details about the sample protocol and map features.

2.2.1 Available designs (cont'd)

2.2.1.6 / Design 6: Two-stage, area-microcensus (cont'd)

Although this is an adaptive sample design, the randomized selection of grid cells and the use of area-microcensus sampling by grid cell enables the standard weights formula to be used. By treating each grid cell in the PSU as a segment, and accounting for the possibility of sampling multiple segments, the sample weight is calculated as:

$$w_{ijk} = \frac{P_k \div s_k}{n_k \times p_{jk} \div s_k} \times \frac{B_{jk}}{b_{jk}} \times \frac{M_{jk}}{m_{jk}} \times \frac{n_k}{n_{k*}} \times \frac{b_{jk}}{b_{jk*}} \times \frac{m_{jk}}{m_{jk*}}$$

Where:

P_k is the estimated population in stratum k according to the sample frame

p_{jk} is the estimated population in PSU j in stratum k according to the sample frame

s_k is the average household size in stratum k according to a census or past survey

B_{jk} is the number of grid cells in PSU j in stratum k

b_{jk} is the number of grid cells sampled in PSU j in stratum k

b_{jk*} is the number of grid cells found and visited in PSU j in stratum k

n_k is the number of PSUs sampled in stratum k

n_{k*} is the number of sampled PSUs that were found and visited in stratum k

M_{jk} is the number of households enumerated in PSU j in stratum k during fieldwork

m_{jk} is the number of sampled households in PSU j in stratum k

m_{jk*} is the number of sample households that responded in PSU j in stratum k

Box 2.5. 2018 Urban Essential Needs Assessment in Kinshasa, D.R. Congo

The World Food Programme's (WFP) Vulnerability Analysis and Mapping (VAM) unit implemented an Urban Essential Needs Assessment in Kinshasa, D.R. Congo in 2018 to understand baseline food insecurity and access to essential services (WFP-VAM, 2018). The survey took place in five communes across Greater Kinshasa amidst brewing political tensions that had potential to erupt into full crisis.

With the last census conducted in 1984, the team sought an alternative sample frame. They used an official 2014 Kinshasa population count to generate a bespoke 50x50 m gridded population dataset. Using the GridSample R package (now defunct precursor to the GridSample2.0 algorithm) (Thomson et al., 2017), the team stratified the sample frame by commune (one commune was further divided into urban and peri-urban to form six strata), and they sampled 35 grid cells per stratum with PPS. Using the same R package, they then generated PSUs of approximately 500 people by grouping neighboring grid cells around each of the 210 sampled grid cells.

The WFP-VAM team then introduced an innovation that would set gridded population sampling apart from census-based sampling by leveraging the underlying grid cells: they developed and implemented the two-stage, area-microcensus design (Design 6) to minimize risk to field staff while avoiding the pitfalls of field-based sampling techniques (e.g., random-walk) which are known to lead to conscious or unconscious bias. In the WFP-VAM protocol, three grid cells were selected at random from each PSU and then randomly ordered, such that field teams performed an area-microcensus of regular residents living in structures in the ordered grid cells until they had interviewed at least 10 households per PSU. Sample weights were then calculated and applied to generate survey results as outlined in **Section 2.2.1.6**.

The WFP-VAM team had the following observations after implementing their survey:

- One visit to the field instead of two (due to no household listing) reduced the survey cost as well as the turnaround time between data collection and reporting.
- The inclusion of only regular residents (living in a structure) excluded a large number of homeless people including children. Future two-stage, area-microcensus surveys should consider including street-sleepers in vulnerability needs assessments.
- Just 2% of the sample was comprised of single-member households, partly because they were absent at the time of data collection and interviewers did not return on subsequent days due to security concerns. Response rates could be improved by giving advanced notice of interviews.

Skill level: Advanced-GIS

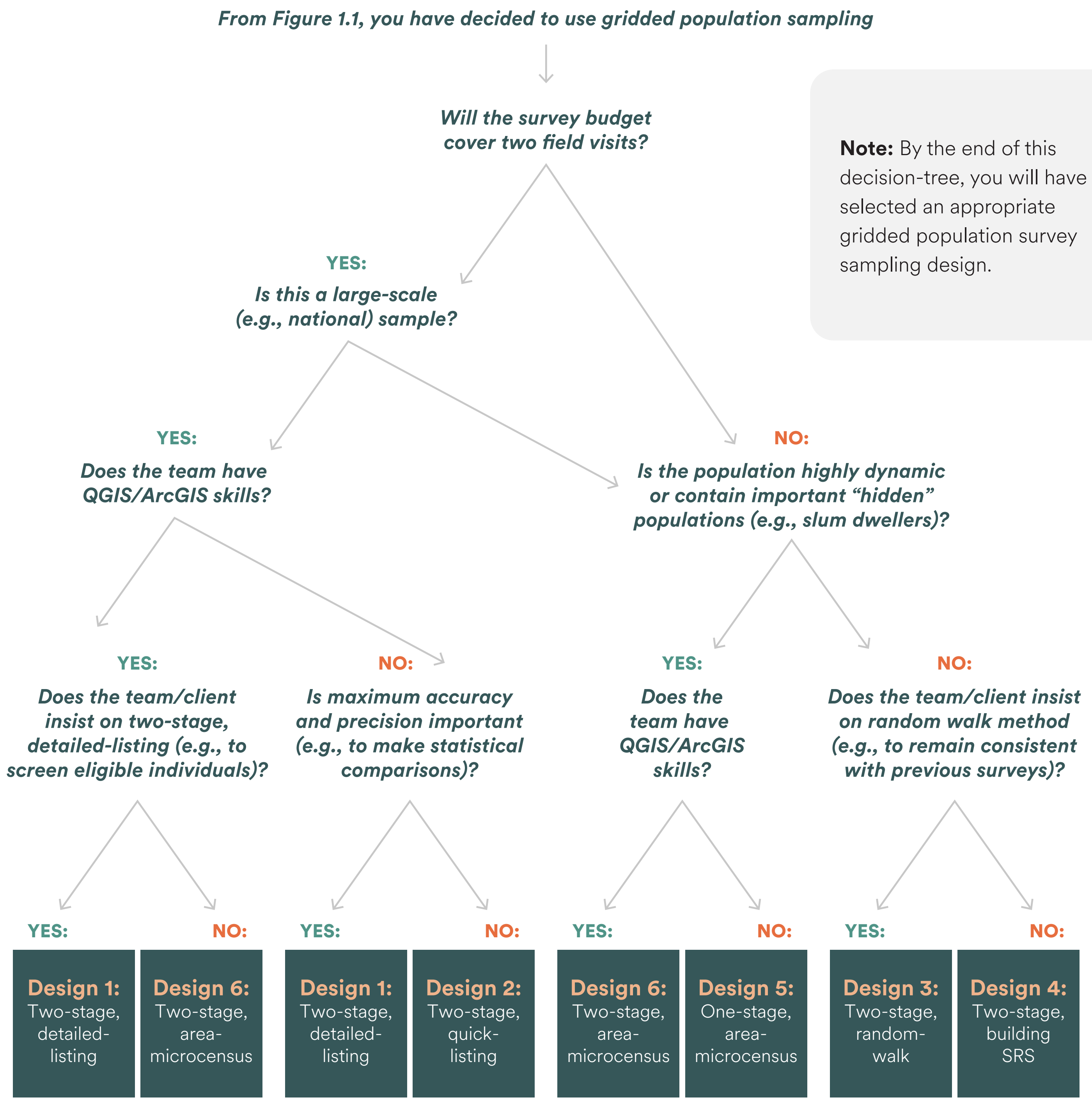
Toolkit: (see Section 2.4)

- Frame: R
- PSU selection: R
- PSU review: ArcGIS
- SSU selection: R (random selection and ordering of grid cells in PSUs)
- Map production: ArcGIS
- Navigate to PSU: Printed paper map
- Navigate within PSU: Printed paper map
- Data collection: ODK

2.2.2 Decide your gridded population sample design

Now that you are familiar with six potential gridded population survey designs, you are prepared to decide which design is most appropriate for your survey. Figure 2.2 guides you through each gridded population sample design decision, and starts with the assumption that you have consulted Figure 1.1 and confirmed that a gridded population survey is appropriate for you.

Figure 2.2. Decide which sample design to use



Note: By the end of this decision-tree, you will have selected an appropriate gridded population survey sampling design.

Key decision points include:

Will your survey budget cover two field visits?

Note that we do not necessarily recommend two field visits just because your team has the resources. It is possible to achieve high accuracy and precision while spending less time and money during one field visit if your team has the right skills.

Is this a large-scale sample?

"Large-scale" surveys can refer to either a large geographic coverage area (e.g., national survey), or a large sample size, or both. For national or multi-province surveys, for example, we steer you toward survey designs that maximize precision, and thus provide more statistical information about sub-groups in the population. We also steer you away from sample designs that require non-automated tools, such as GeoSampler (Design 4).

Is the population highly dynamic or does it contain important "hidden" populations such as slum dwellers, multi-household dwellings, refugees, economic migrants, or atypical housing arrangements?

If your sample focuses on one or more rapidly growing cities in Africa, Asia, or Latin America, you should answer "yes" to this question and we will steer you toward area-microcensus sample designs that are best equipped to identify and include "hidden" populations. We might also recommend other sample design options depending on your situation.

Does the team have Intermediate-level GIS skills?

Skills to manually modify spatial data and produce bespoke field maps are helpful to implement most gridded population sample designs, but these skills are essential to implement a "two-stage, area-microcensus" (Design 6).

Does your team/client insist on a "two-stage, detailed-listing" (Design 1)?

There might be several reasons to insist on this design. First, design effects are well understood for this design across many contexts and indicators, which is important to survey teams that produce national and other authoritative statistics. A second reason is for comparability over time. If a routine survey program has collected data with the "two-stage, detailed-listing" design for years, it is important that results be comparable across surveys over time. A third reason to insist on this design is if the survey's target population is rare and/or heterogeneously distributed across households. For example, a childhood vaccination survey might target only children age 12 to 23 months. The "two-stage, detailed-listing" ensures that eligible individuals are listed and sampled before interviewers are sent to the field so that (a) time and energy are not wasted on contacting households without any eligible individuals during the interview phase, and (b) a target number of eligible individuals are sampled in each PSU.

Does your team/client insist on a "random-walk" method (Design 3)?

Although the "two-stage, random-walk" method is generally not recommended, one reason to insist on it is that the survey is repeated routinely and results will be compared over time. A second reason is that the local survey implementer(s) are already familiar with a random-walk method, and retraining the field team(s) is unfeasible or too costly.

Is maximum accuracy and precision important, for example to make statistical comparisons?

This question is used to distinguish the classic "two-stage, detailed-listing" (Design 1) from the slightly less resource-intensive "two-stage, quick-listing" option (Design 2), though we generally recommend against Design 2.

2.3 Gridded population sample frames

2.3.1 Gridded population datasets

By the end of Section 2.3.1, you will have general knowledge of available gridded population datasets, the strengths and limitations of each, and which are more desirable for gridded population sampling and why. We also summarize what is involved in creating your own gridded population estimates. **Given that the choice of which gridded population dataset to use or create can influence the accuracy of the gridded population sample, this section is especially important if you are not already familiar with gridded population dataset options.**

2.3.1.1 / Availability and types of gridded population datasets

Gridded population datasets emerged in the early 2000s as satellite imagery, volunteered geographic information, and other spatial datasets became increasingly publicly available and spatially detailed. Early gridded population datasets tended to be coarser (e.g., 5x5 km grid cells) and have become increasingly finer in scale over time. At the time of writing, eight multi-country gridded population datasets were available in LMICs (Table 2.4).

2.3.1 Gridded population datasets (cont'd)

2.3.1.1 / Availability and types of gridded population datasets (cont'd)

Table 2.4. Summary of available gridded population datasets

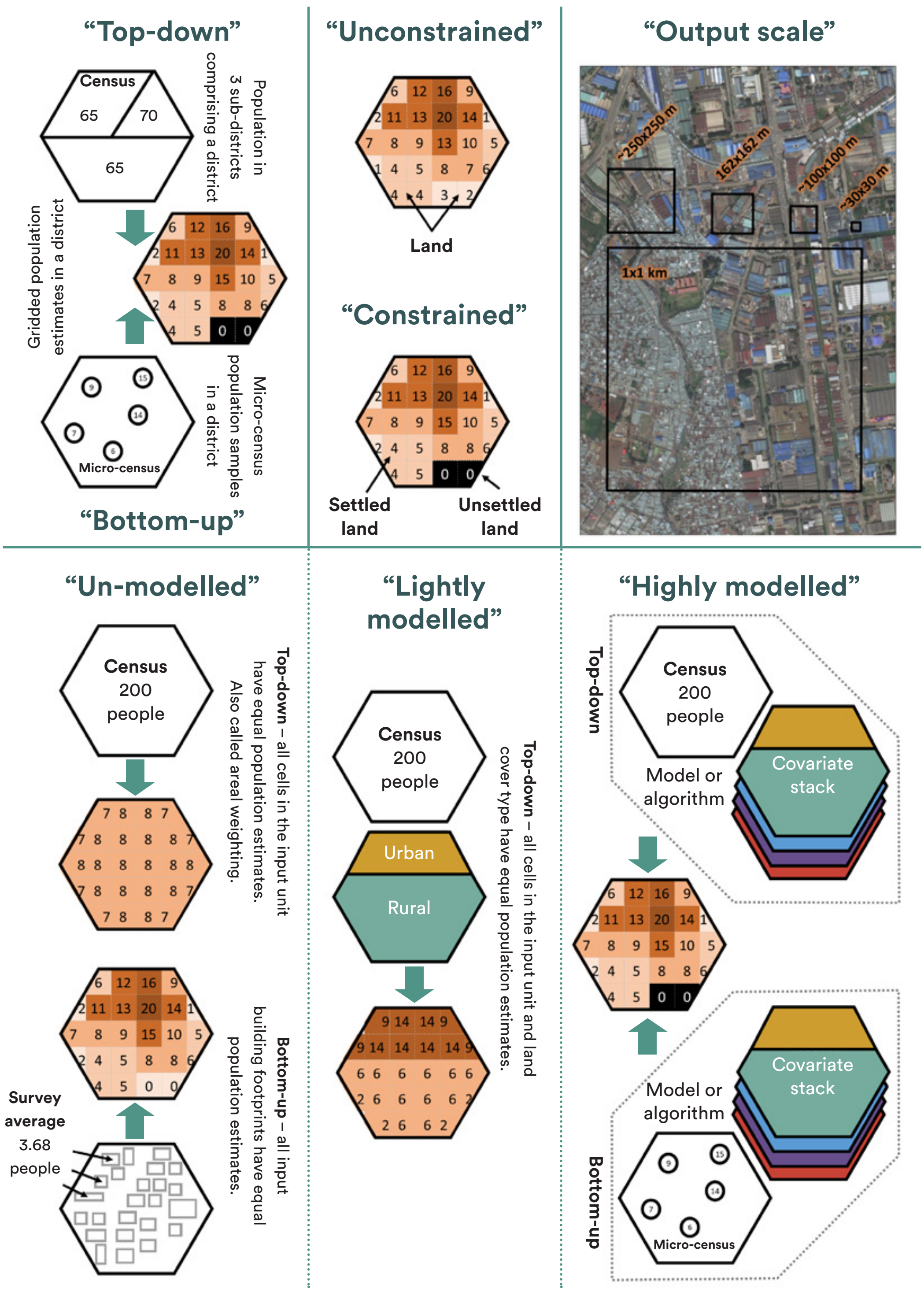
Dataset	Producer	Model approach	Output scale
Geo-Referenced Infrastructure and Demographic Data for Development (GRID3)	CIESIN (University of Columbia), UNFPA, WorldPop (University of Southampton), and Flowminder	Bottom-up, Constrained, Highly modelled	~100×100 m
Global Human Settlement Layer (GHS-POP)	European Commission Joint Research Centre (EC-JRC)	Top-down, Constrained, Lightly modelled	~100x100 m
Gridded Population of the World version 4 (GPWv4)	CIESIN (University of Columbia)	Top-down, Unconstrained, Un-modelled	~1x1 km
High Resolution Settlement Layer (HRSL)	Meta (formerly Facebook) and CIESIN (University of Columbia)	Top-down, Constrained, Lightly modelled	~30x30 m
LandScan Global	US Oak Ridge National Laboratory	Top-down, Constrained, Highly modelled	~1x1 km
LandScan HD	US Oak Ridge National Laboratory	Bottom-up, Constrained, Highly Modelled	~100x100 m
WorldPop Global Constrained (WPG-C)	WorldPop (University of Southampton)	Top-down, Constrained, Highly modelled	~100×100 m
WorldPop Global Unconstrained (WPG-U)	WorldPop (University of Southampton)	Top-down, Unconstrained, Highly modelled	~100×100 m

To understand how these datasets are made, let us briefly review the visual glossary of terms presented in Figure 2.3 and created by Thomson, Stevens, et al. (2021). "Top-down" gridded population datasets are derived by disaggregating census or other complete population counts to grid cells, while "bottom-up" estimates are derived from microcensus population counts or assumptions about the average population per building. Datasets are referred to as "unconstrained" when non-zero population estimates are provided for all grid cells on land including vast deserts and forests, while "constrained" gridded population datasets have estimates in only those grid cells that are classified as settled or built-up.

2.3.1 Gridded population datasets (cont'd)

2.3.1.1 / Availability and types of gridded population datasets (cont'd)

Figure 2.3. Glossary of terms to understand the characteristics of gridded population datasets, reproduced with permission from Thomson, Stevens, et al. (2021)



2.3.1 Gridded population datasets (cont'd)

2.3.1.1 / Availability and types of gridded population datasets (cont'd)

"Output scale" refers to the size of the grid cells in which population estimates are made. Most gridded population data-producers define grids based on the decimal degree system, which means that grid cells cover smaller areas and are elongated near the poles. This is why you often see grid cell sizes described as approximations, for example, ~100×100 m at the equator.

An important distinction among gridded population datasets is the degree to which the outputs are modelled. "Un-modelled" gridded population datasets are created through direct disaggregation or aggregation based on simple assumption and no auxiliary datasets. "Lightly modelled" gridded population datasets involve simple direct disaggregation, but make use of an auxiliary dataset such as land cover type to vary the population disaggregation. "Highly modelled" datasets are created with a geo-statistical model or geographic algorithm that uses multiple auxiliary datasets, and often include a measure of model accuracy or output uncertainty. For a less technical review of gridded population datasets and their applications, see 'Leaving No One Off the Map' by the POPGRID Data Collaborative (2020), or see Leyk et al. (2019) for a more technical review.

2.3.1.2 / Accuracy of gridded population datasets

In household surveys, we are concerned about the accuracy of gridded population datasets at the scale of PSUs. For simplicity, let us consider the size of a two-stage PSU as approximately the size of a census EA or neighborhood, and of a one-stage PSU as the size of a city block. Few accuracy assessments have been performed on gridded population datasets at these fine geographic scales, and any existing assessments tend to be in high-income countries where spatially detailed and reliable population data are available (see, for example, Bustos et al. (2020) who compared five gridded population datasets in Sweden). However, a few relevant accuracy assessments are available in LMICs including a comparison of nine gridded population datasets against field-referenced population counts in slum areas in Kenya and Nigeria (Thomson, Gaughan, et al., 2021), a comparison of four gridded population datasets against local government data in China (Xu et al., 2020), and grid cell-level accuracy assessments performed with simulated data (Thomson, Stevens, et al., 2021; Thomson et al., 2022). Visual story maps are also available about LMIC gridded population accuracy assessments for **technical** and **non-technical** audiences. There are several factors that contribute to the accuracy of gridded population data at fine geographic scale.

2.3.1 Gridded population datasets (cont'd)

2.3.1.2 / Accuracy of gridded population datasets (cont'd)

Factors outside the control of data producers:

- In top-down models, the age of the input population data and its level of aggregation (e.g., census EA versus sub-district) strongly influence fine-scale accuracy.
- The age, completeness, and detail of auxiliary datasets can also influence the accuracy of top-down gridded population estimates at fine scale. For example, if roads have not been fully mapped in slums and rural areas, then a top-down model will be less likely to allocate population to cells in those areas. As another example, night-time lights are highly correlated with population location and density; however, this dataset is generally only available in ~1×1 km grid cells and thus results in a "halo" effect (smoothing out beyond actual settlement boundaries) of the population allocation in models with finer scale output (e.g., ~100×100 m).

Factors within the control of data producers:

- Highly modelled datasets tend to be more accurate than less-modelled or un-modelled datasets. This is because more auxiliary datasets and more sophisticated assumptions are used to attribute varying amounts of the population to grid cells.
- Gridded population models which use building footprints as auxiliary data tend to be more accurate at fine geographic scale than models that do not include building footprints. This is because building footprints are among the only auxiliary datasets currently available that correlate with population density variation at fine geographic scale.
- We see from the HRSL dataset that modelling in extremely small grid cells (i.e., ~30×30 m) contributes to variability at the scale of city block or neighborhood, even when light modelling techniques are used.
- In countries where census data are extremely outdated (e.g., 15+ years old) or inaccurate, bottom-up models are likely to be more accurate than top-down models because they will make use of more recent microcensus population counts.

2.3.1 Gridded population datasets (cont'd)

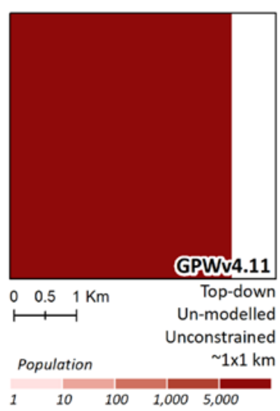
2.3.1.3 / Recommended gridded population datasets for survey sample frames

Based on the limited scientific evidence, our own experiences of conducting gridded population surveys, and speaking with other gridded population survey teams, we provide some recommendations about which gridded population datasets are better suited for household surveys. Note, however, that these recommendations might change as new fine-scale accuracy assessments are performed and as new gridded population datasets are released.

We do not recommend GPWv4 for gridded population sample frames, though there are good reasons to use this dataset for other purposes; our precaution is specific to gridded population surveys and fieldwork at the city block and neighborhood scales. Based on current evidence, we recommend five gridded population datasets for use as survey sample frames across diverse settings: HRSL, the new 2022 GHS-POP, WPG-C, LandScan HD, and GRID3. Two additional gridded population datasets are potentially suitable as sample frames under certain circumstances: LandScan Global and WPG-U. Each dataset and our recommendation rationale are described below.

Not recommended

GPWv4 is not designed for use at fine geographic scale. The ~1×1 km grid cells are far too large in many contexts to be useful as a PSU; for example, in many Asian cities tens of thousands of people live in a ~1×1 km area. Furthermore, population estimates are highly smoothed due to the lack of auxiliary datasets, and large portions of the population are allocated to unsettled areas by design. The main use case for GPWv4 is as an independent input to national and global models. The lack of auxiliary datasets is a strength in this case because it ensures that the population dataset is not artificially correlated with other model inputs. GPW is updated periodically with the most recent and finest-scale census datasets available, and these inputs are shared by GPW and used as the input population values for several other top-down gridded population datasets. GPWv4 methods are described by Doxsey-Whitfield and colleagues (2015) and publicly available to download from the website of the Center for International Earth Science Information Network (CIESIN) at the University of Columbia.

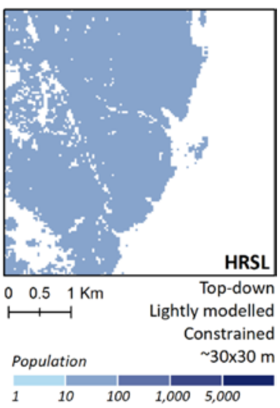


2.3.1 Gridded population datasets (cont'd)

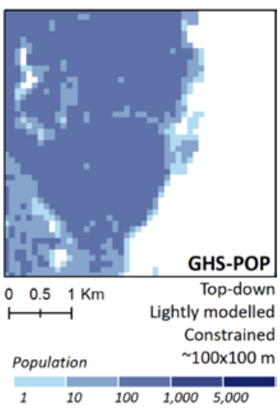
2.3.1.3 / Recommended gridded population datasets for survey sample frames (cont'd)

Recommended

HRSL tends to perform well in fine-scale accuracy assessments, particularly within urban areas and larger settlements. HRSL is produced by directly disaggregating census population counts to extremely fine-scale cells (~30×30 m) which have been classified as built-up. While HRSL is only lightly modelled, its ~30×30 m output promotes heterogeneity in population estimates as cells are aggregated to PSU. HRSL datasets are released for new countries periodically, though most countries had a 2020 HRSL gridded population estimate at the time of writing. HRSL methods are summarized on the websites of Meta (2022) and CIESIN (2016), and publicly available to **download** from the Humanitarian Data Exchange.



GHS-POP was re-released in 2022 by the European Commission Joint Research Centre (EC-JRC) at ~100×100 m resolution, and supersedes the previous GHS-POP ~250x250 m resolution dataset. The old GHS-POP dataset is not recommended as a household survey sample frame because grid cells were too aggregated, and the auxiliary dataset used to define built-settlement types was coarse, resulting in the exclusion of smaller settlements in rural areas and the overestimation of population counts in urban areas. However, the 2022 GHS-POP dataset leverages a new high-resolution layer of built-up areas derived from building footprints and AI modelling, as well as a dataset that distinguishes residential from non-residential built-up areas. While the lightly modelled methods detailed by Pesaresi et al. (2016) are unchanged, the new auxiliary data and ~100x100 m resolution of the 2022 GHS-POP dataset result in more accurate fine-scale population estimates and they are recommend for use as a survey sample frame. A strength of this dataset is consistency of the model outputs over time, which makes population estimates comparable across years. The updated dataset is publicly available to **download** from the Global Human Settlement Layer website.

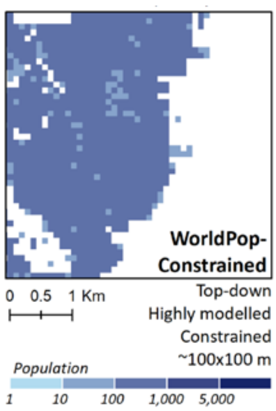


2.3.1 Gridded population datasets (cont'd)

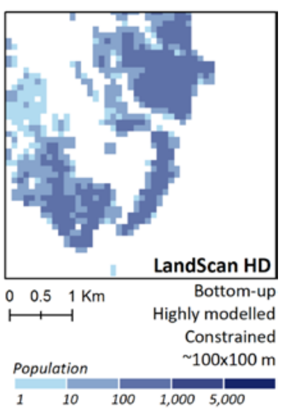
2.3.1.3 / Recommended gridded population datasets for survey sample frames (cont'd)

Recommended (cont'd)

WPG-C performs well in fine-scale accuracy assessment in Sub-Saharan Africa, but not necessarily other regions of the world (yet). The WorldPop Global-Constrained machine-learning model is considered to produce robust results with more than 20 standard auxiliary input datasets (see Stevens et al., 2015). Ten additional auxiliary datasets derived from Maxar/Ecopia building footprints (only available for Sub-Saharan Africa at the time of writing) are used to both constrain population estimates and to improve the accuracy of population distribution as model covariates. Where building footprint datasets are not available, the WPG-C dataset uses an urban settlement layer to constrain estimates, but not as a model covariate. Therefore, the accuracy of WPG-C data are almost certainly less accurate at fine scale in countries where building footprints were not included in the model (outside of Sub-Saharan Africa). These methods are described and visualized on the **WorldPop website**. WPG-C data are publicly available to **download** from the WorldPop website.



LandScan HD performs well in accuracy assessments, especially compared with top-down gridded population estimates in countries experiencing population redistribution due to conflict, natural hazards, or rapid growth. Therefore, it is recommended for use as a household survey sample frame. LandScan HD s a bottom-up, constrained, highly modelled ~100×100 m dataset developed by the US Oak Ridge National Laboratory (ORNL). The model uses estimates of people per building, along with two auxiliary datasets generated by ORNL – a high resolution building footprint layer, and a detailed neighborhood typology – as well as data from other sources about land use and infrastructure. At the time of writing, LandScan HD estimates were available for two dozen countries, most of which were grappling with conflict or population displacement. These datasets are available via the “Download” link at **LandScan’s main website**, and documentation is provided with each file.

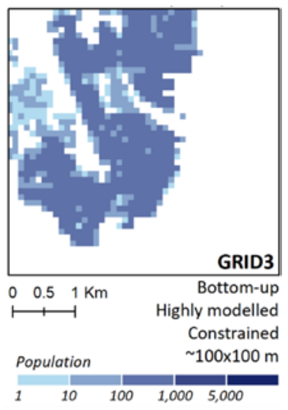


2.3.1 Gridded population datasets (cont'd)

2.3.1.3 / Recommended gridded population datasets for survey sample frames (cont'd)

Recommended (cont'd)

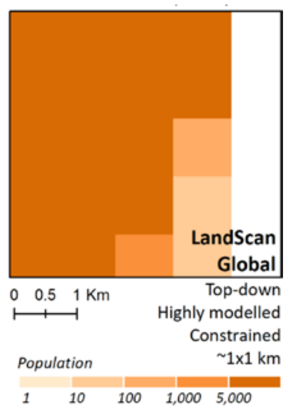
GRID3 performs well in fine-scale accuracy assessments, especially compared to top-down gridded population estimates in countries with an outdated or inaccurate census. This census-independent bottom-up model is based on recent population counts in a sample of small areas (microcensuses), and several auxiliary spatial datasets, which differ by country. In Nigeria, for example, only two auxiliary inputs were used to generate GRID3 population estimates – settlement type and an existing top-down gridded population layer – as detailed by Leasure et al. (2020). Some strengths of GRID3 are its hierarchical model which allows nested geographies to "borrow" information across spatial units and scales (e.g., PSUs within districts within provinces), and for model errors to be calculated at any scale from a single ~100×100 m grid cell to the largest administrative unit. GRID3 datasets are produced in close collaboration with an NSO, so government officials may be aware of, and especially willing to use, this dataset as the basis of a sample frame in official household surveys. However, GRID3 gridded population estimates have only been produced for a handful of African countries to date. GRID3 data are publicly available to **download** at the GRID3 Data Hub.



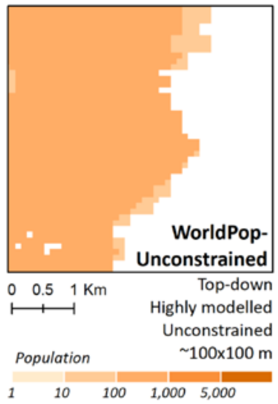
2.3.1 Gridded population datasets (cont'd)

2.3.1.3 / Recommended gridded population datasets for survey sample frames (cont'd)

Potentially suitable



LandScan Global is not designed for use at fine geographic scale, as its output is ~1×1 km resolution and too large to serve as PSUs in many urban contexts. Furthermore, LandScan Global estimates do not represent night-time residential population, but rather the 24-hour "ambient" population, which is the average of the day-time commuter population and night-time residential population. LandScan Global was initially designed to support city-scale disaster planning and response, enabling users to gain a general sense of the population at any moment that a disaster might strike. This dataset, however, has been available for longer than many other gridded population datasets, so it was widely used to generate sample frames in early gridded population surveys. Over the last decade, survey implementers have developed a range of techniques to segment LandScan Global's ~1×1 km grid cells to form PSUs, however most techniques were manual (see Thomson, Rhoda, et al., 2020). RTI International developed a proprietary set of algorithms to automate cell segmentation and selection for LandScan Global data as described by Cajka et al. (2018) and Chew et al. (2018). LandScan Global is produced by the US Oak Ridge National Laboratory, their methods are described by Dobson et al. (2000), and data are available to **download** at LandScan Global's website.



WPG-U estimates tend to be smoothed, resulting in relative inaccuracy at fine geographic scale, with overestimates of rural populations. The same model and 20+ auxiliary datasets are used to produce WorldPop Global-Constrained and -Unconstrained datasets, however, a key difference in how the model is executed makes WPG-C more accurate at fine scale. The population densities in the WPG-U model are derived from total population divided by the entire land area in an administrative unit, while WPG-C is derived from the total population divided by the *settled area only* in an administrative unit. This means that lower population density values are fed into the unconstrained model, capping the maximum population value that can be assigned to a given cell and effectively smoothing estimates. However, like LandScan Global, the WPG-U dataset has been available much longer than most other gridded population datasets, and in the past it was the finest scale (~100×100 m) and most accurate output available, so it has been used in a number of gridded population surveys. WorldPop methods are detailed by Stevens et al. (2015), and the data are publicly available to **download** from the WorldPop website.

2.3.1 Gridded population datasets (cont'd)

2.3.1.4 / Producing one's own gridded population dataset

NOTE: Definitions of user skill level in this manual:

- **Basic:** Team has used Google Earth and Excel, but not ArcGIS or QGIS
- **Intermediate:** Team is comfortable using SPSS, Stata, or SAS, but not ArcGIS or QGIS
- **Intermediate-GIS:** Team is comfortable using SPSS, Stata, or SAS, and includes an Intermediate-level GIS user
- **Advanced:** Team is comfortable programming in R or Python, but not ArcGIS or QGIS
- **Advanced-GIS:** Team is comfortable programming in R or Python, and includes an Intermediate-level GIS user

As outlined above (Section 2.3.1.3), we recommend using GHSL, GHS-POP (2022 version), WPG-C (in Africa where building footprints were included as auxiliary data), LandScan HD, or GRID3 gridded population datasets to generate survey sample frames because these datasets generally have accurate population estimates at fine geographic scale. However, there may be circumstances, for example when working with a sub-national government that has recently completed a regional census, when you might want to generate your own top-down gridded population dataset to derive a survey sample frame. Alternatively, if your survey covers a highly dynamic city for which you have intimate context knowledge, you may be able to apply assumptions about average people per building to generate a bespoke bottom-up estimate, as detailed below.

Box 2.6. 2021 Refugee Population-based HIV Impact Assessment (RUPHIA) in Uganda

The RUPHIA team conducted a cross-sectional, household-based survey using a multi-stage cluster sample design. This involved a detailed listing of households in 40 PSUs located across 11 refugee settlements. The detailed listing was essential in this survey because some settlements are home to non-refugees; the full listing enabled the refugee population to be listed and subset in each PSU before SSUs (households) were sampled.

While refugee populations were counted in the 2014 Ugandan Census, they were not included in the main census population counts and thus were expected to be under-represented in all “top-down” gridded population datasets. Furthermore, the refugee population in Uganda has grown substantially since the last census, with people seeking refuge from South Sudan and the Democratic Republic of Congo. To monitor this special, and highly dynamic, population, UNHCR performs regular population censuses of Uganda’s refugee settlements.

To overcome known inaccuracies in all available gridded population datasets, and to leverage the recent ground-referenced population counts, the RUPHIA study team generated a bespoke gridded population dataset using the WorldPop-peanutButter tool by disaggregating UNHCR population counts in spatially defined settlements based on the density of building footprints per ~100x100 m grid cell. A sample frame of PSUs of approximately equal population was generated from the gridded population dataset using the GridEZ R algorithm, and then sampled in R. These steps are documented in the Tutorials linked in Section 3. In 2021, RUPHIA field teams used Avenza maps to geofence PSUs and CSPro to list all households, and then conducted interviews with sampled eligible households and individuals.

The RUPHIA team shared the following experiences from their first gridded population survey:

- Field teams found the implementation process to be straightforward, and appreciated the use of Avenza maps and geofencing to stay within GridEZ boundaries.
- The survey planning team found it easy to review household listings using the households mapped in Avenza Maps, and to use the sample frame generated in GridEZ for replacement of unsuitable PSUs with a randomly selected neighboring PSU.

Skill level: Advanced-GIS

Toolkit: (see Section 2.4)

- Frame: Bespoke from UNHCR refugee settlement census using WorldPop-peanutButter “disaggregate” tool
- PSU selection: R
- PSU review: ArcGIS and QGIS
- SSU selection: CSPro
- Map production: ArcGIS
- Navigate to PSU: MAPS.ME and Google Maps
- Navigate within PSU: Avenza Maps app and printed paper map
- Data collection: CSPro

2.3.1 Gridded population datasets (cont'd)

2.3.1.4 / Producing one's own gridded population dataset (cont'd)

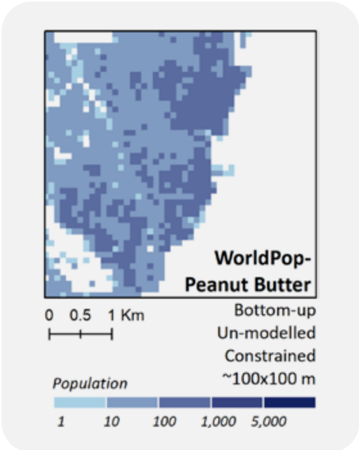
Top-down ~50×50 m or ~100×100 m model resources

Two toolkits are available for Intermediate- and Advanced-GIS users to disaggregate census-like population counts from administrative boundaries to grid cells:

- WorldPop-peanutButter "disaggregate" algorithm: This tool, created by the WorldPop team at the University of Southampton, is a web application that requires the user to upload a GeoJSON file of administrative units (i.e., polygons) with population counts. The user then optionally chooses whether to use building counts or total area covered by buildings in ~100×100 m grid cells (available in the tool) to proportionally disaggregate population totals. The user can also optionally set a threshold to exclude very small buildings (e.g., a latrine) and/or very large buildings (e.g., a factory) from being used in the model. Unfortunately, the pre-loaded building footprints datasets (from Maxar/Ecopia) were not available for all countries at the time of writing, so the tool mainly supports gridded population production in Sub-Saharan African countries.
- GHS-POP2G: This tool, created by the EC-JRC, requires the user to specify both a shapefile of administrative unit population counts (i.e., polygons), and a built-up area raster (i.e., grid cells) file to constrain estimates. This model disaggregates administrative boundary population counts uniformly into built-up ~50×50 m, ~100×100 m, or larger grid cells. The tool is available as a stand-alone application that can be downloaded and installed on a computer, or as an ArcGIS software extension, and can be applied anywhere in the world. However, the lack of auxiliary data in this model means that the gridded population estimates produced are uniformly disaggregated within polygons and settlement types, and will likely suffer in terms of fine-scale accuracy.

Bottom-up ~100×100 m model resources

- WorldPop-peanutButter "aggregate" algorithm: The WorldPop-peanutButter "aggregate" algorithm enables Intermediate- and Advanced-GIS users to apply three parameters to preloaded Maxar/Ecopia building footprints to estimate the total population in ~100×100 m grid cells. The three parameters are (1) average household size; (2) average number of households per building; and (3) percentage of buildings that are residential. While the algorithm provides default values for each parameter, these values represent national averages and should be updated to represent the setting(s) across the survey coverage area. It is plausible that a fairly accurate gridded population dataset could be generated if the user creates a few different bottom-up estimates for different types of sup-populations, and merges them. For example, a user with GIS skills could use (a) geographic boundaries to stratify areas with distinct population-building relationships (e.g., rural, urban-non-slum, urban-slum); and (b) context knowledge to specify sensible parameters for each stratum and merge the different population estimates across geographic strata.



2.3.1 Gridded population datasets (cont'd)

2.3.1.4 / Producing one's own gridded population dataset (cont'd)

Bottom-up ~100×100 m model resources (cont'd)

- **GHS-POP2G:** The same GHS-POP2G tool described above for top-down disaggregated modelling can also be used to aggregate a shapefile of household or population point data into a ~50×50 m, ~100×100 m, or larger gridded population dataset. This is a helpful tool if the survey team has access to a georeferenced population census.

Users with Advanced modelling and programming skills in R or Python might wish to manually apply existing open source algorithms to their own input population data to produce bespoke gridded population estimates, though this is an extremely resource-intensive undertaking and requires a learning curve, even for experienced modelers.

Top-down ~100×100 m model resources

Advanced users who wish to model their own gridded population dataset can access the WorldPop algorithm code and pre-processed auxiliary datasets from the WorldPop website (links below). The initial code was designed to produce unconstrained estimates. We strongly suggest including building footprint auxiliary data and modifying the code to produce constrained gridded population estimates to improve fine-scale accuracy. Below are the datasets, code, and methodological references that you will need in order to apply the WorldPop Global-Unconstrained or -Constrained algorithm to your input population data.

- **WorldPop algorithm code**
- WorldPop preprocessed auxiliary datasets:
    - **All non-building footprints**
    - **Building footprints**
- WorldPop methods
    - **Paper:** General modelling approach
    - **Website:** Constraining estimates

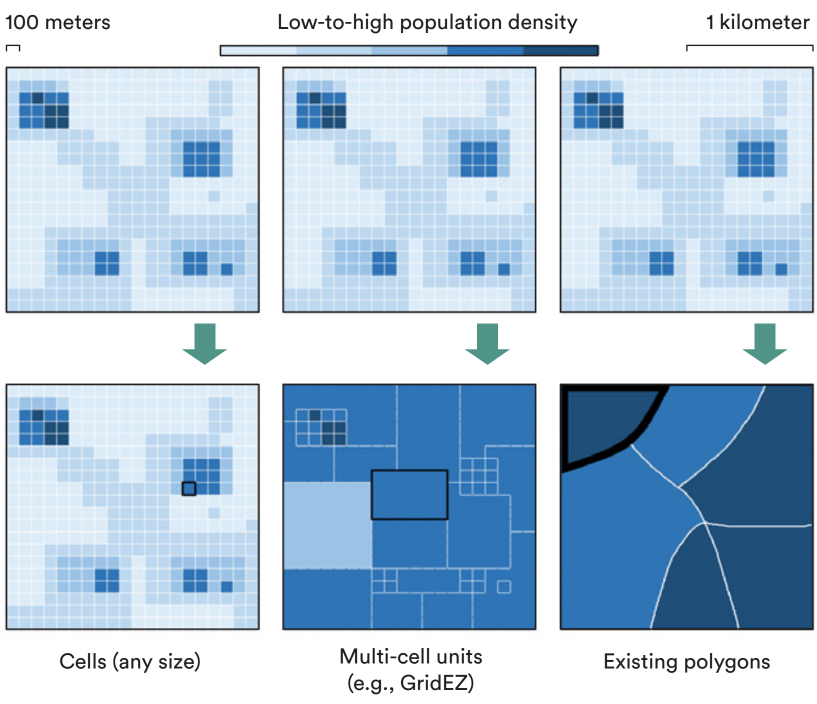
GRID3 customizes each gridded population model based on country government needs and available data. Advanced users may wish to replicate the GRID3 approach using code and descriptions about their bottom-up models in Nigeria and the D.R. Congo.

- **Paper:** GRID3 modelling approach and code used in Nigeria
- **Paper:** GRID3 modelling approach used in the D.R. Congo
- Methods to classify settlement types for different GRID3 model inputs:
    - **Report:** Mapping and classifying settlement locations
    - **Paper:** Using GIS and machine learning to classify residential status of urban buildings
    - **Paper:** Classifying settlement types from multi-scale spatial patterns of building footprints

2.3.2 PSU boundaries

By the end of this section, you will understand how gridded PSUs are similar to and different from census EAs, and the strengths and weaknesses of three types of gridded PSU units: cells, multi-cell gridded units, and existing polygons (see **Figure 2.4**).

Figure 2.4. Options to create a gridded population sample frame from an estimated gridded population dataset (reprinted with permission from Thomson et al., 2020)



While it is entirely possible to treat grid cells as PSUs and sample them directly with PPS, this is rarely done in practice. This is because census data and gridded population data are fundamentally different in form. Census EAs are (nearly) uniform in population size, but vary in geographic area, while in a gridded population dataset, each grid cell is (nearly) uniform in geographic area, but varies in population size. Modern household survey designs in most LMICs leverage the uniformity of population across EAs to draw clustered samples, moderate variance (design effects), and facilitate field logistics (see **Supplement A**). Therefore, when gridded population datasets are used in household surveys, grid cells are generally not sampled directly, and instead they are aggregated into units with similar population totals and varying geographic areas.

2.3.2 PSU boundaries (cont'd)

2.3.2.1 / Cells

When cells are used as PSUs in gridded population surveys, they have almost always been aggregated from their original resolution into a geographic size that is likely to contain approximately the PSU target population in the particular survey context (e.g., aggregate from ~100x100 m to ~200×200 m). For coarse resolution datasets (e.g., LandScan Global at ~1×1 km) this has been done via a bespoke machine-learning disaggregation model called Geo-Sampling (see Cajka et al., 2018; Chew et al., 2018). For fine resolution gridded population datasets (e.g., WorldPop at ~100×100 m), this is done by aggregating neighboring grid cells into larger cells using a GIS or programming language. As a result, gridded population sample frames composed of grid cells generally vary the grid cell geographic area by strata or region. Survey designers decide the appropriate geographic area of grid cells for each strata or region by visually inspecting satellite imagery first. Grid cell aggregation into larger units can be performed by GIS users (in ArcGIS or QGIS) and non-GIS users (in GridSample, R, or Python) (see **Section 2.4.1**).

2.3.2.2 / Multi-cell gridded units

Another way to generate a sample frame from grid cells is to use an optimization algorithm to group contiguous grid cells into units with similar population totals, and a maximum area threshold that ensures the fieldwork is feasible. At the time of writing, **GridEZ** was the main such algorithm to form gridded PSUs from cells, and was available as a stand-alone R package as well as a feature in the GridSample.org tool (both detailed in **Section 2.4.1**). GridEZ is designed to work with fine-scale gridded population estimates (e.g., HRSL, GHS-POP, WorldPop, LandScan HD, GRID3), and starts by creating rectangular blocks that meet the maximum area requirement, and sub-dividing blocks into smaller chunks and sometimes re-aggregating them until the target population is met (+/- a percentage of the target population) (see **Figure 2.4**). The algorithm includes three pre-set parameter combinations to produce GridEZ units that are small (target 75 people, maximum area 1×1 km), medium (target 500 people, maximum area 3×3 km), or large (target 1200 people, maximum area 5×5 km).

2.3.2.3 / Existing census EA polygons

In settings where census EAs or similar geographic boundaries have been mapped and are available as a polygon dataset, gridded population data can be used to update or create population estimates within those boundaries. This is done by aggregating cells within polygons via GIS or programming language.

Box 2.7. Creating and updating existing sample frames boundaries

What if the population estimates across your existing polygon boundaries vary widely?

Teams with GIS skills can use an ArcGIS extension called **GHS-SmartDissolve** created by the EC-JRC. This tool merges contiguous polygons to meet a target population and optional area threshold. This tool cannot divide polygons with population totals that exceed the target population. If your team has GIS capabilities, then you might manually divide polygons in areas where major population growth has occurred into smaller units along roads, rivers, or other physical features before running GHS-SmartDissolve.

Box 2.8. Creating polygon PSUs in the absence of existing census EA polygons

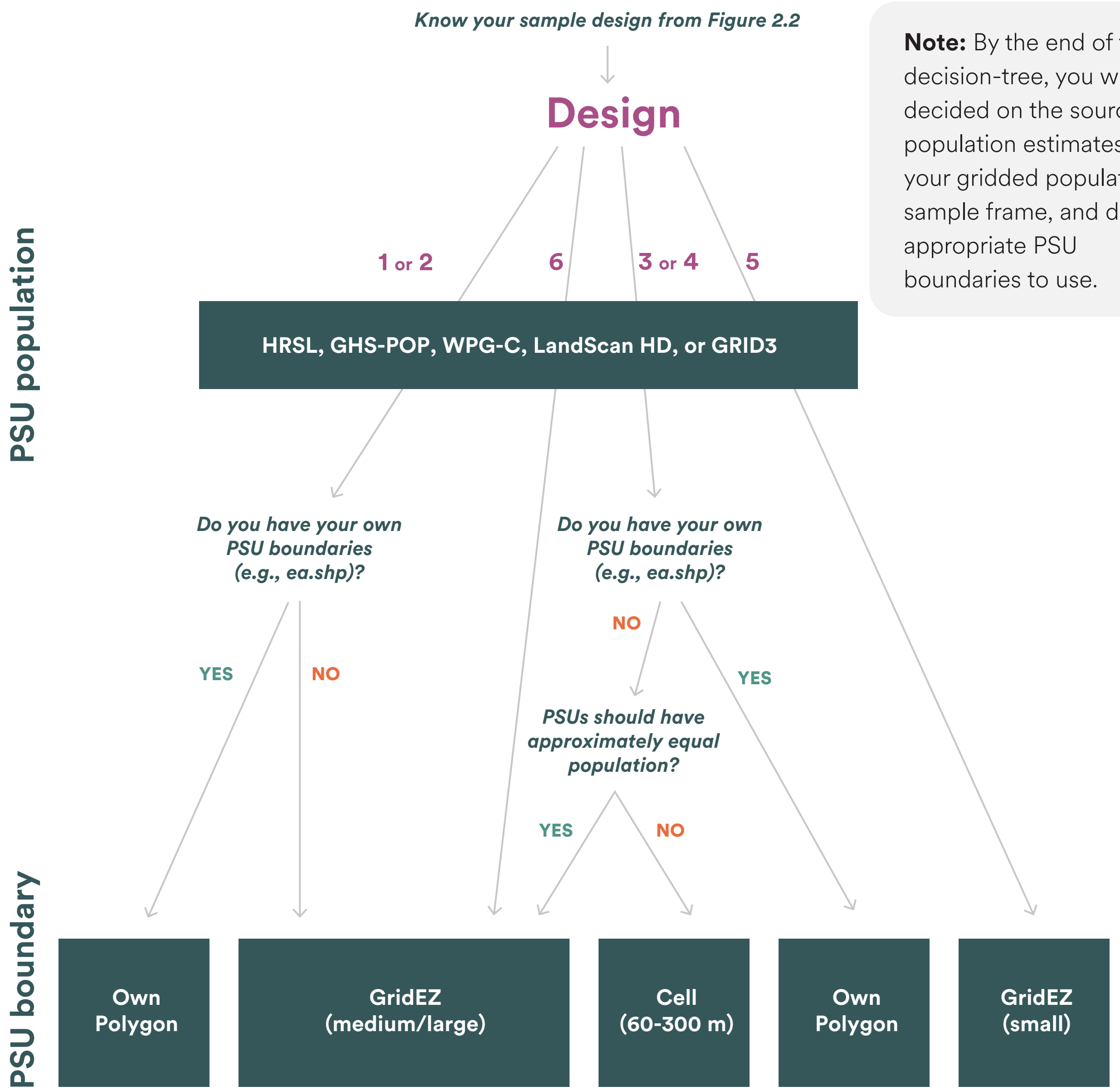
What if you want PSUs that follow roads, rivers, and other real-world features, but you do not have an old census (or other) boundary dataset?

At the time of writing, such a tool was not yet available but was under development. The preEA Tool under development by WorldPop and GRID3 uses line and boundary data from OpenStreetMap (e.g., roads and rivers) and administrative boundaries to divide a country (or other region) into the smallest polygons possible, estimate total population in each polygon based on a fine-scale gridded population dataset, and then merge the tiny polygons into EA-like units based on parameters of a target population and maximum area (Qader et al., 2021). If census EA boundaries exist, but are outdated, the preEA Tool will be able to preserve old census frames by only splitting boundaries where population growth greatly exceeds an EA target population. The preEA Tool is expected to be released as a QGIS plug-in, and is demonstrated with the release of **preEAs for Burkina Faso**.

2.3.3 Decide your gridded population sample frame

Now that you are familiar with eight available gridded population datasets, several options to generate your own gridded population data (Section 2.3.1), and three options to aggregate grid cells into sample frame units (Section 2.3.2), it is time to decide which dataset and sample frame unit is most appropriate for your survey. Use Figure 2.5 to decide the ideal composition of your gridded population survey sample frame.

Figure 2.5. Decide from which dataset and boundary to create your sample frame



Note: By the end of this decision-tree, you will have decided on the source of population estimates for your gridded population sample frame, and decided appropriate PSU boundaries to use.

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus

2.3.3 Decide your gridded population sample frame (cont'd)

From **Figure 2.2**, you know which of the six gridded population sample designs you will follow. If you indicated that you were conducting a large-scale (e.g., national, regional) survey in **Figure 2.2**, we encouraged you to select Design 1 or 2 (two-stage with a detailed- or quick-listing, respectively). In **Figure 2.5**, we recommend use of HRSL, GHS-POP, WPG-C (in sub-Saharan Africa), LandScan HD, or GRID3 data for Designs 1 and 2. At the time of writing, the tool available to Basic users for sample frame design and PSU selection (GridSample) did not include several of these datasets, so consider WPG-U as a potential substitute.

Note: Some users are hesitant to use GridEZ units as PSUs because boundaries do not align with real-world physical features. Rest assured that navigation and enumeration of PSUs with block-shaped boundaries is not as challenging as you may think! See **Section 3** Tutorials **E3** and **E4** for guidance.

If the survey team has access to an old census EA boundary file, we encourage you to use it to define PSU boundaries. Defining PSUs with existing polygons will be familiar to most survey planning and implementation teams, and therefore might reduce the learning curve of new tools and protocols. However, if polygon boundaries are not available, the next best option is to use GridEZ (or a similar tool) to group cells into EA-like PSUs.

GridSample.org provides two pre-defined GridEZ unit sizes that are appropriate for two-stage sampling:

- Medium GridEZ units which have approximately 500 people each and a maximum area of 3x3 km
- Large GridEZ units which have approximately 1200 people each and a maximum area of 5x5 km

To decide which of the GridEZ unit sizes is most appropriate in your setting, first determine how many households should ideally be located in each PSU, and second, divide the GridEZ target population by average household size to approximate the number of households per PSU (e.g., target 500 people per PSU ÷ 4.1 people per household = ~122 households per PSU).

In **Figure 2.5**, we make similar recommendations for Designs 3 and 4 which also require PSUs for two-stage sampling. As above, we recommend using existing polygon boundaries if they are available for ease of planning and fieldwork. However, given that Designs 3 and 4 tend to be used in rapid assessments in which some survey teams place less emphasis on complete and exclusive coverage of PSUs (particularly in Design 3 – random-walk), grid cells might be used for the sample frame instead of EA or GridEZ units.

While we do not necessarily endorse this practice, some teams define grid cells (e.g., between 60×60 m and 300×300 m), sample them with PPS, identify a start point near the geographic center of the sampled cell, and use a field app (e.g., SurveyCTO) to set a circular geo-fence around the start point that mostly, but not entirely, covers the sampled grid cell. As mentioned in **Section 2.3.2.1**, survey planners should visually inspect satellite imagery across the study area to decide an appropriate grid cell size, and potentially vary grid cell size by strata or regions according to the population density and distribution. If you are unsure whether to define a sample frame with grid cells or GridEZ units, we recommend use of GridEZ units because they will be more uniform in terms of total population per PSU.

Designs 5 and 6 (one-stage and two-stage, area-microcensus samples, respectively), are uniquely enabled by fine-scale gridded population datasets. Design 6 requires use of GridEZ units (or similar) to preserve the underlying gridded population dataset grid cell boundaries. For Design 5 (one-stage, area-microcensus sampling) most teams will find the small GridEZ units suitable with a target of 75 people per PSU and maximum area of 1×1 km. For Design 6 (two-stage, area-microcensus sampling), medium or large GridEZ units are appropriate.

2.3.4 Survey coverage and stratification boundaries

If your survey design team requires datasets to define the boundaries of the survey coverage area or strata in a GIS or software program, we offer a few suggested global datasets here. Local collaborators may have more up-to-date, accurate, or fit-for-purpose datasets to define boundaries in your survey context.

Administrative boundaries. When considering administrative boundary datasets, check the age and resolution (detail) of the boundaries. The global datasets linked here may lack important detail of boundaries at the local level, and are only updated periodically.

SALB. The Second Administrative Level Boundaries (SALB) dataset is maintained by the UN and reflects official first level (e.g. provincial) and second level (e.g. district) administrative unit boundaries in all countries.

GADM. The Global Administrative (GADM) database provides administrative boundaries down to the second, third, fourth, and sometimes even lower level administrative boundaries, but these are not necessarily official boundaries.

Urban/rural boundaries. The definition of urban and rural areas varies widely by country, so check with local collaborators about which boundary definitions make most sense in your survey context. Several of the newly revised Global Human Settlement (GHS) Layer datasets by the EC-JRC are worth considering to delineate urban–rural areas, and are endorsed by the UN Statistical Commission.

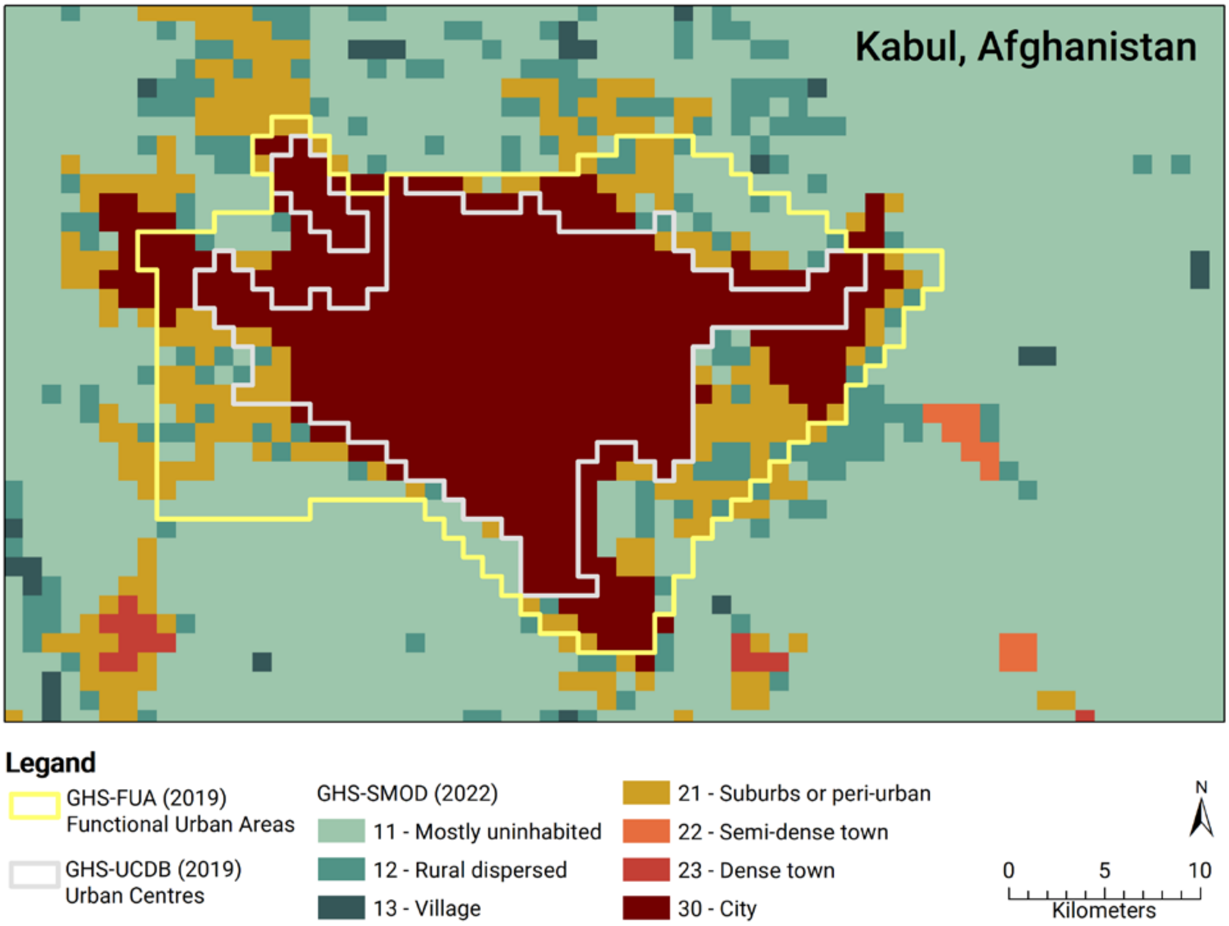
GHS-SMOD. The 2022 GHS Settlement Model (SMOD) dataset classifies ~1x1 km cells as one of seven urbanicity levels based on built-up area and population density. This dataset is formatted as a raster, so it must be converted to vector polygons to define area boundaries. Consider defining urban boundaries as all cells that are classified as larger than a village (code=21, 22, 23, 30), and rural boundaries with the remaining urbanicity levels. Alternatively, classify cities and large settlements (code=30), towns and semi-dense areas (code=21, 22, 23), and rural with the remaining urbanicity levels (code=10,11,12,13). See **Figure 2.6** to get a sense of how these options differ.

GHS-UCDB. The GHS Urban Centres Data Base (UCDB) is derived from 2019 GHS-SMOD cities and large settlements (code=30), and is formatted as a vector polygon of urban areas only, which are defined with ~1x1 km cells. Each of the more than 10,000 urban centers in this dataset are named, and dozens of secondary datasets have been summarized and joined to each city/town center in a geodatabase file (e.g., travel time to capital city, CO_2 pollution levels, greenness index, GDP, etcetera). GHS-UCDB boundaries do not reflect city administrative boundaries, areas of urban sprawl, or suburbs that might be considered part of "urban" areas, so only use this dataset to define urban centers.

GHS-FUA. The GHS Functional Urban Areas (FUA) dataset is an extension of the GHS-SMOD and GHS-UCDB datasets, and aims to characterize the "commuting zone" around cities, or what might commonly be referred to as the metropolitan area. These functional urban area boundaries are determined by the geographic size and population of the urban center, as well as GDP and travel time to its center. This geodatabase includes more than 2400 larger cities and metropolitan areas globally. See **Figure 2.6** for a visual comparison of GHS-FUA, GHS-UCDB, and GHS-SMOD.

2.3.4 Survey coverage and stratification boundaries (cont'd)

Figure 2.6. Visual comparison of three Global Human Settlement Layer datasets



2.4 Gridded population survey tools

2.4.1 Available tools

Section 2.4.1 provides an overview of each tool that might be used for gridded population surveys, including the level of skill required. Note that we focus on free and low-cost tools, or tools that are generally considered industry standards. Table 2.4 plots each tool to the survey step(s) where it is used.

NOTE: Definitions of user skill level in this manual:

- **Basic:** Team has used Google Earth and Excel, but not ArcGIS or QGIS
- **Intermediate:** Team is comfortable using SPSS, Stata, or SAS, but not ArcGIS or QGIS
- **Intermediate-GIS:** Team is comfortable using SPSS, Stata, or SAS, and includes an intermediate-level GIS user
- **Advanced:** Team is comfortable programming in R or Python, but not ArcGIS or QGIS
- **Advanced-GIS:** Team is comfortable programming in R or Python, and includes an intermediate-level GIS user

Word processor and spreadsheet

Basic/Intermediate/Advanced

All survey teams will likely use a word processor (e.g., Microsoft Word or OpenOffice Write) and spreadsheet tool (e.g., MS Excel or OpenOffice Calc) to calculate sample size, draft a budget, or generate documents such as contractor terms of reference, press releases, or final reports. In paper-based surveys, the questionnaire is generally developed and manually formatted in a word processor or spreadsheet. In tablet-based surveys, the original questionnaire wording and question order may be drafted in one of these tools.

GridSample.org

Basic/Intermediate/Advanced

GridSample.org (hereafter GridSample) is a free online tool for creating a gridded population sample frame and selecting PSUs. The tool contains preloaded gridded population datasets (WPG-U, WPG-C, GRID3), administrative boundaries (GADM), and urban/rural boundaries (2019 GHS-SMOD), and the GridEZ algorithm is embedded. It also allows users to upload bespoke boundaries to specify PSU, coverage, and/or strata boundaries. GridSample has a point-and-click interface that walks users through five screens to specify sample frame and sample design parameters, and then draw a sample of PSUs without GIS or programming skills. The website is designed for lower bandwidth settings to support surveys in LMICs. After a sample is drawn, users download a shapefile of the selected PSUs, along with an excel file with population counts and instructions to calculate sample weights.

2.4.1 Available tools (cont'd)

GeoSampler
Basic/Intermediate/Advanced

GeoSampler is a simple, free online tool created by Epicentre to randomly sample buildings from satellite imagery or a roads base map. The idea is that the user manually generates a series of points within a boundary, and then decides whether to keep each point based on whether it appears on top of a building. Users are able to (1) upload boundaries of their own sampling units or select from pre-defined administrative boundaries; (2) define a radius distance around each point to improve the chance of landing over a building; (3) download the sampled points as a .csv, .kml (to visualize in Google Earth), or .gpx (to upload to many navigation applications); and (4) save and return to the project via a unique URL. Epicentre also makes GeoSampler available as an R Shiny app that can be run on a local computer or server.

Google Earth
Basic/Intermediate/Advanced

Google Earth is a free desktop-based tool for visualizing very high resolution satellite imagery, plotting your own spatial data files over imagery (e.g., .kml, .shp, .geojson), and producing basic maps. Although Google Earth is technically not a GIS (which enables spatial data management and analysis), users can create field-ready paper maps of each PSU and publication-quality map images. A benefit of Google Earth is that it often contains the most detailed and updated imagery available for free. A limitation of Google Earth for users in low and intermittent bandwidth settings is that it requires your desktop to be connected to the internet to render imagery.

Map Campaigner
Basic/Intermediate/Advanced

Map Campaigner is an open-source tool created to manage OpenStreetMap enumeration campaigns. These campaigns generally take place in small areas, and require fieldworkers to canvass and map all features (e.g., buildings, wells, schools) in a small area. Map Campaigner allows users to upload a boundary file of all small areas to be canvassed, and automatically produces an A4 PDF map of each area for fieldwork. Although household survey PSUs are sometimes larger than OpenStreetMap campaign areas, we recommend use of this tool for non-GIS teams who wish to use OpenStreetMap-based PSU maps in the field.

ArcGIS and QGIS
Intermediate-GIS/Advanced-GIS

ArcGIS is a commercial GIS software for generating, cleaning, mapping, and analyzing spatial data, and QGIS is an open-source alternative with most of the same functionality. Both programs include extensive point-and-click user interfaces, and the ability to automate steps using Python code. Users who are familiar with one of these GIS programs can use it for monitoring, analyzing, and reporting spatial data in gridded population surveys. If the team has GIS skills, we recommend using one of these tools to produce paper field maps and digital maps for navigating on mobile devices.

SPSS, Stata, and SAS
Intermediate/Advanced

SPSS, Stata, and SAS are commercial statistical software programs commonly used by analysts across industries to analyze household survey data. All of these programs allow the user to draft code to clean, summarize, graph, and model tabular datasets. In SPSS and Stata, most functions can be implemented via point-and-click menus to aid users who are less comfortable drafting code. Users who are already familiar with one of these programs can use it for monitoring, analyzing, and reporting tabular data in gridded population surveys.

2.4.1 Available tools (cont'd)

R and Python
Advanced

R and Python are both open-source programming languages that have a range of applications across industries including statistical and spatial data management, analysis, and visualization. Compared to the statistical and geographic programs described above, R and Python are more "raw", often requiring more lines of code to achieve the same output, but R and Python are more flexible.

Users who are familiar with these programming languages may wish to manually run and adapt one or both of the following gridded population survey-related algorithms.

GridEZ (R) algorithm

The GridEZ R algorithm is publicly available on GitHub. The algorithm is designed to group gridded population cells into EA-like units of approximately similar population totals while restricting units to a maximum geographic area to ensure feasibility of fieldwork (see **Figure 2.4** and **Section 2.3.2.2**). The algorithm is designed to create contiguous GridEZ units within a geographic stratum (such as an administrative unit) and settlement type (to maximize population homogeneity within PSUs). The user must specify the input gridded population dataset, strata boundaries, and settlement layer. For constrained gridded population input data, ensure that unpopulated grid cells have the value zero, and not NA, to ensure that the algorithm produces contiguous PSUs across your coverage area with target population totals. The following two publicly available datasets can be used to define strata boundaries (**GADM**) and settlement types (**GHS-SMOD**) in GridEZ if the user does not have a better alternative (see **Section 2.3.4**).

GridSample2.0 (Python) algorithm

The GridSample2.0 Python algorithm supersedes the GridSample R algorithm released in 2016/17 by Thomson et al. (2017). Like the earlier algorithm, GridSample2.0 is publicly available. Note that GridSample2.0 is designed to work with GridSample.org, so users of the Python script need to manually generate parameters calculated on the website, and manually specify the survey coverage area boundary, any strata boundaries, and PSU boundaries (including PSU IDs and total populations).

2.4.1 Available tools (cont'd)

Field navigation applications

Basic/Intermediate/Advanced

We suggest having one or two dedicated applications for navigating between PSUs (i.e., with a roads network map) and within PSUs (e.g., with satellite imagery or OpenStreetMap base map).

Google Maps

Google Maps is a mobile application that provides free online navigation services using the Google roads base map visualized over high-resolution satellite imagery. Google Maps is good for navigating long distances, and might be appropriate for navigation within PSUs if the road base map is complete in the area. Google Maps allows for offline navigation, and it is available in the Google Play and Apple stores.

MAPS.ME

MAPS.ME is an open-source equivalent to Google Maps using the OpenStreetMap (OSM) roads base map, and permits offline navigation by storing OSM roads data to your device. Generally, major roads are accurately mapped in OSM, so MAPS.ME is useful for long-distance navigation (e.g., between PSUs). However, MAPS.ME is not recommended for local navigation because (a) roads are poorly mapped within OSM in some regions, and (b) the base map does not include satellite imagery to visualize where local road data might be missing. MAPS.ME is available in the Google Play and Apple stores.

SW Maps

SW Maps is a free mobile application that provides offline navigation, enabling the user to visualize PSU boundaries over Google satellite imagery or a roads base map. This app caches ("remembers") satellite imagery that was previously accessed via the device without actually downloading satellite imagery files. This enables the legal use of Google's current, very high resolution imagery, instead of relying on other sources of free satellite imagery that are often older and have coarser resolution. During fieldwork, the user might periodically connect their device to data to show their own location over the PSU and satellite imagery layers to aid or confirm local navigation. SW Maps is available on Android devices in the Google Play store, but not in the Apple store.

Avenza Maps

Avenza Maps is a paid service for offline household survey field navigation, enabling the user to visualize PSU boundaries and the device's location over a georeferenced GeoPDF online or offline. Although a free personal use version is available, geo-fencing (alerts when the user leaves the PSU boundary), multiple users, and uploading of more than three GeoPDFs requires a Pro license of US$135 per year.

Data collection applications

Several of the data collection tools described below link to Google Maps and/or enable map files (e.g., MBTiles, GeoTIFFs, GeoPDFs) to be preloaded for each cluster. This enables local navigation from within the data collection app, in many cases offline.

2.4.1 Available tools (cont'd)

Data collection applications

We describe a few common data collection applications for face-to-face household surveys. If your team prefers a data collection application that is not described here, it will likely work for your gridded population survey. All of the applications presented in this manual allow for collection of GPS points and photographs in addition to common text, numeric, multiple choice, one-of-many, and date questions. All of these applications also support different levels of access to the questionnaire and collected data according to role: (a) survey administration, (b) survey manager or supervisor, and (c) data collector.

KoBoCollect

Basic/Intermediate/Advanced

KoBoCollect is a free, open-source data collection tool that is popular among community-based organizations, NGOs, humanitarian organizations, and academic teams. We recommend this tool for basic users because it is free, includes free cloud server functionality, has an easy-to-use questionnaire builder for fairly complex questions including rule-based validation, allows offline data collection, and includes basic tools to monitor data completeness and quality in near real time. For survey teams that are not part of a supported humanitarian organization, KoBoCollect is limited to 10,000 submissions and 5GB of data storage per month which is plenty for most surveys.

SurveyCTO

Basic/Intermediate/Advanced

SurveyCTO is one of several data collection tools that are commercially available and widely used for field surveys. A subscription to SurveyCTO includes server set-up, technical support, ability to monitor both data submissions as well as paradata (e.g., time spent on each question), and to customize questionnaire layouts and internal checks. This tool is designed for Android, Apple, and other operating systems, and is well-suited for multi-lingual surveys and large surveys. SurveyCTO supports navigation to specific points and spatial data collection (points, lines, and polygons) over Google Maps (online) or an uploaded MBTile (offline).

ODK

Intermediate/Advanced

ODK is a free, open-source data collection tool that serves as the base for other tools (i.e., KoBoCollect, SurveyCTO) and is popular across sectors, including in humanitarian, development, and government surveys. Strong connections between the ODK and OSM communities means that ODK is well suited to collect or validate OSM data, and multiple spatial data types can be collected (points, lines, and polygons). ODK displays MBTiles for offline navigation and spatial data collection. However, more technical expertise is needed to use ODK than KoBoCollect or SurveyCTO, including skills to program the questionnaire as an XLSForm and set up a cloud server. Teams who are comfortable performing these tasks will be able to use ODK for free with support from the open-source community, though paid subscriptions are available if you would like to use ODK-provided cloud computing and support services.

2.4.1 Available tools (cont'd)

Data collection applications (cont'd)

Survey Solutions

Intermediate/Advanced

Survey Solutions is a suite of free tools developed by the World Bank and tailored to the needs of large-scale, routine government survey programs. Survey Solutions supports the collection of face-to-face CAPI surveys (including panel surveys). Technical expertise is needed to set-up a Survey Solutions server.

For survey administrators and managers, the Survey Solutions Questionnaire Designer tool is easy to use and offers a range of complex question options (e.g., nested rosters, barcode reader, audio recording). Unlike most data collection applications, Survey Solutions allows survey managers to sample households or individuals from the first-stage household listing and assign specific households to interviewers, all within the tool. Alternatively, the survey manager can simply specify a number of interviews to be conducted per PSU for use with a field-sampling protocol (e.g., random-walk). Survey managers also have the ability to monitor both data submissions as well as paradata (e.g., time spent on each question, data-collector location) for data quality.

Field-data collectors can be provided with high-resolution satellite images for their devices as GeoTIFF files to aid offline navigation within PSUs, and to enable spatial data collection (e.g. distance and area calculations). Furthermore, Survey Solutions allows geo-fencing so that data collectors are notified when they depart their assigned PSU.

CSPro

Intermediate/Advanced

The Census and Survey Processing System (CSPro) is a free, open-source tool designed by, and for, census and survey agencies to collect, manage, and tabulate field data. The tool was created by the US Census and DHS programs in 2000, building on several previous similar tools used by census and survey agencies. CSPro has been used in a majority of countries by hundreds of government and non-government teams. The tool is designed for use with Android operating systems for large surveys, and is accompanied by extensive e-learning materials and an active online community of practitioners.

Table 2.5. Overview of gridded population sampling and implementation tools, by survey step and minimum skill level required

KEY

- Basic
- Intermediate
- Intermediate-GIS
- Advanced

	Planning		Sampling							Map production		Navigation				Data collection				
	Word processor	Spreadsheet	GridSample	GeoSampler	R/Python	GridSample2.0 (Python)	GridEZ (R)	SPSS/Stata/SAS	ArcGIS/QGIS	Google Earth	Map Campaigner	Google Maps	MAPS.ME	SW Maps	Avenza Maps	KoBoCollect	SurveyCTO	ODK	Survey Solutions	CS Pro
Create sample frame			Basic		Advanced	Advanced	Advanced		Intermediate-GIS											
Draw PSUs with PPS			Basic		Advanced	Advanced		Intermediate	Intermediate-GIS											
Aggregate PSUs									Intermediate-GIS											
Segment PSUs									Intermediate-GIS	Basic										
Develop and test questionnaire	Basic	Basic																		
Prepare field maps									Intermediate-GIS	Basic	Basic									
Program questionnaire	Basic	Basic														Basic	Basic	Intermediate	Intermediate	Intermediate
Navigate to PSU												Basic	Basic							
Navigate within PSU														Basic	Basic		Basic	Intermediate	Intermediate	Intermediate
Map and list households																Basic	Basic	Intermediate	Intermediate	Intermediate
Draw SSUs (Designs 1, 2)		Basic		Basic	Advanced			Intermediate											Intermediate	Intermediate
Interview households																Basic	Basic	Intermediate	Intermediate	Intermediate
Monitor tabular data		Basic			Advanced			Intermediate								Basic	Basic	Intermediate	Intermediate	Intermediate
Monitor spatial data					Advanced				Intermediate-GIS	Basic						Basic	Basic	Intermediate	Intermediate	Intermediate
Edit and archive data		Basic			Advanced			Intermediate												
Calculate indicators		Basic			Advanced			Intermediate												
Calculate sample weights		Basic			Advanced			Intermediate												
Analyze tabular data		Basic			Advanced			Intermediate												
Analyze spatial data (optional)					Advanced				Intermediate-GIS	Basic										
Report results	Basic																			

2.4.2 Decide your gridded population survey sampling tools

Now that you are familiar with a range of tools used for gridded population survey sample selection and implementation, this section will help you decide which tools to use for your survey. Figure 2.7 guides you through key decisions to identify tool(s) to create a gridded population sample frame and draw PSUs. **Key decision points include:**

What is the skill level of your team?

If the team is not comfortable using GIS software or a programming language, we recommend using GridSample.org. GridSample.org currently provides two of the five recommended gridded population datasets to generate a sample frame. If the team has GIS skills, you can use ArcGIS/QGIS to create a sample frame with grid cells of a specified size, or within predefined polygon units. Note that if you use the ArcGIS or QGIS toolbox interface to perform each GIS operation (and not Python programming language), the sample selection process will be non-replicable, and you will have to draw independent samples in each stratum. These constraints are absolutely acceptable for many surveys, but might not be ideal for implementers of routine or large-scale surveys.

Do you plan to use GridEZ (multi-cell) PSU boundaries?

The GridEZ algorithm is programmed in R and available in the GridSample.org tool, so we recommend use of one of these tools.

Which gridded population dataset do you prefer to generate your sample frame?

If you prefer the HRSL, GHS-POP, or LandScan HD dataset to create a gridded population sample frame, you will not be able to use GridSample.org (at the time of writing). Instead we point you toward a GIS software or programming language to create the frame and select PSUs, if your team has these skills. If you would like to use HRSL, GHS-POP, or LandScan HD as the foundation of the sample frame and if it is not available in GridSample.org (as was the case at the time of writing), then we recommend using GRID3 if it is available or WorldPop Global-Constrained instead.

Table 2.6 and this web tool include all potential combinations of sample designs, sample frames, and tools for drawing your gridded population sample as described in this section. Before progressing to the next step, please verify that you have made a viable combination of decisions in previous decision trees. If you cannot find your combination, please return to Figure 2.2, Figure 2.5, and Figure 2.6.

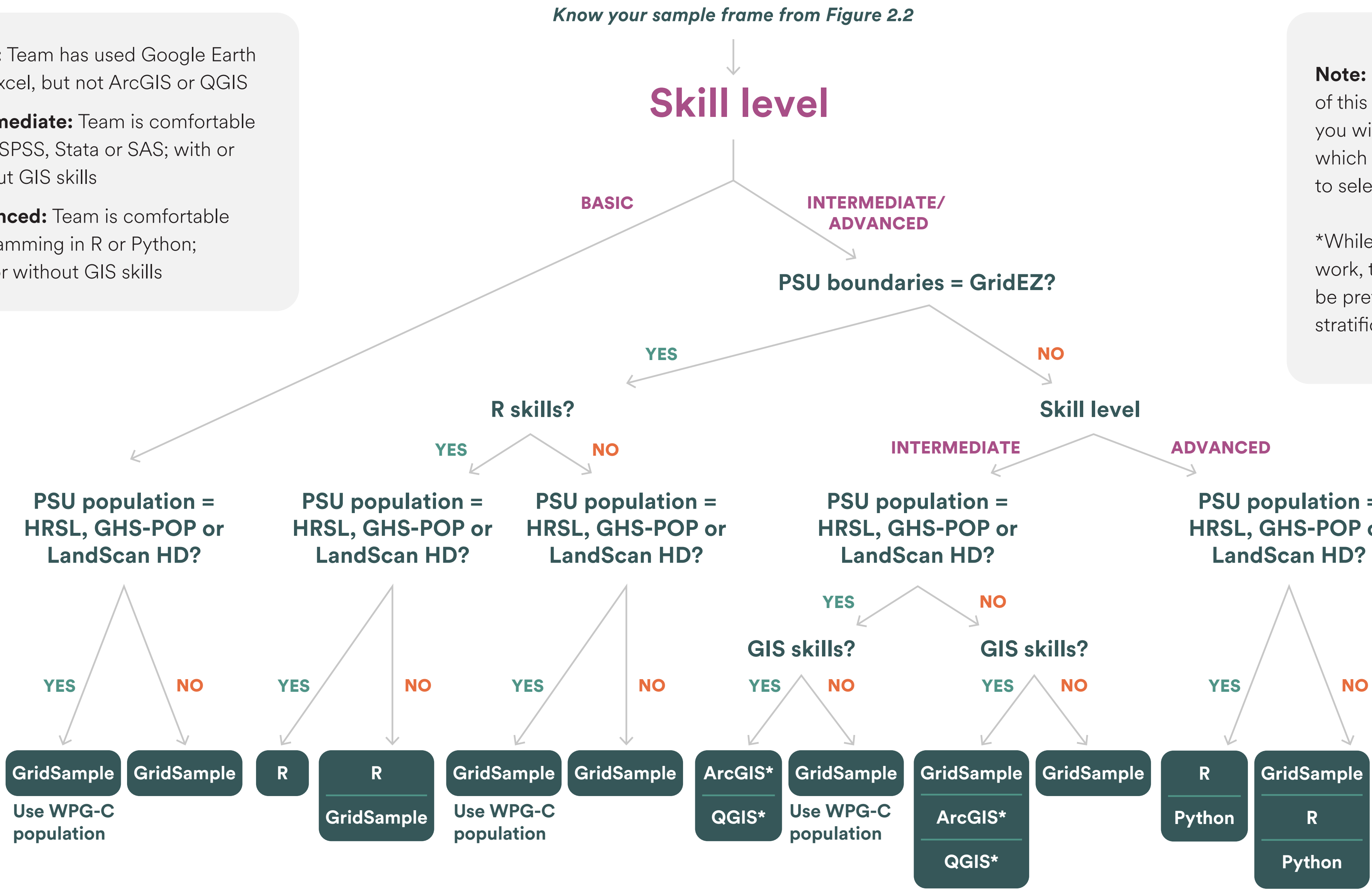
2.4.2 Decide your gridded population survey sampling tools (cont'd)

Figure 2.7. Decide which PSU sample selection tool to use

Basic: Team has used Google Earth and Excel, but not ArcGIS or QGIS

Intermediate: Team is comfortable using SPSS, Stata or SAS; with or without GIS skills

Advanced: Team is comfortable programming in R or Python; with or without GIS skills



Note: By the end of this decision tree, you will have decided which tool to use to select PSUs.

*While these tools work, they may not be preferred with stratification

Table 2.6. Summary of viable Sample Designs, Sample Frames, and PSU selection tools by skill level. Find your skill level, and confirm you have assembled a viable plan.

BASIC

Basic: The core survey team has used Google Earth & Excel, but not ArcGIS/QGIS

Design (Fig 2.2)	Tool-sampling (Fig 2.6)	Frame population (Fig 2.5)	Frame units (Fig 2.5)
1 or 2	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
1 or 2	GridSample	WPG-C/GRID3	Polygon
3 or 4	GridSample	WPG-C/GRID3	Cell
3 or 4	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
3 or 4	GridSample	WPG-C/GRID3	Polygon
5	GridSample	WPG-C/GRID3	GridEZ (Small)

INTERMEDIATE

Intermediate: The core survey team is comfortable using SPSS, Stata, or SAS, but not ArcGIS/QGIS

Design (Fig 2.2)	Tool-sampling (Fig 2.6)	Frame population (Fig 2.5)	Frame units (Fig 2.5)
1 or 2	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
1 or 2	GridSample	WPG-C/GRID3	Polygon
3 or 4	GridSample	WPG-C/GRID3	Cell
3 or 4	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
3 or 4	GridSample	WPG-C/GRID3	Polygon
5	GridSample	WPG-C/GRID3	GridEZ (Small)

Intermediate-GIS: The core survey team is comfortable using SPSS, Stata, or SAS, and ArcGIS/QGIS

Design (Fig 2.2)	Tool-sampling (Fig 2.6)	Frame population (Fig 2.5)	Frame units (Fig 2.5)
1 or 2	ArcGIS or QGIS	Any recommended*	Polygon
1 or 2	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
1 or 2	GridSample	WPG-C/GRID3	Polygon
3 or 4	ArcGIS or QGIS	Any recommended*	Cell
3 or 4	ArcGIS or QGIS	Any recommended*	Polygon
3 or 4	GridSample	WPG-C/GRID3	Cell
3 or 4	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
3 or 4	GridSample	WPG-C/GRID3	Polygon
5	GridSample	WPG-C/GRID3	GridEZ (Small)
6	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
5 or 6	GridSample		GridEZ-WPG/ GRID3

ADVANCED

Advanced: The core survey team is comfortable using R or Python, but not ArcGIS/QGIS

Design (Fig 2.2)	Tool-sampling (Fig 2.6)	Frame population (Fig 2.5)	Frame units (Fig 2.5)
1 or 2	GridSample	Any recommended*	GridEZ (Med/Lrg)
1 or 2	GridSample	WPG-C/GRID3	Polygon
1 or 2	Python	Any recommended*	Polygon
1 or 2	R	Any recommended*	GridEZ (Med/Lrg)
1 or 2	R	Any recommended*	Polygon
3 or 4	GridSample	WPG-C/GRID3	Cell
3 or 4	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
3 or 4	GridSample	WPG-C/GRID3	Polygon
3 or 4	Python	Any recommended*	Cell
3 or 4	Python	Any recommended*	Polygon
3 or 4	R	Any recommended*	Cell
3 or 4	R	Any recommended*	GridEZ (Med/Lrg)
3 or 4	R	Any recommended*	Polygon
5	GridSample	WPG-C/GRID3	GridEZ (Small)
5	R	Any recommended*	GridEZ (Small)
6	R	Any recommended*	GridEZ (Med/Lrg)

Advanced-GIS: The core survey team is comfortable using R or Python, and ArcGIS/QGIS

Design (Fig 2.2)	Tool-sampling (Fig 2.6)	Frame population (Fig 2.5)	Frame units (Fig 2.5)
1 or 2	ArcGIS	Any recommended*	Polygon
1 or 2	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
1 or 2	GridSample	WPG-C/GRID3	Polygon
1 or 2	Python	Any recommended*	Polygon
1 or 2	QGIS	Any recommended*	Polygon
1 or 2	R	Any recommended*	GridEZ (Med/Lrg)
1 or 2	R	Any recommended*	Polygon
3 or 4	ArcGIS	Any recommended*	Cell
3 or 4	ArcGIS	Any recommended*	Polygon
3 or 4	GridSample	WPG-C/GRID3	Cell
3 or 4	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
3 or 4	GridSample	WPG-C/GRID3	Polygon
3 or 4	Python	Any recommended*	Cell
3 or 4	Python	Any recommended*	Polygon
3 or 4	QGIS	Any recommended*	Cell
3 or 4	QGIS	Any recommended*	Polygon
3 or 4	R	Any recommended*	Cell
3 or 4	R	Any recommended*	GridEZ (Med/Lrg)
3 or 4	R	Any recommended*	Polygon
5	GridSample	WPG-C/GRID3	GridEZ (Small)
5	R	Any recommended*	GridEZ (Small)
6	GridSample	WPG-C/GRID3	GridEZ (Med/Lrg)
6	R	Any recommended*	GridEZ (Med/Lrg)

**Recommended gridded popoulation datasets include: HRSL, GHS-POP (2022), LandScan HD, WPG-C (in sub-Saharan Africa), and GRID3*

2.4.3 Decide your gridded population survey implementation tools

There are many effective combinations of tools that gridded population survey teams use, or could use, in the field. We present here a few options for a variety of skills, survey designs, and budgets, though feel free to integrate tools that you are already comfortable using. For fieldwork, you generally need tools to generate field maps, navigate to and within PSUs, and collect respondent data. We invite you to share your experiences with the gridded population survey community at www.gridpopsurvey.com.

Map production.

Although not necessary, GIS programs are extremely useful for multiple tasks involved in implementing a gridded population survey, for example to manage and visualize spatial data; produce bespoke paper field maps; produce MBTiles, GeoPDFs, or GeoTIFF files for offline navigation in apps; and monitor spatial data and paradata from the field. For teams without GIS skills, we recommend using Google Earth or Map Campaigner to produce paper field maps, Google Earth to visualize and monitor spatial data, and SW Maps to navigate offline in the field without the need for MBTiles or GeoPDF files.

Navigation.

We recommend the same navigation apps to all teams: MAPS.ME or Google Maps to navigate to PSUs, and SW Maps or Avenza Maps to navigate within PSUs.

Table 2.7. Comparison of select tools for collecting survey data

Data collection tool	Basic	Intermediate	Advanced	Free	Server included	Monitoring included
KoBoToolbox	✓	✓	✓	✓	✓	✓
SurveyCTO	✓	✓	✓		✓	✓
Survey Solutions		✓	✓	✓		✓
ODK (free)		✓	✓	✓		✓
ODK (paid)		✓	✓		✓	✓
CSPro		✓	✓	✓	✓	✓

Data collection.

Data collection apps that are appropriate for collecting respondent data in traditional census-based household surveys are generally appropriate for collecting data in a gridded population survey, so use the app(s) that you are already comfortable with. Table 2.7 summarizes key characteristics of several common data collection apps. Teams with basic skills will be most comfortable using KoBoCollect (free) or SurveyCTO (paid) to collect data.

Find the relevant decision tree in Figure 2.8 to identify a set of tools suited to your survey design and team skillset. Separate decision trees are presented for teams with Basic, Intermediate, and Advanced skills, as well as teams that do or do not have GIS skills.

2.4.3 Decide your gridded population survey implementation tools (cont'd)

Figure 2.8(a). Decide which gridded population survey implementation tool to use – Basic users

User: Team has used Google Earth and Excel, but not ArcGIS or QGIS

Design 6 currently requires GIS skills, and thus is not an option

Know your sample design from Figure 2.2

↓

Basic skill level

↓

Design

Note: By the end of this decision-tree, you will know which tools and tutorials are needed to implement your gridded population survey.

	1 or 2	3	4	5
PSU Selection	• GridSample	• GridSample	• GridSample	• GridSample
PSU Review	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features (optional) + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs
SSU Selection	• Excel to select SSUs		• GeoSampler	
Map Production	• Map Campaigner • Map Campaigner + OpenStreetMap • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth
Navigation	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps
Data Collection	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus (requires GIS)

2.4.3 Decide your gridded population survey implementation tools (cont'd)

Figure 2.8(b). Decide which gridded population survey implementation tools to use – Intermediate users without GIS skills

User: Team is comfortable using SPSS, Stata, or SAS, but not ArcGIS or QGIS

Design 6 currently requires GIS skills, and thus is not an option

Know your sample design from Figure 2.2

↓

Intermediate skill level, no GIS

↓

Design

Note: By the end of this decision-tree, you will know which tools and tutorials are needed to implement your gridded population survey.

	1 or 2	3	4	5
PSU Selection	• GridSample	• GridSample	• GridSample	• GridSample
PSU Review	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features (optional) + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs
SSU Selection	• Stata to select SSUs		• GeoSampler	
Map Production	• Map Campaigner • Map Campaigner + OpenStreetMap • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth
Navigation	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps
Data Collection	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus (requires GIS)

2.4.3 Decide your gridded population survey implementation tools (cont'd)

Figure 2.8(c). Decide which gridded population survey implementation tools to use – Intermediate users with GIS skills

User: Team is comfortable using SPSS, Stata, or SAS, and includes an Intermediate-level GIS user

Know your sample design from Figure 2.2

Intermediate skill level, GIS

Design

Note: By the end of this decision-tree, you will know which tools and tutorials are needed to implement your gridded population survey.

	1 or 2	3	4	5	6
PSU Selection	• GridSample • ArcGIS frame + Excel to select PSUs	• GridSample • ArcGIS frame + Excel to select PSUs	• GridSample • ArcGIS frame + Excel to select PSUs	• GridSample • ArcGIS frame + Excel to select PSUs	• GridSample
PSU Review	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features (optional) + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs
SSU Selection	• Stata to select SSUs		• GeoSampler		
Map Production	• ArcGIS Atlas • ArcGIS Atlas + OpenStreetMap • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas
Navigation	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps
Data Collection	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus (requires GIS)

2.4.3 Decide your gridded population survey implementation tools (cont'd)

Figure 2.8(d). Decide which gridded population survey implementation tools to use – Advanced users without GIS skills

User: Team is comfortable programming in R or Python, but not ArcGIS or QGIS

Design 6 currently requires GIS skills, and thus is not an option

Know your sample design from Figure 2.2

↓

Advanced skill level, no GIS

↓

Design

Note: By the end of this decision-tree, you will know which tools and tutorials are needed to implement your gridded population survey.

	1 or 2	3	4	5
PSU Selection	• GridSample • GridEZ frame + R selection	• GridSample • GridEZ frame + R selection	• GridSample • GridEZ frame + R selection	• GridSample • GridEZ frame + R selection
PSU Review	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features (optional) + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs	• Google Earth to segment features + Excel to drop and replace PSUs
SSU Selection	• R to select SSUs		• GeoSampler	
Map Production	• Map Campaigner • Map Campaigner + OpenStreetMap • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth	• Map Campaigner • Google Earth
Navigation	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps
Data Collection	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus (requires GIS)

2.4.3 Decide your gridded population survey implementation tools (cont'd)

Figure 2.8(e). Decide which gridded population survey implementation tools to use – Advanced users with GIS skills

User: Team is comfortable using SPSS, Stata, or SAS, and includes an Intermediate-level GIS user

Know your sample design from Figure 2.2

↓

Advanced skill level, GIS

↓

Design

Note: By the end of this decision-tree, you will know which tools and tutorials are needed to implement your gridded population survey.

	1 or 2	3	4	5	6
PSU Selection	• GridSample • ArcGIS frame + R selection • GridEZ frame + R selection	• GridSample • ArcGIS frame + R selection • GridEZ frame + R selection	• GridSample • ArcGIS frame + R selection • GridEZ frame + R selection	• GridSample • ArcGIS frame + R selection • GridEZ frame + R selection	• GridSample • GridEZ frame + R selection
PSU Review	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features (optional) + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs	• ArcGIS to segment features + ArcGIS PSU aggregation • Excel to drop and replace PSUs
SSU Selection	• Excel, Strata, R select SSUs		• GeoSampler		
Map Production	• ArcGIS Atlas • ArcGIS Atlas + OpenStreetMap • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas • Google Earth	• ArcGIS Atlas
Navigation	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps	• MAPS.ME • Google Maps + SWMaps • Avenza Maps
Data Collection	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)	• KoBo Toolbox or similar (e.g., SurveyCTO, ODK, Survey Solutions, CSPro, etc.)

Design 1. Two-stage, detailed-listing
Design 2. Two-stage, quick-listing
Design 3. Two-stage, random-walk
Design 4. Two-stage, building SRS
Design 5. One-stage, area-microcensus
Design 6. Two-stage, area-microcensus (requires GIS)

2.5 Gridded population surveys and the global COVID-19 pandemic

Like all face-to-face household surveys, few gridded population surveys were conducted during the first two years of the global COVID-19 pandemic, to minimize risk of transmission. As statistical agencies, polling firms, researchers, and other survey teams adjust to work under COVID-19, some face-to-face household surveys have resumed with modified or new safety protocols, and many surveys have been replaced by phone surveys, or hybrids of face-to-face and phone surveys.

Where face-to-face surveys are necessary, for example to make field measurements or to reach "hidden" or vulnerable populations, we strongly encourage readers to refer to the guidance provided by the Inter-Secretariat Working Group on Household Surveys (ISWGHS) to minimize face-to-face contact during planning, training, and fieldwork.

Guidance provided by the ***Inter-Secretariat Working Group on Household Surveys (ISWGHS)***

Credit: Community Mappers, Kibera, Nairobi, Kenya

Although the use of phone surveys has increased substantially during COVID-19, multiple issues prevent representative sampling of respondents, for example, phone companies have uneven penetration across a region, or respondents own multiple or no SIM cards (phone numbers). Furthermore, in LMICs especially, phone penetration is limited among vulnerable sub-populations, and most respondents pay directly for airtime and thus may not be willing or able to pay for airtime spent in a phone interview. Therefore, in LMICs, face-to-face sampling methods have been used to identify a representative sample of respondents who can then be engaged one or more times for phone data collection, usually with compensation for airtime. Sampled respondents who do not have a mobile phone might be provided a phone by the survey team. This approach is increasingly used by the World Bank for Mobile Phone Panel Surveys. These panels proved to be enormously helpful during the COVID-19 pandemic because existing representative cohorts of people were contacted regularly to monitor rapidly evolving conditions, needs, and opinions.

World Bank Mobile Phone Panel Surveys in Developing Countries

The use of gridded population sampling might be particularly helpful for identifying representative cohorts of respondents for phone surveys because several gridded population survey designs enable representative, robust sampling with just one visit to the field. Design 4 (**Section 2.2.1.4**) and Design 6 (**Section 2.2.1.6**) are particularly well-suited for the task by maximizing accuracy and precision of the sample with just one field visit and minimal face-to-face contact.

Section 3.

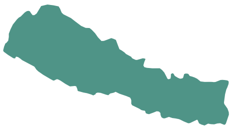
Operationalizing your gridded population survey

3 Operationalizing your gridded population survey

This section links to a series of tutorials, a subset of which can be chosen and combined to support your survey team to operationalize your gridded population survey. Each tutorial is marked with the skill level(s) and sample design(s) that it supports. Each tutorial is provided as a downloadable Microsoft Word file that can be edited and combined with other tutorials. We encourage you to compile the relevant tutorials into a bespoke training manual, or to develop similar tutorials for additional tools and share these back through **www.gridpopsurvey.com** for other gridded population survey teams to use.

The provided tutorials are not exhaustive of the tools discussed in this manual. Where tools are similar (e.g., Stata, SAS, SPSS), we developed a tutorial for one tool with the idea that practitioners would be able to "translate" steps into other relevant tools. The aim, however, is to develop and incorporate additional tutorials over time. As additional gridded population survey tutorials are developed, including for new datasets and tools, they will be made available via **www.gridpopsurvey.com**. In **Table 3.1**, we summarize the tutorials that are currently available online.

On the next page we describe four example gridded population surveys that are used throughout the tutorials. Two of these surveys are actual surveys, and the other two are hypothetical examples that are similar to gridded population surveys that have been implemented. The examples cover the full range of sample designs, skill levels, and tools discussed throughout this manual.



Nepal

The Nepal survey example is a **one-stage, area-microcensus (Design 5)** in Kathmandu Valley, Nepal. This example is based on an actual gridded population survey carried out in 2017 by the Surveys for Urban Equity (SUE) project, which is summarized in Box 2.4 and detailed by Elsey, et al. (2018) and Thomson, Bhattarai, et al. (2021). We use this example to demonstrate tools that are appropriate for research teams with a **Basic** level of skills.

Nigeria

The Nigeria example is a hypothetical national **two-stage, area-microcensus (Design 6),** stratified by states. The sample size and design are loosely based on the Nigeria 2016–17 MICS (NBS and UNICEF, 2017). We use this example to demonstrate tools that are appropriate for teams with **Intermediate**-level skills and some **GIS** capabilities.

Namibia

The Namibia example is hypothetical, developed to highlight tools for **Intermediate**-level teams, particularly teams comfortable using **GIS.** We use real-world datasets and a realistic sample design in this national **two-stage, building SRS (Design 4),** stratified by region.

Uganda

The Uganda survey example follows a **two-stage, full listing (Design 1)** in refugee settlements. The example is based on an actual gridded population survey carried out in 2021 as part of the Uganda Refugee Population-based HIV Impact Assessment (RUPHIA) (see Box 2.6 for more details). We use this example to showcase **Advanced** skills in R, plus **GIS.**

Table 3.1. Summary of tutorials available at www.gridpopsurvey.com, including which survey designs they support and skills required

Design 1: Two-stage, detailed-listing. **Design 2:** Two-stage, quick-listing, **Design 3:** Two-stage, random-walk. **Design 4:** Two-stage, building SRS. **Design 5:** One-stage, area-microcensus. **Design 6:** Two-stage, area-microcensus.

Tool purpose	Tutorial	Sample design (Figure 2.2)						Skill level				
		1	2	3	4	5	6	Basic	Int.	Adv.	Int. GIS	Adv. GIS
A. PSU sample	A1. GridSample	■	■	■	■	■	■	■	■	■	■	■
	A2. ArcGIS frame	■	■	■	■						■	■
	A3. Excel to select PSUs	■	■	■	■	■	■	■	■	■	■	■
	A4. WP-PB population	■	■	■	■	■	■				■	■
	A5. GridEZ frame	■	■	■	■	■	■			■		■
	A6. R to select PSUs	■	■	■	■	■	■			■		■
B. PSU review	B1. ArcGIS aggregation	■	■	■	■	■	■				■	■
	B2.Google Earth segment	■	■	■	■	■		■	■	■	■	■
	B3.ArcGIS segment features	■	■	■	■	■					■	■
	B4.ArcGIS segment cells						■				■	■
	B5.Excel to drop and replace	■	■	■	■	■	■	■	■	■	■	■
	B6.Stata to drop and replace	■	■	■	■	■	■		■		■	
	B7. R to drop and replace	■	■	■	■	■	■			■		■
C. SSU sample	C1. GeoSampler				■			■	■	■	■	■
	C2. Excel to select SSUs	■	■					■				
	C3. Stata to select SSUs	■	■						■	■	■	■
	C4. R to select SSUs	■	■							■		■
D. Map production	D1. Map Campaigner	■	■	■	■	■		■	■	■		
	D2. OpenStreetMap	■	■					■	■	■	■	■
	D3. Google Earth maps	■	■	■	■	■	■	■	■	■	■	■
	D4. ArcGIS Atlas	■	■	■	■	■	■				■	■
E. Navigation	E1. MAPS.ME	■	■	■	■	■	■	■	■	■	■	■
	E2. Google Maps	■	■	■	■	■	■	■	■	■	■	■
	E3. SWMaps	■	■	■	■	■	■	■	■	■	■	■
	E4. Avenza Maps	■	■	■	■	■	■	■	■	■	■	■
F. Data collection	F1. KoBoCollect	■	■	■	■	■	■	■	■	■	■	■
	F2. CSPro	■	■	■	■	■	■		■	■	■	■

A1. PSU sample – GridSample selection

View tutorial

Generate sample frame and select PSUs with GridSample

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Users of all skill levels can use this tutorial to create sample frames from the WorldPop and GRID3 gridded population datasets, and then select stratified or non-stratified samples of PSUs that are suitable for use with area-microcensus or two-stage sample designs. Survey coverage and strata boundaries that follow administrative or urban/rural boundaries can be defined within the tool without specialized GIS skills by selecting from pre-loaded datasets. Users, however, can define bespoke survey coverage, strata, and/or PSU boundaries by uploading zipped shapefiles.

A2. PSU sample – ArcGIS frame

View tutorial

Generate sample frame in ArcGIS

Skill level needed: Intermediate/Advanced with GIS skills

Sample designs supported: 1 2 3 4 (not 5, 6)

Motivation: GIS users with their own PSU boundaries can use this tutorial to aggregate gridded population estimates within PSU boundaries, thereby updating the population count in each sample frame unit. Generally, users will not have PSU boundaries small enough to support sample Design 5, and Design 6 requires multi-cell gridded units.

A3. PSU sample – Excel to select PSUs

View tutorial

PSU sample selection in Excel

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: After a PSU sample frame has been constructed, use this tutorial to draw a probability proportional to population size (PPS) sample of PSUs from a list of sample frame units with population totals.

A4. PSU sample – WP-peanutButter population

View tutorial

Create gridded population dataset in WP-peanutButter

Skill level needed: Intermediate/Advanced with GIS skills

Sample designs supported: 1 2 3 4 5 6

Motivation: This tutorial is to be used in the rare circumstance that an existing gridded population dataset is not suitable as a sample frame, and the user has the skills to create a more accurate gridded population dataset themselves with the WorldPop-peanutButter tool. WorldPop-peanutButter is a web-based tool to either disaggregate population counts to grid cells from bespoke areal units, or aggregate population estimates from user-specified parameters (e.g. average number of people per building) to ~100x100 m grid cells based on Maxar/Ecopia building footprints. At the time of writing, building footprints were only publicly available for African countries.

A5. PSU sample – GridEZ frame

View tutorial

Generate sample frame with GridEZ R algorithm

Skill level needed: Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to generate your own GridEZ sample frame when a gridded population dataset is not available in GridSample.org (e.g., HRSL or a bespoke gridded population dataset), or you are an Advanced user with a reason to select your sample in R. GridEZ is an R algorithm that groups contiguous gridded population cells into EA-like units of approximately similar total population. The algorithm requires (1) gridded population raster; (2) strata boundaries of the area(s) of interest, converted to raster; and (3) settlement type (e.g., urban/rural areas) raster. Recommended sources of strata and settlement-type boundaries are provided if the user does not have their own.

A6. PSU sample – R to select PSUs

View tutorial

PSU sample selection in R

Skill level needed: Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: After a PSU sample frame has been constructed, use this tutorial to select a sample of PSUs if you are an Advanced user with a reason to select your sample in R.

B1. PSU sample – ArcGIS aggregation

View tutorial

Sample frame unit aggregation in ArcGIS

Skill level needed: Intermediate/Advanced with GIS skills

Sample designs supported: 1 2 3 4 5 6

Motivation: After an initial PSU sample frame is constructed, use this tutorial to manually review PSUs and aggregate very small PSUs with a neighboring PSU before sample selection. This tutorial is most relevant for Designs 1, 2, and 5 because fieldworkers will visit all households in each PSU, and you want to ensure that time and resources are well spent, though it can be used with any design.

B2. PSU review – Google Earth segment

View tutorial

Review and segment PSUs by natural features in Google Earth

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 (6 not supported)

Motivation: If your team does not have GIS skills, use this tutorial to review each selected PSU over recent satellite imagery and manually segment PSUs with exceptionally large populations before fieldwork. Reviewing each PSU before fieldwork is recommended for all gridded population surveys, though segmentation might be skipped for Designs 3 (random-walk) and 4 (building SRS). Design 6 specifically requires segmentation of PSUs by their component grid cells in a GIS software (see Tutorial B4).

B3. PSU review – ArcGIS segment features

View tutorial

Review and segment PSUs by natural features in ArcGIS

Skill level needed: Intermediate/Advanced with GIS skills

Sample designs supported: **1** **2** **3** **4** **5** 6

Motivation: If your team has GIS skills, use this tutorial to review each selected PSU over recent satellite imagery and manually segment PSUs with exceptionally large populations before fieldwork. Reviewing each PSU before fieldwork is recommended for all gridded population surveys, though segmentation might be skipped for Designs 3 (random-walk) and 4 (building SRS). Design 6 specifically requires segmentation of PSUs by their component grid cells in a GIS software (see Tutorial B4).

B4. PSU review – ArcGIS segment cells

View tutorial

Review and segment PSUs by original grid cells in ArcGIS

Skill level needed: Intermediate/Advanced with GIS skills

Sample designs supported: 1 2 3 4 5 **6**

Motivation: This tutorial assumes that you have used the GridEZ R algorithm or GridSample.org to generate the sample frame, and that you will implement a two-stage, area-microcensus sample (Design 6). Use this tutorial to segment the GridEZ units by their original component grid cell boundaries. It also instructs users to review and exclude component grid cells with no buildings to save time and effort in the field, and to assign a random order to the remaining cells so they can be adaptively sampled at random during fieldwork (see **Section 2.2.1.6** for more information).

B5. PSU review – Excel to drop and replace

View tutorial

PSU substitution in Excel

Skill level needed:PSU substitution in Excel

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial while you are reviewing each PSU over satellite imagery (Tutorial B1, B2, or B3). When you discover a PSU that is in an *insecure* or *inaccessible* location, and/or visual inspection of satellite imagery shows that there are none *(or very few) habitable buildings* (e.g., because the PSU is located over a power plant, airport, or graveyard), then use this tutorial to (systematically or randomly) select a suitable replacement PSU.

C1. SSU sample – GeoSampler

View tutorial

Select a simple random sample of buildings from satellite imagery in GeoSampler

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 **4** 5 6

Motivation: GeoSampler is a simple tool to create random points (with an optional buffer) over satellite imagery, and results in a simple random sample of buildings by guiding the user to keep only those points which land directly on top of a building. Use this tutorial to select a simple random sample of buildings within PSU boundaries for sample Design 4.

C2. SSU sample – Excel to select SSUs

View tutorial

Select households (or individuals) from a listing in Excel

Skill level needed: Basic

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to draw a simple random sample of households, buildings, or other second-stage sampling units (SSUs) that have been listed in tabular format for each selected PSU.

C3. SSU sample – Stata to select SSUs

View tutorial

Select households (or individuals) from a listing in Stata

Skill level needed: Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to draw a simple random sample of households, buildings, or other second-stage sampling units (SSUs) that have been listed in tabular format for each selected PSU.

C4. SSU sample – R to select SSUs

View tutorial

Select households (or individuals) from a listing in R

Skill level needed: Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to draw a simple random sample of households, buildings, or other second-stage sampling units (SSUs) that have been listed in tabular format for each selected PSU.

D1. Map production – Map Campaigner

View tutorial

Prepare simple OpenStreetMap field maps in Map Campaigner

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Map Campaigner is designed for OpenStreetMap mapping teams to implement a building and/or infrastructure census in one or more small areas. As part of their workflow, field team coordinators use Map Campaigner to generate basic A4 paper field maps with the OpenStreetMap base map for each small area. We advise survey teams without GIS skills to use this tool to generate field maps showing PSU boundaries over roads and buildings. Given that roads and buildings might be incompletely mapped in OpenStreetMap, this tutorial is best paired with Tutorial D2 to update OpenStreetMap based on satellite imagery before PSU map production. However, read **Section 2.1.2.3** before using this approach to ensure that you understand the potential risks to respondent anonymity. A benefit of Map Campaigner is the ability to batch produce PSU maps, though non-GIS users can alternatively use Google Earth to produce field maps (Tutorial D3).

D2. Map production – OpenStreetMap (OSM)

View tutorial

Update paper maps and edit roads and buildings in OpenStreetMap (OSM)

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 (3 4 5 6 not supported)

Motivation: Use this tutorial to update building footprints, roads, and pathways in OpenStreetMap (OSM). This tutorial can be used in support of any sample design, but is most useful if your team is performing a two-stage sample with a separate listing of households before interviews (e.g., Designs 1 or 2). Specifically, update OSM within PSUs based on satellite imagery (preloaded in the tool) before producing field maps for the listing team, and then make any minor edits to OSM buildings, roads, and paths after the listing to improve the accuracy of maps produced for interview teams. This tutorial is particularly helpful in high-density, complex urban settings.

D3. Map production – Google Earth maps

View tutorial

Prepare simple imagery-based field maps in Google Earth

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to manually generate A3 or A4 paper field maps with imagery base maps for each PSU. A benefit of Google Earth is that imagery tends to be very high resolution and fairly current, and no special GIS skills are required. However, a limitation of this tool is that each PSU map must be generated manually; there is no batch processing capability. Users with GIS skills might use Tutorial D4 instead to batch produce PSU maps with satellite imagery base maps.

D4. Map production – ArcGIS Atlas

View tutorial

Prepare paper field maps and GeoPDFs as an atlas in ArcGIS

Skill level needed: Intermediate/Advanced with GIS

Sample designs supported: 1 2 3 4 5 6

Motivation: User that are comfortable in GIS software can use this tutorial to batch produce GeoPDFs with OpenStreetMap or satellite imagery base maps for each PSU. GeoPDFs serve as both printable paper field maps as well as app uploads for offline navigation.

E1. Navigation – MAPS.ME

View tutorial

Navigate to a PSU using MAPS.ME

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to navigate longer distances (e.g., between PSUs) while offline. MAPS.ME stores a road network map from OpenStreetMap to your mobile device, and thus is limited by device storage capacity, and might not include secondary and tertiary roads.

E2. Navigation – Google Maps

View tutorial

Navigate to a PSU using Google Maps

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Use this tutorial to navigate longer distances (e.g., between PSUs) while offline.

E3. Navigation – SW Maps

View tutorial

Navigate offline within PSUs by visualizing the device location over a detailed interactive map

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Regardless of survey design or whether the survey was derived from a gridded population, teams that provide fieldworkers with a device will usually find value in an app that visualizes the device's location on a detailed, interactive (OSM or imagery) base map while offline. This tool allows the fieldworker to navigate within the PSU, confirm when they have reached the PSU boundary, and/or locate specific assigned locations within the PSU.

E4. Navigation – Avenza Maps

View tutorial

Navigate offline within PSUs by visualizing the device location over a detailed interactive map

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: Regardless of survey design or whether the survey was derived from a gridded population, teams that provide fieldworkers with a device will usually find value in an app that visualizes the device's location on a detailed, interactive (OSM or imagery) base map while offline. This tool allows the fieldworker to navigate within the PSU, confirm when they have reached the PSU boundary, and/or locate specific assigned locations within the PSU.

F1. Data collection – KoBoCollect

View tutorial

Set-up and monitor tabular, multimedia, and spatial data collection, then download data

Skill level needed: Basic/Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: This tutorial links to external training material that describes how to program a digital questionnaire in KoBoCollect, deploy it to data collectors' tablets, and monitor submitted questionnaire responses

F2. Data collection – CSPro

View tutorial

Set-up, edit, and monitor tabular and spatial data collection, then download data

Skill level needed: Intermediate/Advanced

Sample designs supported: 1 2 3 4 5 6

Motivation: This tutorial links to external training material that describes how to program a digital questionnaire in CSPro, deploy it to data collectors' tablets, and monitor submitted questionnaire responses.

Section 4.

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Supplement A.

Brief survey overview

This supplement briefly reviews traditional census-based probability survey concepts and processes to clarify key differences and similarities between census-based and gridded population-based probability surveys. This overview is **not** sufficiently detailed or technical enough to be used as a general survey manual; however, we link to several common household survey manuals and resources for reference.

SA.1 Types of survey samples

Probability sampling.

A good probability sample is not biased, meaning that it represents a microcosm of the population, or universe, from which it was drawn. Probability sampling means that every unit in the population (e.g., household, woman age 15–49, etc.) has a calculable, non-zero probability of being selected. Rigorous random selection is a necessary condition for a probability sample because it prevents bias. Non-randomized sampling, for example purposefully selecting units from the population, or selecting units that are convenient, might also have non-zero, knowable probabilities of selection, but the lack of randomization can lead to bias. A simple random sample (SRS) is the most basic form of a randomized sample. In an SRS we make a list of all units in the population, and select a fixed number of them at random.

Non-probability sampling.

Non-probability sampling means that the probability of being sampled is not known for some or all eligible respondents. The most obvious non-probability sample is one in which randomization is not applied. For example, selecting the households of people that you already know (purposeful sampling), or households along major roads (convenience sampling), would not provide data that could be generalized to the entire population.

Random-walk and spin-the-pen sampling.

Random-walk and spin-the-pen are field methods designed to randomly sample households within a sampling unit. In a random-walk (sometimes called serpentine walk), the interview team starts at a major landmark or intersection, follows a prescribed pattern of turns, and skips a fixed number of dwellings between interviews. The method is often combined with a quota of households visited or of interviews completed, so the team usually does not walk past every household in the unit, but, hypothetically, they could do so if it took that much walking to fill the sample quota. Similarly, spin-the-pen is meant to be a method of selecting the first household to interview. The method derives from **WHO Expanded Programme on Immunization (EPI) guidance** whereby the team starts at a central point, spins a pen to select an initial direction, counts all households from the starting point to the periphery of the PSU, selects a random number between 1 and N, and goes back to that household for the first interview. In older EPI work, nearby households were selected for subsequent interviews. If implemented strictly, random-walk and spin-the-pen can result in a random selection of households. However, these methods result in a non-probability sample because the probability of household selection is unknown without enumerating all households in the sampling unit.

Random-walk, spin-the-pen, and other types of randomized field-based household selection methods can easily lead to systematic bias toward middle- and upper-class households in settings with multi-household dwellings or with atypical or "hidden" households because fieldworkers miscount the number of households that have been skipped (Thomson et al., 2020). These methods are also harshly criticized for their susceptibility to conscious and unconscious bias by fieldworkers (to avoid undesirable households), which can further lead to systematic bias toward middle-class or accessible households (Grais, Rose, and Guthmann, 2007).

SA.1 Types of survey samples (cont'd)

Quota sampling.

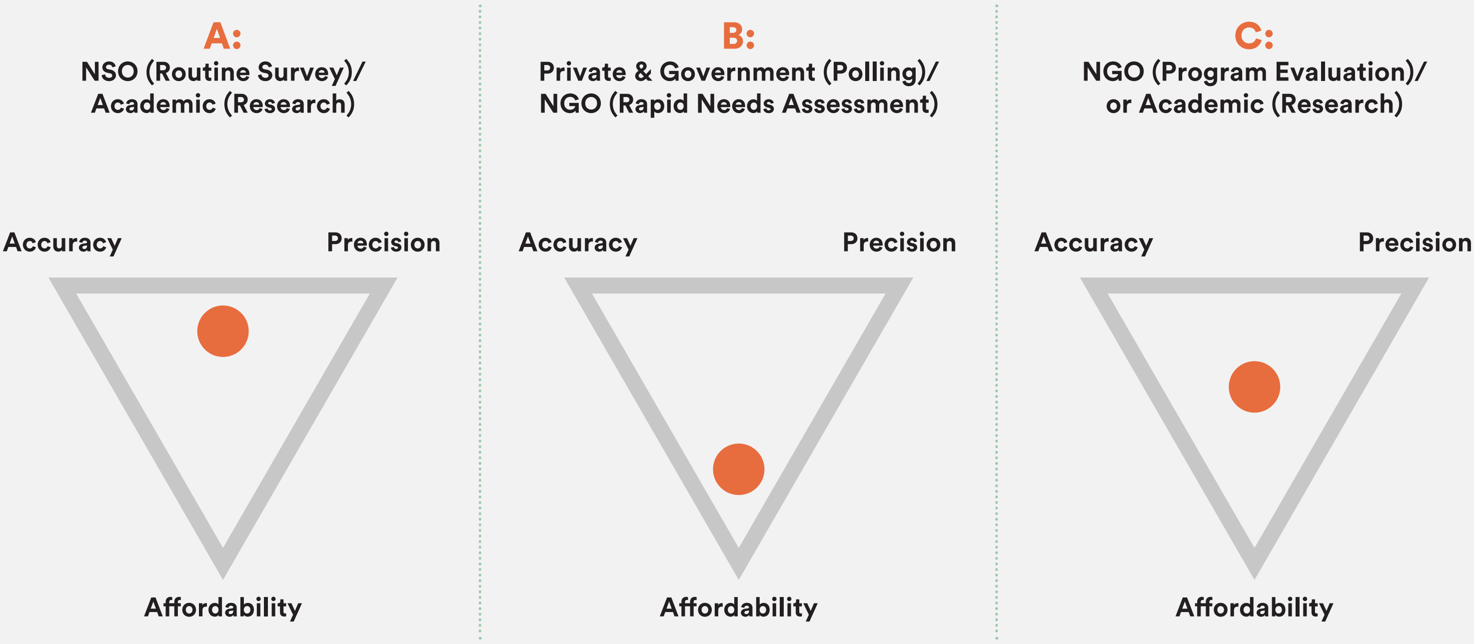
In quota sampling, the population is divided into groups and a target number of samples is set for each group before sampling. In low- and middle-income country (LMIC) household surveys, quota sampling is often combined with random-walk or spin-the-pen methods; for example, in **WHO EPI Surveys**, a quota of seven children per PSU were interviewed. The field protocol was to continue the random-walk/spin-the-pen method until the fixed number of households were interviewed to meet the quota. The WHO has since updated its **vaccination coverage survey reference manual** because the selection probabilities of sampled households could not be known. The protocol also ignored eligible households that refused or where no one was home, which biased the samples toward the types of households who were at home and responsive at the time the interviewers did their work.

SA.2 Balancing survey accuracy, precision, and resources

In probability surveys, survey implementers are forced to balance **(1) survey accuracy** and **(2) survey precision** with **(3) resource constraints** (the time and money available). Any given survey design can perform very well at up to two, but usually not all three, of these dimensions.

NSOs and high-profile research projects spend hundreds of thousands of dollars over months to collect very large samples that generate accurate and precise national statistics, and to make comparisons between population sub-groups (Figure S1, Panel A). Conversely, a population needs assessment performed immediately after a disaster, or an opinion poll about fast-changing socio-political phenomena, both require rapid results, and thus the leadership team is willing to compromise accuracy or precision to get a quick "pulse" of the outcomes of interest (Figure S1, Panel B). Program evaluations and smaller-scale research projects are often faced with budget restrictions that result in survey designs and sample sizes that aim to strike a balance between all three dimensions (Figure S1, Panel C).

Figure S1. A framework for balancing survey accuracy, precision, and affordability



SA.3 Probability survey concepts

Section SA.3 provides a refresher of key technical concepts and definitions encountered in probability surveys. If you are still learning key concepts in household survey design and implementation, we recommend reviewing existing texts, for example:

Sampling: Design and Analysis (Lohr 2009)

UNSD Designing Household Survey Samples: Practical Guidelines

Multi-stage cluster sampling.

Every time that all units in a population are listed and then sampled, we call this a stage of sampling. Multi-stage sampling refers to surveys where more than one list is created and sampled, for example, a list and a sample of census EAs, followed by a list and a sample of households. The first set of samples is referred to as the primary sampling units (PSU), the second set of samples is called the secondary sampling units (SSU), and so on. Multi-stage sampling is used for two reasons:

1

Because a list – or sample frame – of the units that the survey team ultimately wishes to sample (e.g., households, women age 15–49) does not exist. Thus, the smallest administrative unit (e.g., EA) for which population counts are recorded by census is often used as the first-stage, or primary, sample frame.

2

Multi-stage cluster sampling can improve the feasibility of implementing the survey. A simple random sample of households in a province or country would simply cost too much money and time to justify, as interviewers would need to travel potentially long distances between each sampled household, and when they arrived, the respondent might not be home. Cluster sampling enables field teams to plan logistics and collect data from several respondents in one village or neighborhood for several days at a time, which also facilitates revisiting respondents who are not available at the first attempt.

Stratification.

Strata refer to non-overlapping groups that comprise the entire population. Operationally, to stratify is to select an independent sample in groups within the population. Stratification is used for one or more of the following reasons:

- To ensure representation of important groups in the sample.
- To achieve a fixed level of precision in the estimates for each group.
- To improve the feasibility of implementing the survey.
- To increase the statistical power or precision of a sample if the units within each stratum are more similar to each other than to units in the rest of the population.

SA.3 Probability survey concepts (cont'd)

Oversampling.

Oversampling means that the sample size is boosted in part of the population. In countries with majority rural populations, it is routine to oversample urban areas if there are not enough resources to stratify by both administrative unit and urban/rural areas. The purpose of oversampling, in this case, is to produce a sufficient sample size in the smaller important sub-group to generate precise estimates at the national level. Although rarely practiced in human population surveys, another reason to oversample is to ensure spatial coverage of the sample. This type of oversampling is more common in environmental and animal population surveys, though it could be useful in human population surveys to improve errors of small area estimates generated with household survey data (Thomson et al., 2020).

Area-microcensus.

This is not a term widely used by survey statisticians, but we use it throughout this manual to refer to single-stage cluster surveys in which all households are sampled in a small area. The term "census" indicates that there are no further listing and sampling steps. We specify "area"-microcensus to differentiate the concept from other uses of the term "microcensus" (e.g. census of all residents in a sample of households).

Segmentation.

Segmentation is a step performed in the field when a PSU is found to have far more people than expected, for example, due to a new housing development or emergence of a "slum" or informal settlement. In routine government surveys, there is usually not enough time or resources allocated to list more than 200 or 300 households per PSU. Thus the mapping-listing team divides the area into two or more approximately equal-sized segments, and randomly selects one segment to represent the PSU. As long as the segments have approximately equal population totals, probability of household selection can be calculated by recording the number of segments (because number of households in the listed segment, multiplied by the number of segments, equals approximately the number of households in the originally sampled EA).

Design effect.

Stratification, cluster sampling, oversampling, and other complex survey designs modify the precision of household survey estimates. The design effect quantifies the ratio of precision of a given survey's estimates compared to that from a hypothetical simple random sample of the same size. The design effect varies by indicator, depending on the variability and pattern of dispersion of that indicator in the population. Thus, survey implementers often report the design effects (DEFFs) or square root of the design effects (DEFTs) of key indicators with their survey results. Design effect can be interpreted as a factor by which to increase the sample size calculated for a simple random sample to achieve the target level of precision in a sample drawn with a complex design (e.g., 95% confidence level). The planners of household surveys review past surveys which used a similar sample design in a similar context, and use reported DEFFs/DEFTs to calculate sample size requirements for key indicators (for example, see the **WHO Vaccination Coverage Cluster Surveys Reference Manual**).

SA.3 Probability survey concepts (cont'd)

Coverage error.

An ideal sample frame includes all units of the target population (e.g., census EAs) such that the units are exhaustive, non-overlapping, and uniquely identifiable; however, perfect frames are rare. Known problems in population sample frames include under-coverage and over-coverage, and can occur at each stage of sampling. Under-coverage means that units are missing from the frame (e.g., EAs in a disputed territory), but might be supplemented from a different sample frame and treated as a separate stratum. Under- and over-coverage can also occur during survey implementation if areal unit boundaries are not identified accurately in the field, resulting, for example, in a unit not being fully enumerated, or a field enumeration extending incorrectly beyond the unit boundary.

Coverage errors also occur at the household or individual level because a household has recently moved, or an individual moved between households. These coverage errors can be minimized with field protocols and strict definitions of the household and its members (e.g., usual residence (dejure) versus presence at time of survey (defacto)) to minimize the chance that any one person or household can be counted more than once. An error increasingly common in cities today is under-coverage of individuals or households living in atypical dwellings (e.g., shops) because data collectors were not provided with a protocol to adequately identify these households (Thomson, Bhattarai, et al., 2021).

Non-response error.

Non-response errors occur when an individual refuses to participate in the survey, is unavailable, or unable to participate in the survey (e.g., not at home, unwell), or stops responding part-way through the survey. Usually survey protocols require several follow-up visits to households that were unavailable to minimize this type of non-response error. It is important to document, as best as possible, all eligible respondents and the specific reason for non-response (e.g., refusal, unavailable, incomplete survey) so that the effects of different types of non-response on sample results can be assessed.

Sample probability weights.

If the probability of selection for each unit in the population is equal and non-response occurs completely at random, we call this a self-weighting sample. In practice, surveys are rarely, if ever, self-weighting. Most surveys use a combination of stratification, oversampling, and segmentation which results in some households having a greater probability of selection than others, and essentially all surveys will face some level of non-response. Furthermore, unequal population growth since the last census will mean that the number of households observed in the field at the time of survey will differ from the counts made in the last census, and these census counts are often used to select PSUs. In this case, we calculate and apply a weight for each unit (e.g., household) in the sample to make unbiased estimates about the population. Conceptually, the weight represents the number of eligible respondents who might have been interviewed in the place of the respondent who was interviewed.

Sample probability weights are composed of up to three components: (1) the design weight; (2) design weight optionally adjusted for nonresponse; and (3) design weight optionally post-stratified so the sums of weights for important sub-groups closely match those groups' relative size in the population. The weights may be further adjusted by optionally scaling so the sum of all the weights equals the survey sample size.

SA.3 Probability survey concepts (cont'd)

The design weight is the reciprocal of the probability that unit (respondent) i was selected into the survey sample (π_i):

$$w_i = \frac{1}{\pi_i}$$

In turn, π_i is the cumulative product of probabilities of selection. In a three-stage sample design, those probabilities might be:

$$\pi_i = \text{Prob(PSU selection)} \times \text{Prob(Segment selection)} \times \text{Prob(Household selection)}$$

If every respondent had the same probability of selection, then the design weights would be uniform.

Often the design weight is multiplied by adjustments for non-responding, absent, or incapacitated households. The topic of accounting for survey nonresponse is rich, and a full treatment is beyond the scope of this manual. In the equations for weights presented here, we assume that the weight for nonresponding units would have been equal to the average weight of responding units, and we simply shift the weight that would have been carried by non-responders onto units that did respond. In the equations in Section 2, these simple ratio adjustments are sometimes made for PSUs that are not found and therefore do not contribute respondents, and for households that are not found or do not have anyone at home, or who refuse to participate in the survey.

Next, when survey outcomes are going to be estimated across multiple strata, it is important for the sum of weights in each stratum to be proportional to the size of the eligible population there. A stratum that has twice as many eligible respondents as another should contribute twice as much analytic weight to the result. If the sums of design weights, (or of nonresponse-adjusted design weights), closely mirror the proportions of the eligible populations, then no further adjustment may be needed. But if the sums of weights give more or less weight than is appropriate to some strata, it will be prudent to post-stratify the weights. This is accomplished by making a uniform multiplicative adjustment to all the weights in the stratum to bring its total in line with its population size. Poststratification requires obtaining a list of the size of the eligible population in each stratum and then applying the adjustment formula below.

$$\text{Poststratified Weight}_i = \text{Weight}_i \frac{\text{Known Eligible Population Total for the Stratum}}{\Sigma \text{ Unscaled Weights in the Stratum}}$$

The known eligible population totals might come from an administrative list from the census bureau, or might consist of the sum of the gridded population in each stratum. It will be important for the survey team to use a source of totals that is well-regarded by the survey stakeholders.

SA.3 Probability survey concepts (cont'd)

As a final step it is common to rescale all of the weights by a common factor so the sum of weights for all respondents equals the number of respondents in the survey.

$$\text{Normalized Weight for Respondent } i = \text{Unnormalized Weight } i \; \frac{\text{Survey Sample Size}}{\sum \text{All Unnormalized Weights}}$$

For additional information on calculating weights, see:

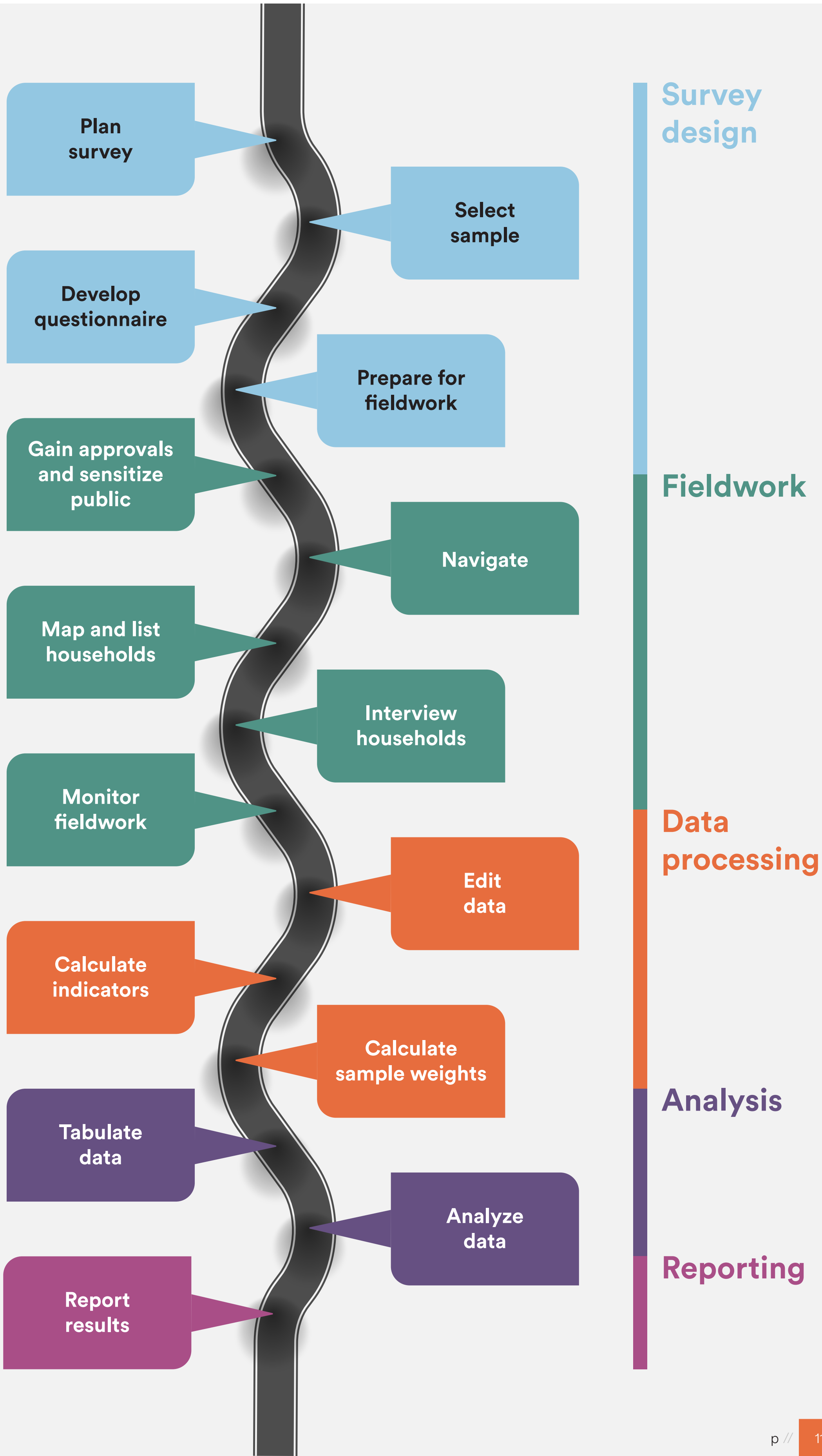
- Valliant, Dever, and Kreuter, 2013
- Heeringa, West, and Berglund, 2017
- Valliant and Dever, 2018

SA.4 Survey phases and steps

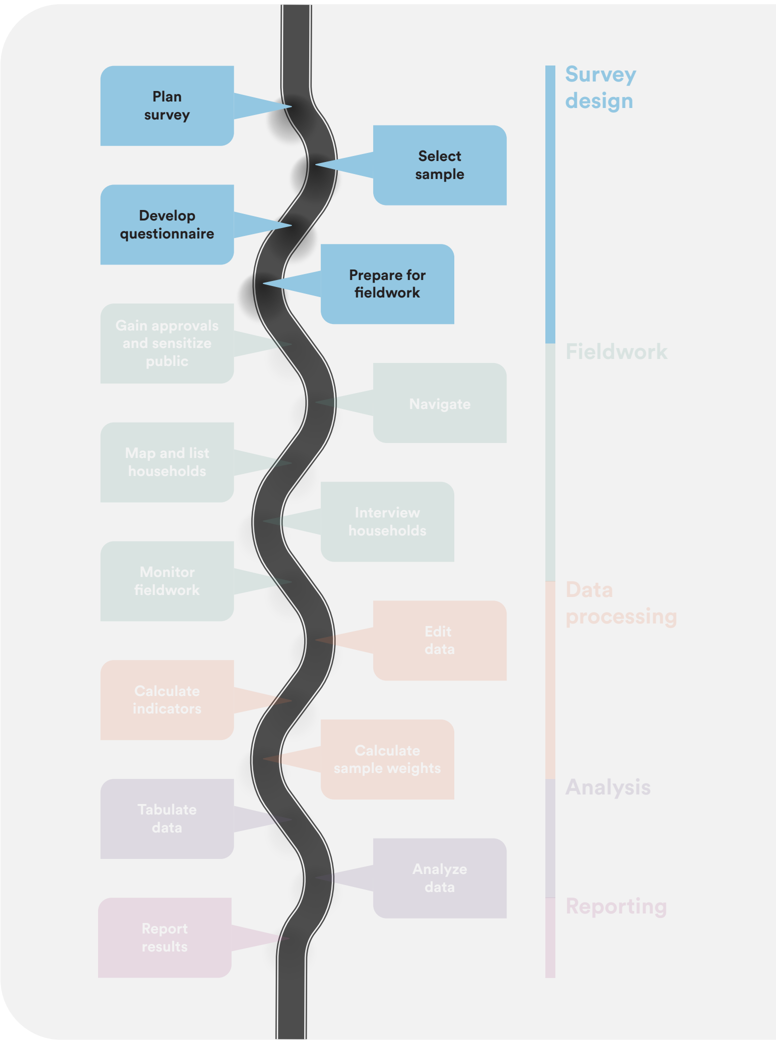
Figure S2.

Probability survey phases and steps

Figure S2 outlines the basic phases and steps involved with any population-representative probability survey, including the survey design, fieldwork, data processing, data analysis, and reporting phases.



SA.4.1 Survey design



SA.4.1.1 / Plan survey

To find the right balance between accuracy, precision, and affordability, the survey design process needs to be iterative (see Figure S3). The survey team should iterate inferential goals, sample designs, sample sizes, and budget estimates before arriving at a final survey design and sample size that is achievable, affordable, and answers the primary survey question(s).

After the survey design is decided, the initial sampling frame can be prepared, and primary sampling units drawn. The final steps in the design phase are to develop and test the questionnaire and prepare for fieldwork.

While we provide a brief refresher below, we recommend referencing **practical tools created by routine survey implementers for survey design, sample size, and budget estimation,** for example:

- UNSD Household Sample Surveys in Developing and Transition Countries
- WHO Vaccination Coverage Surveys Manual
- UNICEF Multiple Indicator Cluster Surveys Tools

Survey planning starts by identifying the primary question(s) to be answered via the survey. Three types of questions can be answered in a probability survey, each with different sample size and resource requirements.

Comparative or hypothesis-test question.

This type of question generally requires the largest sample size and budget because high precision and accuracy is needed in multiple groups, or at multiple time points, to answer the question. An example of this type of question is: *"How much has the **outcome** improved since the last survey measurement?"*

Descriptive or estimation question.

This type of question generally requires a moderate sample size and budget because it requires high precision and accuracy in the overall target population (but not sub-groups, nor over multiple time periods). An example of this type of question is: *"What is the prevalence of the **outcome** in the population?"*

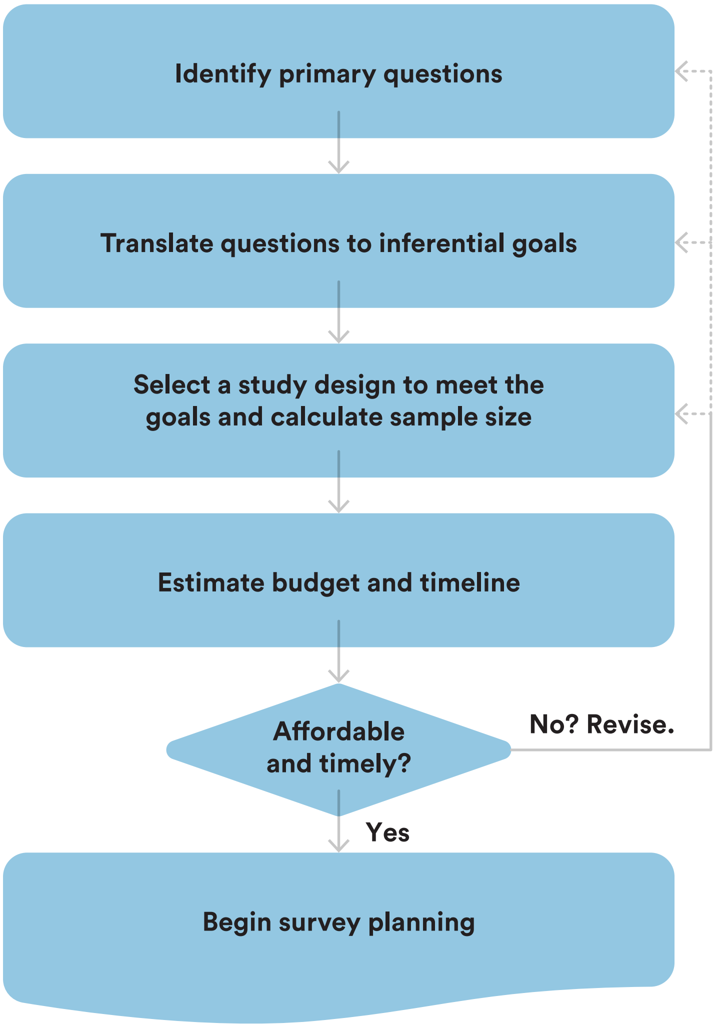
Classification questions.

This type of question generally requires the smallest sample size and budget because we set thresholds to classify the outcome, for example as "low", "middle", "high", without precisely estimating the outcome. An example of this question type is: *"In which districts is the prevalence of the **outcome** particularly high?"*

SA.4.1 Survey design (cont'd)

SA.4.1.1 / Plan survey (cont'd)

Figure S3. The general process to balance survey goals, design, and budget (reprinted with permission from WHO (2018))



Once the primary question(s) have been identified, the survey planners must identify the target population (e.g., households or women age 15–49), and choose a sample design in terms of stratification, stages of sampling, and oversampling (see Section SA.3).

Next, the survey planners translate the question(s) and sample design into a specific inferential goal to calculate sample size. An inferential goal is stated in statistical terms, and differs depending on the type of question. The WHO Vaccination Coverage Surveys Manual and appendices provide especially helpful guidance to develop an inferential goal and calculate sample size.

With the design and sample size calculated, survey planners can draft a budget and rough timeline for the survey. Both WHO and UNICEF provide budget templates to ensure that all survey expenses and steps are fully planned for.

Often survey planners find that their initial inferential goals were a bit too ambitious for their budget, and thus need to be iteratively adjusted (see Figure S3). This is when survey planners should consider less precision in inferential goals, and/or a sample design that requires fewer resources (e.g., one visit to the field instead of two).

SA.4.1 Survey design (cont'd)

SA.4.1.2 / Select sample

Sampling begins with preparing the primary sample frame. A sample frame is a list of non-overlapping units that include the entire population, for example, a list of all households, postcodes, or districts. In traditional household surveys, the primary sample frame is a list of enumeration areas (EA) from the last census with associated population counts. EA-level data, however, is sensitive, and often only available to government survey teams and their immediate partners.

Survey teams that are unable to access a previous census EA sample frame might instead use more aggregated publicly available census counts (e.g., sub-districts) and then perform additional stages of sampling. Alternatively, the team might collaborate with local partners who maintain other types of population data, for example, a local government or NGO might maintain a list of villages with total population estimates based on local government records or survey data.

If the population counts in the sample frame are grossly outdated (i.e., 20+ years old), survey teams sometimes perform targeted rapid enumeration activities in areas that are known to have experienced substantial population growth (e.g., in peri-urban areas) to selectively update EA population counts. For example, the 2013–14 D.R. Congo Demographic and Health Survey (DHS) used 1984 census EAs and population counts that were updated via several local censuses and pre-election enumerations (MPSMRM, MSP, and ICF International, 2014).

In settings of civil conflict, the census or other official population records may be incomplete or be missing information about populations because the government cannot access certain areas. In these situations, the survey team may choose to combine two or more sample frames from different sources that each cover distinct, non-overlapping geographic regions. If insecurity or logistical hurdles prevent survey fieldwork altogether, an area might instead be omitted from the sample. For example, recent DHSs in Jordan combined the national census units with a list of refugee camps to create a national survey sample frame, but acknowledged the omission of nomads (DoS and ICF International, 2013; DoS and ICF, 2019).

Once the initial sample frame of areal units with population counts is created, units are selected with probability proportional to population size (PPS) using a statistical software program or spreadsheet tool. Implicit stratification is often incorporated by ordering the frame by urban then rural units, and then further ordering units by location (e.g., latitude/longitude coordinate) before PPS sampling. Implicit stratification spreads the sample across sub-groups of interest to help ensure that the sample is representative.

SA.4.1 Survey design (cont'd)

SA.4.1.3 / Develop questionnaire

The survey questionnaire is often designed and tested in parallel with sample design and sampling. Effective questionnaire design is as much an art as a science. To achieve effective question wording, response options, question order, instructions, layout, delivery format, and overall questionnaire length, we recommend reviewing a **household survey manual** such as:

- UNSD Household Sample Surveys in Developing and Transition Countries
- Poverty Action Lab Survey Design guidance

We recommend that you take advantage of **existing tested questions and questionnaire modules from routine household survey programs** where possible, for example:

- Demographic and Health Surveys (DHS)
- Multiple Indicator Cluster Surveys (MICS)
- Living Standards Measurement Study (LSMS)
- WHO Vaccination Coverage Surveys (Annex H)

Questionnaire development is difficult because responding to a questionnaire is difficult. Consider the steps that are involved with answering a single question. The respondent must *comprehend* the question, *retrieve* information from memory, make an *estimate* or *judgement* about past or hypothetical events, and then *report* an answer, often by mapping her/his own answer onto a predefined list of acceptable answers (Groves et al., 2009). For these reasons, it is crucial to pretest your questionnaire. Language translations can be checked through forward- and backward-translation by different experts. There are a number of other desk- and field-based methods available to test a questionnaire for content, understandability, and usability including expert reviews, focus groups, interviews, and field pretesting.

Field pretesting is especially important, even if you have selected questions from existing surveys. By testing the questionnaire in the field within your context, you might find that the questionnaire would be improved by reordering questions, by adding context-specific response categories or examples, or by improving the instructions. Field testing is also an opportune time to provide your field interviewers and supervisors with practical field training and experience.

For more guidance on piloting your questionnaire, see:

Poverty Action Lab Questionnaire Piloting guidance

SA.4.1 Survey design (cont'd)

SA.4.1.4 / Prepare for fieldwork

It is now time to prepare for fieldwork. In a typical routine government survey, mapping-listing teams will be recruited and trained to visit each sampled PSU, and map and list all households (as well as eligible individuals, in some surveys). The list that they compile will serve as the sampling frame for the next stage of selection. For large surveys, mapping and listing staff are different than interviewers, with skillsets focused on navigation and map sketching or collecting digital geographic data. One of four techniques are generally used to map and list households (see Figure S4). For each option, this is how to prepare for fieldwork:

Figure S4. Four approaches to mapping households during mapping-listing activity

A. Hand-sketched map of PSU, with paper listing form.

Limited preparation is needed for this approach; a blank listing form needs to be designed and copied.

A. **Hand-sketched map of PSU, with paper listing form**

Source: https://dhsprogram.com/pubs/pdf/DHSM4/DHS6_Sampling_Manual_Sept2012_DHSm4.pdf

B. Mark up existing census paper EA map, with paper listing form.

To prepare for fieldwork with paper census maps, survey coordinators travel to the NSO office, then identify and make copies of all sampled EAs maps. They also need to design a listing form.

B. **Mark up existing census paper EA map**

Source: https://www.jstor.org/stable/41145618

C. Mark up bespoke paper map of PSU, with paper or digital listing form.

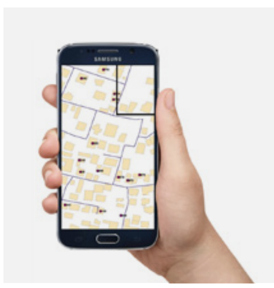
Production of bespoke paper maps involves one or more GIS experts, who might need to be contracted if they are not already a survey coordinator. If a digital listing form is used, it needs to be programmed, tested, and set up on mobile devices for field teams.

C. **Mark up bespoke paper map of PSU**

Source: https://link.springer.com/article/10.1007/s11524-020-00485-z

D. Navigate via device and collect household GPS coordinates within a digital listing form.

To prepare for use of digital devices in the field, the survey coordinators should set up and test all devices and ensure that field staff have back-up power banks. It is also smart to have contingency plans in case devices are lost or disabled during fieldwork.



D. **Collect household GPS coordinates**

Source: https://medicinehealth.leeds.ac.uk/downloads/download/95/planning_team_guide

SA.4.1 Survey design (cont'd)

SA.4.1.4 / Prepare for fieldwork (cont'd)

After households are listed, the survey coordination team generally compiles all listings and randomly selects a fixed number of households to be interviewed in each PSU. This core survey team will either mark existing paper maps, generate new bespoke paper maps, or generate a file of geographic point locations so that interviewers can be hired and trained, and then be able to navigate directly to sampled households. Interviewers generally have previous experience interacting with the public and are trained in basic field navigation skills, and they might be specialists on the survey topic (e.g., health).

In random-walk surveys, only one field visit is performed per PSU and mapping-listing is not performed. Instead, interviewers are hired directly, and trained in a random-walk procedure from a defined starting location in each PSU.

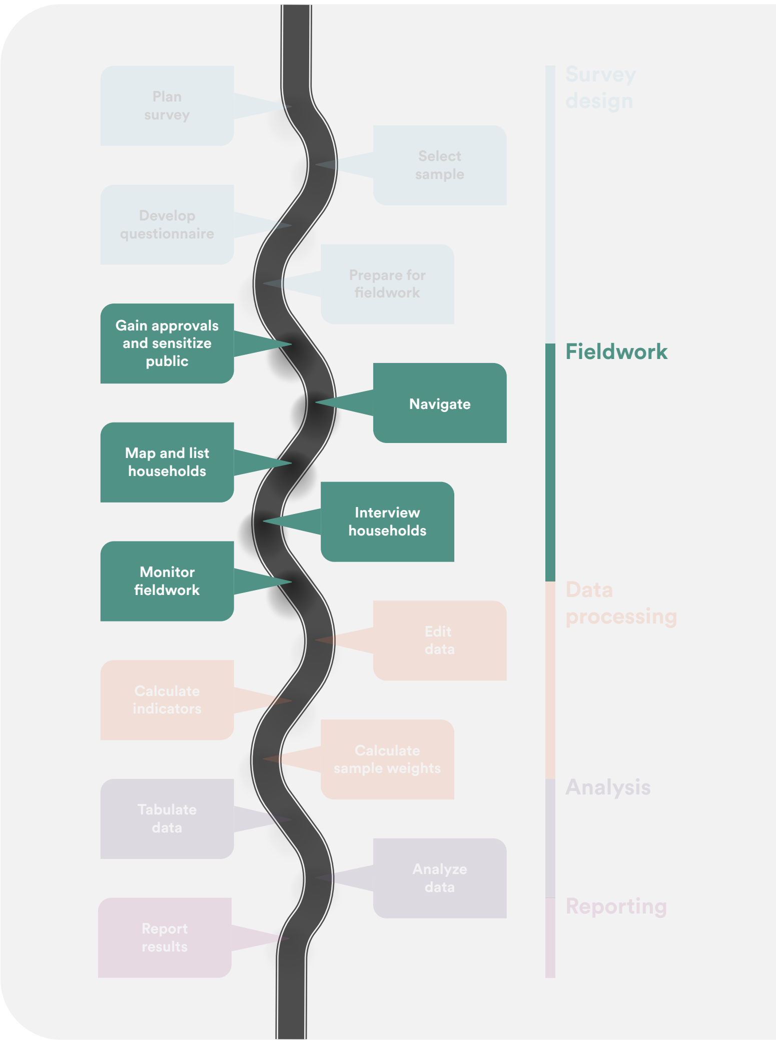
Today, nearly all interview responses are collected via a mobile device that is connected periodically to a central server. Therefore, regardless of the mapping-listing tools, the survey coordination team sets up server hardware and software to compile and securely store survey responses. They also oversee the programming and testing of the digital questionnaire, and set up and test mobile devices for interviewers.

SA.4.2 Fieldwork

SA.4.2.1 / Gain approvals and sensitize public

In most contexts, it is important to contact local leaders in sampled PSUs ahead of fieldwork to inform them about the survey scope and timeline, and seek their official approval. This contact might take the form of an official letter, phone call, face-to-face visit, or all three. If you are not part of an official government survey team, it is wise to select a few back-up PSUs during the sampling process so that PSUs can be easily swapped if you are denied access to a PSU during fieldwork.

It is also wise to sensitize residents in sampled PSUs about the survey ahead of field work. Local leaders may wish to inform residents of the survey through existing channels. Your team may also decide to distribute fliers within sampled PSUs, and/or make an announcement via local TV, radio, or newspaper. Note that local newspaper clippings about the survey can be carried by field staff and shown to residents to help build trust.



SA.4.2 Fieldwork (cont'd)

SA.4.2.2 / Navigate

Fieldwork will begin with navigation to PSUs. In traditional census-based surveys, each EA is often identified by the name of its district, sub-district, or other regional identifier which would be familiar to the supervisor and/or driver. Once the field team nears the EA, they might ask local people for directions based on local place names provided with the map. Today, navigation to PSUs also often involves assistance from a mobile GPS-enabled device to a specified intersection or landmark near the PSU.

Once the mapper-listers (or interviewers) have arrived in the PSU, they navigate on foot to specific households or a random-walk start location. Within-PSU navigation differs based on the resources provided to mapper-listers (or interviewers).

Navigation protocols based on the provided map:

A. Hand-sketched map of PSU.

If no paper or digital field map of the PSU is provided, field staff must find a local guide to identify the boundary of the named PSU (e.g., EA, village). This can lead to survey under- or over-coverage errors if the guide(s) use a different boundary than the sample frame, or give unclear instructions to the field staff.

B. Existing census paper EA map.

If a copy of an old census EA map is provided, this can be used for within-PSU navigation by the field team, as long as the road and building configurations have not changed substantially since the map was produced.

C. Bespoke paper map of PSU.

A bespoke paper map showing the PSU boundary over recent satellite imagery (or buildings and roads) is perhaps the most reliable within-PSU navigation tool. PSU paper maps are also helpful for communicating about the survey with local residents, and are often perceived as less official or threatening compared to digital devices with maps.

D. Digital map.

The benefit of within-PSU navigation using a digital device is that many apps provide users with the ability to visualize the device's location over the PSU boundaries and base map. Doing so generally requires phone signal and mobile data, however, so it is more suitable within complex urban settings than remote areas.

SA.4.2 Fieldwork (cont'd)

SA.4.2.3 / Map and list households

The mapping-listing step is only applicable to multi-stage cluster surveys in order to produce a complete listing of households (or eligible respondents) and generate a map for interviewers to return to specific, sampled households later. As described above (Section SA.4.1.4), mapping-listing will use one of four approaches.

The general protocol is that a pair of mapper-listers walk every street and pathway in the PSU, and knock at the door of every building to check if there are residents. If there are, the mapper-listers ask about the number of household members, and sometimes (a) the number of eligible respondents (e.g., children 12–23 months), (b) the head of household name, or (c) the name and age of each household member.

Mapping-listing can be especially tricky and time-consuming in cities where many people do not know their neighbors, live in secure buildings, are away from home during the day, and are skeptical of strangers. Conversations between mapper-listers and residents are generally unscripted, and often mapper-listers ask a variety of strangers about the living situations in nearby buildings, above shops, etcetera. Although some field manuals mention that mapper-listers should visit every building, in practice, field staff sometimes skip locations that appear to be commercial or institutional and assume that no one resides there (we strongly discourage this practice because it is likely to systematically omit vulnerable and atypical "hidden" households).

There are limited training materials specifically focused on preparing mapping-listing staff for fieldwork, however, guidelines and paper-based tools are detailed in:

- DHS Sampling and Household Listing Manual

An example digital listing form is provided in Annex H of:

- WHO Vaccination Coverage Survey Manual

SA.4.2 Fieldwork (cont'd)

SA.4.2.4 / Interview households

Interviewers should receive practice-based training on:

1. basic navigation within PSUs;
2. interpersonal skills, to ensure that respondent feels comfortable and secure during the interview; and
3. the questionnaire content, focusing on particularly tricky questions or procedures (e.g., sampling one of several eligible household members, photographing a vaccination record).

Plenty of role-play practice is important during the training, especially for surveys with sensitive questions (e.g., about personal wealth, sexual history, medical history), for which maintaining respondent confidentiality is essential, and during which some respondents might experience discomfort.

Several interview guides and training materials are available from existing survey programs including:

- DHS Field Staff Training Manual
- DHS Interviewer's Manual
- MICS Instructions for Interviewers

Generally, interviewer trainings are limited to approximately 20 participants each to ensure high-quality practice-based learning experiences, and are offered as a full-time, one- or two-week course.

SA.4.2.5 / Monitor fieldwork

Monitoring by field supervisors during mapping-listing and interviewing processes are both important.

During the **mapping-listing process,** supervisors should monitor the completeness and accuracy of maps and listings by either:

- making a surprise visit to a mapping-listing team in the field, then re-mapping and re-listing approximately 10% of their PSU; or
- having another team re-map and re-list all households in 10% of all sampled PSUs.

The first approach provides supervisors with first-hand, real-time insights about any challenges that teams may be encountering in the field. It also enables the supervisor to shadow field teams directly, enabling more tailored feedback and support to each team during early fieldwork so that they might improve (or be let go if their performance does not improve).

The second approach is less of a burden for the supervisor, but more of a burden for residents and field teams. Depending on the schedule for re-mapping and re-listing PSUs, this approach can also result in delayed awareness about a team that is producing poor-quality listing data. During comparative checks between two mapping-listing teams, the supervisor looks for consistency in how households were recorded (e.g., multi-household buildings) as well as total number of households, and consistency in maps.

SA.4.2 Fieldwork (cont'd)

SA.4.2.5 / Monitoring (cont'd)

Even without repeating any listings, the supervisor can check how well each team is following mapping-listing protocols by visually spot-checking their maps and listing forms on a daily basis. If the supervisor is not in the same physical location as the mapper-listers, paper maps and listing can be shared electronically with the supervisor as photographs.

During the **interview process,** supervisors have a substantial amount of qualitative and quantitative data to monitor in real time. Sometimes the responsibility of managing staff and arranging field logistics are separated from monitoring interviewer performance and reviewing data. Strategies to monitor interviewer performance and data include:

1

A supervisor shadows each interviewer for at least one interview and provides constructive feedback and encouragement about the quality of the interviewer's interactions with respondents, and ability to follow protocols.

2

Before wrapping up work in a PSU, the supervisor should review each completed questionnaire to check that all relevant questions were answered, and that responses are clearly marked (paper forms). It is far easier to tabulate and identify missing responses for tablet-based surveys than paper-based surveys. If any missing data or discrepancies are identified, the supervisor and interviewer should resolve them before leaving the PSU, even if that means returning to the respondent to ask follow-up questions.

For more detailed guidance on field supervision and monitoring data quality, see:

- DHS Supervisor's and Editor Manual

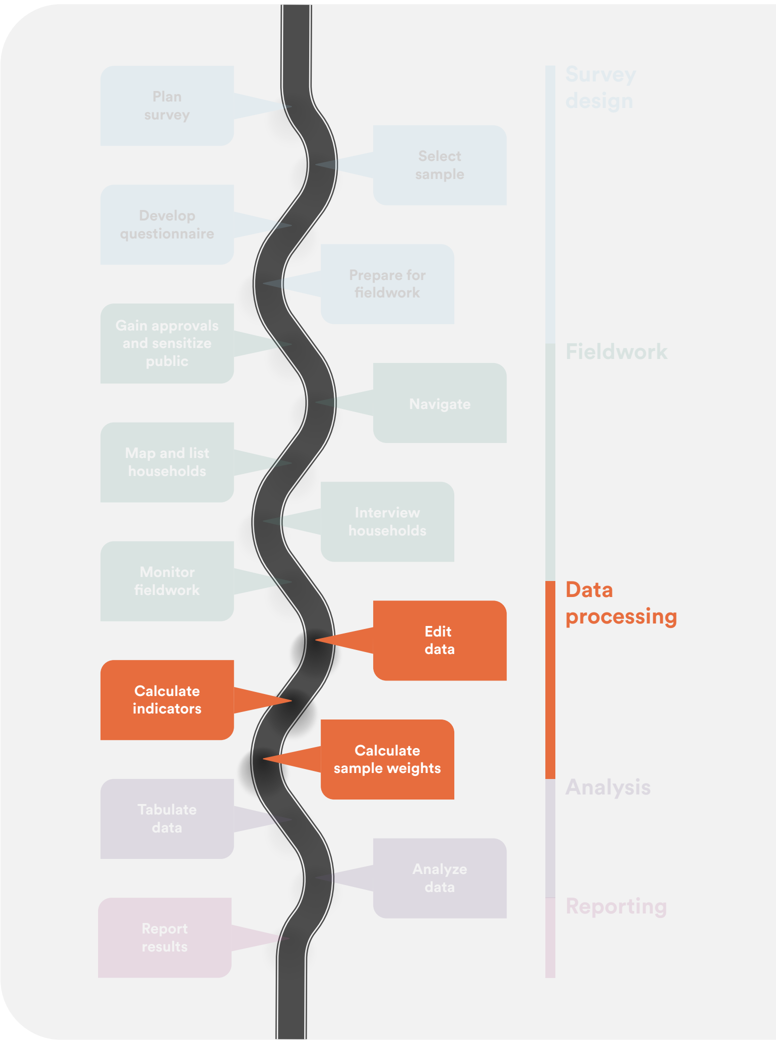
3

As data are submitted (tablet-based survey), or after the survey is complete (paper-based survey), tabulate indicators by team and by period of data collection. Compare indicator frequencies and means for consistency within and between teams.

For a helpful example of data checks, see:

- MICS Interviewer field check template tables
- Poverty Action Lab Data Quality Checks guidance

SA.4.3 Data processing



Before generating reports and performing analyses with survey data, there are a number of important data cleaning and processing steps. **Data cleaning** includes:

1

Checking for surprising results or distributions in key indicators by strata, PSU, and interview team. "Surprising" results include outliers, substantially different results compared to a past survey, or strong patterns in the data. While "surprising" results might actually be true results, they should each be explored for potential errors or bias.

See, for example:

- WHO Vaccination Coverage Survey Manual (Section 6)

2

Resolving and editing inconsistencies that can be resolved, and flagging inconsistencies that cannot be resolved.

Particularly helpful data editing guidelines are provided in:

- MICS Data Editing Guidelines
- DHS Data Editing and Imputation

SA.4.3 Data processing (cont'd)

Across disciplines, a number of important indicators require responses from multiple questions to be combined, for example, stunting in children is calculated from height and age measures. Thus **data processing** involves the application of standard algorithms to generate new derived variables in the dataset from interview variables. Before data are shared with the public, this step often involves removing any identifying information about respondents, households, and communities. Here are key steps and useful resources:

1

Remove variables with identifying information such as respondent's name, address, household GPS coordinates, or neighborhood/village name.

2

Add sample probability weights, adjusted for non-response and possibly post-stratified.

- DHS Sampling and Household Listing Manual (Section 1.13)
- WHO Vaccination Coverage Survey Manual (Section 6 & Annex J)

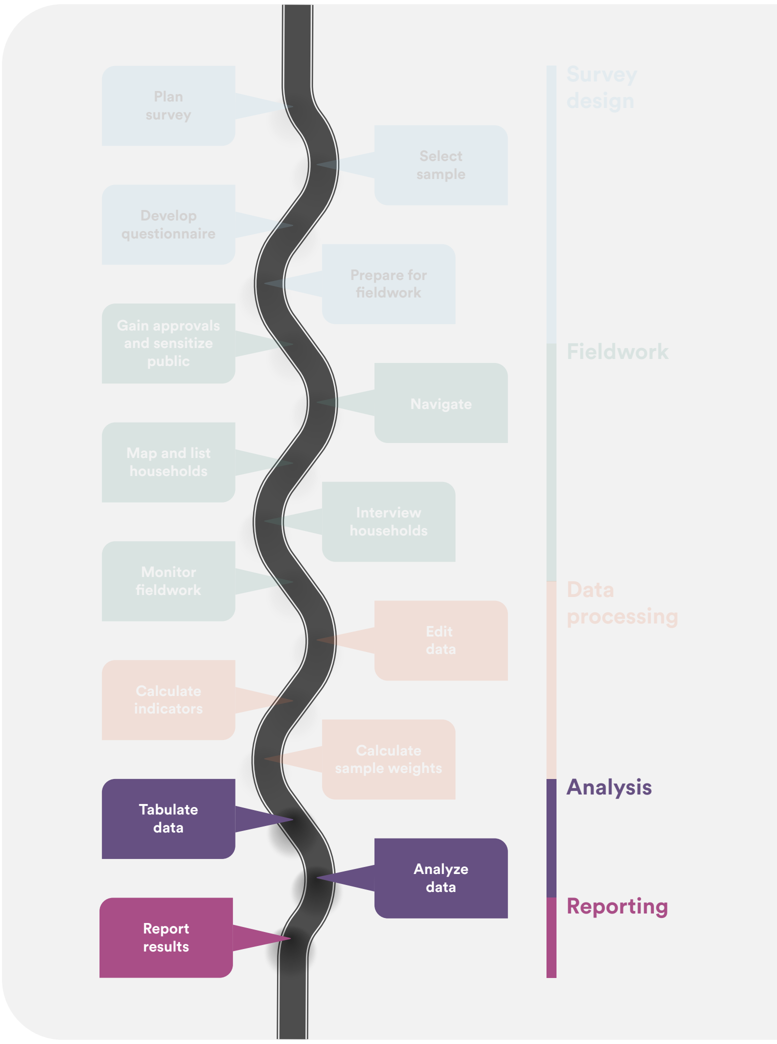
3

Calculate additional complex indicators.

- Guide to DHS Statistics
- Data For Impact FP/RH Indicators Database
- Vaccination Coverage Quality Indicators (VCQI)

SA.4.4 Analysis and reporting

At this point, your team is ready to generate summary tables and figures, and to draft reports. Ideally your team will have developed blank tables based on the key questions and priorities in your survey.



Here are existing resources to inform how you might format your tables:

- DHS Final Report tables
- DHS Key Indicator Report tables
- MICS Tabulation Plan tables

Supplement B.

Hyperlinked URLs

SB.1 Datasets

Bing building footprints	https://www.microsoft.com/en-us/maps/building-footprints
Geo-Referenced Infrastructure and Demographic Data for Development (GRID3)	https://data.grid3.org/
GHS Functional Urban Areas (FUA) dataset	https://ghsl.jrc.ec.europa.eu/ghs_fua.php
GHS Settlement Model (SMOD)	https://ghsl.jrc.ec.europa.eu/ghs_smod2022.php
GHS Urban Centres Database (UCDB)	https://ghsl.jrc.ec.europa.eu/ghs_stat_ucdb2015mt_r2019a.php
Global Administrative (GADM) areas	https://gadm.org
Global Human Settlement Population Layer (GHS-POP)	https://ghsl.jrc.ec.europa.eu/datasets.php#inline-nav-ghs_pop2022
Gridded Population of the World, Version 4 (GPWv4)	https://doi.org/10.7927/H4F47M65
High Resolution Settlement Layer (HRSL)	https://data.humdata.org/organization/facebook
LandScan Global and HD	https://landscan.ornl.gov/
Maxar/Ecopia building footprints	https://www.maxar.com/products/precision-mapping
preEA boundaries for Burkina Faso	https://wopr.worldpop.org/?/preEAs
Second Administrative Level Boundaries (SALB)	https://www.unsalb.org
WorldPop Global-Constrained (WPG-C)	https://hub.worldpop.org/doi/10.5258/SOTON/WP00685
WorldPop Global-Unconstrained (WPG-U)	https://hub.worldpop.org/doi/10.5258/SOTON/WP00660

SB.2 Tools

ArcGIS	https://www.arcgis.com/index.html
Avenza Maps	https://www.avenzamaps.com/mobile-maps
GeoSampler	https://apps.msf.fr/epiGeoSampler/
GHS-POP2G	https://ghsl.jrc.ec.europa.eu/tools.php
GHS-SmartDissolve	https://ghsl.jrc.ec.europa.eu/tools.php
Google Earth	https://www.google.com/intl/en_us/earth/versions/
Google Maps	https://www.google.com/maps
GridEZ algorithm	https://github.com/cadooley/GridEZ
GridSample.org	https://www.gridsample.org
GridSample2.0 algorithm	https://github.com/Flowminder/GridSample2.0
KoBoCollect	https://www.kobotoolbox.org/
Map Campaigner	https://campaigns.hotosm.org
MAPS.ME	https://maps.me/
ODK	https://getodk.org/
OpenOffice	https://www.openoffice.org/
Python	https://www.python.org/downloads/
QGIS	https://qgis.org/en/site/forusers/download.html
R	https://www.r-project.org/
SAS	https://www.sas.com/en_us/home.html
SPSS	https://www.ibm.com/products/spss-statistics
Stata	https://www.stata.com/
SurveyCTO	https://www.surveycto.com/
Survey Solutions	https://mysurvey.solutions/en/
SW Maps	https://play.google.com/store/apps/details?id=np.com.softwel.swmaps
WorldPop-peanutButter	https://apps.worldpop.org/peanutButter/

SB.3 Story maps

Technical story map of gridded population accuracy	https://arcg.is/1Hauby
Non-technical story map of gridded population accuracy	https://arcg.is/5PKfT0

SB.4 Modelling resources

GRID3 – Modelling approach and code used in Nigeria	https://doi.org/10.1073/pnas.1913050117
GRID3 – Modelling approach used in D.R. Congo (PDF)	https://arxiv.org/ftp/arxiv/papers/2106/2106.07461.pdf
GRID3 – Mapping and classifying settlement locations	https://grid3.org/publications/mapping-and-classifying-settlement-locations
GRID3 – Using GIS and machine learning to classify residential status of urban buildings	https://doi.org/10.3390/rs122338
GRID3 – Classifying settlement types from multi-scale spatial patterns of building footprints	https://doi.org/10.1177/2399808320921208
WorldPop algorithm code	https://www.worldpop.org/wprfpms/
WorldPop pre-processed non-building footprint auxiliary datasets	https://hub.worldpop.org/project/categories?id=14
WorldPop pre-processed building footprint auxiliary datasets	https://wopr.worldpop.org/?/Buildings
WorldPop methods – general modelling approach	https://doi.org/10.1371/journal.pone.0107042
WorldPop methods – about constraining estimates	https://www.worldpop.org/methods/top_down_constrained_vs_unconstrained/

SB.5 Survey manuals

Data For Impact FP/RH Indicators Database	https://www.data4impactproject.org/prh/summary-list-of-indicators/
DHS Data Editing and Imputation	https://dhsprogram.com/publications/publication-dhsg3-dhs-question-naires-and-manuals.cfm
DHS Field Staff Training Manual	https://dhsprogram.com/publications/publication-DHSM3-DHS-Question-naires-and-Manuals.cfm
DHS Final Report tables	https://dhsprogram.com/publications/publication-dhsm6-dhs-question-naires-and-manuals.cfm
[DHS] Guide to DHS Statistics	https://dhsprogram.com/publications/publication-dhsg1-dhs-question-naires-and-manuals.cfm
DHS Interviewer's Manual	https://dhsprogram.com/publications/publication-dhsm1-dhs-question-naires-and-manuals.cfm
DHS Key Indicator Report tables (PDF)	https://dhsprogram.com/pubs/pdf/DHSM5/Key_Indicators_Report_Tabula-tion_Plan_20Mar2015_DHSM5.pdf
DHS Sampling and Household Listing Manual (PDF)	https://dhsprogram.com/pubs/pdf/DHSM4/DHS6_Sampling_Manual_Sept2012_DHSM4.pdf
DHS Supervisor's and Editor Manual	https://dhsprogram.com/publications/publication-dhsm2-dhs-question-naires-and-manuals.cfm
MICS Data Editing Guidelines	https://mics.unicef.org/tools#data-processing
MICS Instructions for Interviewers	https://mics.unicef.org/tools#data-collection

SB.5 Survey manuals (cont'd)

MICS Interviewer Field Check Tables	https://mics.unicef.org/tools#data-collection
MICS Tabulation Plan tables	https://mics.unicef.org/tools#analysis
MICS Tools	https://mics.unicef.org/tools
Poverty Action Lab Data Quality Checks guidance	https://www.povertyactionlab.org/resource/data-quality-checks
Poverty Action Lab Questionnaire Piloting guidance	https://www.povertyactionlab.org/resource/questionnaire-piloting
Poverty Action Lab Survey Design guidance	https://www.povertyactionlab.org/resource/survey-design
UNSD Designing Household Survey Samples: Practical Guidelines (PDF)	https://unstats.un.org/unsd/demographic/sources/surveys/handbook23june05.pdf
UNSD Household Sample Surveys in Developing and Transition Countries (PDF)	https://unstats.un.org/unsd/publication/seriesf/seriesf_96e.pdf
WHO Training for Mid-Level Managers on EPI Coverage Surveys	https://apps.who.int/iris/handle/10665/337065
WHO Vaccination Coverage Cluster Surveys Reference Manual (and questionnaires)	https://apps.who.int/iris/handle/10665/272820
Vaccination Coverage Quality Indicators (VCQI) (PDF)	http://www.biostatglobal.com/downloads/VCQI%20Indicator%20List%20with%20Specifications.pdf

SB.6 Survey questionnaires

Demographic and Health Surveys (DHS) questionnaires	https://dhsprogram.com/Methodology/Survey-Types/DHS-Questionnaires.cfm
Multiple Indicator Cluster Surveys (MICS) questionnaires	https://mics.unicef.org/tools
Living Standards Measurement Study (LSMS) questionnaires	https://documents.worldbank.org/en/publication/documents-reports/document-detail/155591468781810134/volume-three