



METHODOLOGY

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# A two-stage cluster sampling method using gridded population data, a GIS, and Google Earth™ imagery in a population-based mortality survey in Iraq

Lindsay P Galway<sup>1</sup>, Nathaniel Bell<sup>2</sup>, Sahar AE Al Shatari<sup>3</sup>, Amy Hagopian<sup>4</sup>, Gilbert Burnham<sup>5</sup>, Abraham Flaxman<sup>4</sup>, William M Weiss<sup>5</sup>, Julie Rajaratnam<sup>4</sup> and Tim K Takaro<sup>1\*</sup>

## Abstract

**Background:** Mortality estimates can measure and monitor the impacts of conflict on a population, guide humanitarian efforts, and help to better understand the public health impacts of conflict. Vital statistics registration and surveillance systems are rarely functional in conflict settings, posing a challenge of estimating mortality using retrospective population-based surveys.

**Results:** We present a two-stage cluster sampling method for application in population-based mortality surveys. The sampling method utilizes gridded population data and a geographic information system (GIS) to select clusters in the first sampling stage and Google Earth™ imagery and sampling grids to select households in the second sampling stage. The sampling method is implemented in a household mortality study in Iraq in 2011. Factors affecting feasibility and methodological quality are described.

**Conclusion:** Sampling is a challenge in retrospective population-based mortality studies and alternatives that improve on the conventional approaches are needed. The sampling strategy presented here was designed to generate a representative sample of the Iraqi population while reducing the potential for bias and considering the context specific challenges of the study setting. This sampling strategy, or variations on it, are adaptable and should be considered and tested in other conflict settings.

**Keywords:** Cluster sampling, Population-based survey, Mortality, Conflict, Iraq war, Geographic information system (GIS), Google Earth™

## Background

Monitoring civilian mortality in conflicts can help target humanitarian assistance and minimize loss of life among those caught up in conflict. While in stable situations surveillance of mortality using vital registration systems is the gold standard, these systems are rarely functional during conflicts and are often nonexistent where major conflicts occur [1-3]. Alternative approaches, such as passive surveillance through news media or press reports have been shown to under-record deaths and may be

distorted by political agendas [4]. Consequently, epidemiologists are often limited to estimating mortality using retrospective population-based surveys at the household level [5]. In these, a representative sample of consenting households is selected to assess mortality events over a given time period, and mortality rates, along with their upper and lower confidence intervals, are calculated [5]. These calculations can also be compared to other time points to estimate excess mortality related to a conflict. However, simple random and systematic random sampling methods are difficult during conflict given data unavailability and logistical and security constraints [6,7].

One alternative approach is to apply cluster sampling to estimate conflict-related mortality rates. Two-stage

\* Correspondence: ttakaro@sfu.ca

<sup>1</sup>Faculty of Health Sciences, Simon Fraser University, Blusson Hall 8888 University Drive, Burnaby, B.C, Canada V5A 1 S6, USA

Full list of author information is available at the end of the article

cluster sampling was standardized in 1978 by the World Health Organization's Expanded Programme on Immunization (WHO EPI) to assess vaccine coverage and has since been extended to estimate conflict-related mortality in Iraq [8,9], Kosovo [10], the Democratic Republic of Congo [11], and Sudan [12]. This approach is relatively fast, can be done with limited financial and human resources, and exposure to unsafe areas can be limited. Additionally, a complete sampling frame is not required. These are all very important considerations in conflict settings.

In conventional two-stage cluster sampling, the first sampling stage involves the selection of a predetermined number of clusters. Clusters are mutually exclusive subpopulations, most frequently constructed from recognized administrative boundaries [13]. Clusters are selected from a list of primary sampling units (e.g. census areas, township boundaries) with the probability of selection proportional to population size (or estimated population size) [14]. In the second stage, starting households are selected from each cluster. As complete and adequate listings of households rarely exist, households are not selected from a sampling frame. Rather, they are selected by the survey team in the field based on a random procedure [15]. Most commonly, starting households are selected in the field based on the "random walk" method, which involves identifying the center of the cluster, or another easily distinguishable feature such as a main street, and selecting a random direction to walk, thus drawing a transect across the cluster. In practice, the random direction is often selected by "spinning a pen" [16]. Among those households that lie along the transect, one household is randomly selected as the starting household and a predetermined number of next nearest households are surveyed. Ultimately, the data collected from each cluster are pooled to make inferences with respect to the target population and standard errors are adjusted for design effects of using a cluster sampling approach [6].

Despite the benefits of this WHO EPI-type cluster sampling, the validity of this approach has been questioned [17]. Most criticisms are related to the potential for bias in the second stage when using the "random walk" approach, which has been shown to introduce bias if the household selection procedure is not in fact random [7,14,16,18,19]. In addition, this approach is subject to interviewer bias, whether conscious or unconscious, and can take a significant amount of time to implement in the field. Too much field time exposes survey team members to risk in conflict settings. It is also impossible to calculate the probability of selection at the household level, so the sample is not a true probability sample [14].

To date, a few variations on this conventional cluster sampling approach have been developed for application

in nation-wide health studies. Relevant examples that have been used and show promise for certain settings include compact segment sampling [14,20] and random spatial sampling using global positioning system (GPS) coordinates [16]. However, these approaches may not be appropriate in conflict settings. Compact segment sampling requires a significant amount of field time exposure and two visits to each cluster [15] while the use of GPS units is often a security risk in the context of modern warfare [9]. Variations on the conventional two-stage cluster sampling designed for nation-wide mortality estimates in conflict settings are needed to generate accurate and useful mortality estimates and to contribute to theoretical and practical advances in the field of conflict epidemiology [21].

This paper presents a two-stage cluster sampling method implemented in a retrospective mortality study in Iraq. Our goal was to develop a cluster-based sampling method while taking into consideration the specific challenges of conflict settings. Our cluster sampling uses a gridded population dataset and a spatial sampling algorithm in a geographic information system (GIS) to select clusters in the first stage. Starting households are selected in the second stage using imagery and a sampling grid in Google Earth™ [22].

## Methods

We received University of Washington Institutional Review Board approval for the study, and also received approval from the Ministries of Health in Baghdad and in Kurdistan. Methods were reviewed to ensure they complied with the ethical guidelines for epidemiological research set out by the Council for International Organizations of Medical Sciences. An ethicist experienced in international research associated with the Institute of Translational Health Sciences at the University of Washington further reviewed the protocols to ensure the safety of subjects and interviewers was adequately protected. Additionally, Simon Fraser University's Research Ethics Board approved the use of secondary data for this project.

## Data and Tools

The sampling method uses a gridded population dataset in the first stage of sampling. As a preliminary step, we reviewed a number of spatial population datasets. To date, three high resolution global gridded population datasets have been generated and used in epidemiological studies: the Gridded Population of the World (GPWv3) [23], Global Rural–Urban Mapping Project (GRUMPv1) [23], and LandScan™ [24]. These datasets use different interpolation methods to generate gridded population counts (see Table 1). These differences are important in selecting the most appropriate spatial

population dataset. Each dataset is publically available (for research and public health purposes), accessible on-line, and can be easily integrated into most GIS platforms. If available, an alternative is to use country-specific datasets, which exist for many countries in Africa (see Afripop Project, 2011 and United Nations Environment Programme Gridded Population Databases) [25,26]. We selected the LandScan™ dataset for reasons described below.

In our approach, the first cluster sampling stage uses the ‘Create Spatially Balanced Points’ (CSBP) function in the ArcGIS (v10) software platform. This tool uses a spatial sampling algorithm based on the work of Theobald et al. (2007) [31] and Stevens & Olsen (2004) [32]. It uses a probability surface depicting relative probabilities of inclusion and a Reversed Randomized Quadrant-Recursive Raster (RRQRR) algorithm to randomly generate a set of spatially balanced points [31,32]. The probabilities of inclusion can be based on any relevant attribute, but the use of population size enables the application of a probability proportional to estimated size (PPES) approach. When using population data to generate the probabilities of inclusion, a sample that mimics the distribution of the target population is generated. This allows researchers to analyze the final dataset without weighting or other constructs to create a full population estimate.

Administrative boundaries are required to implement the sampling strategy presented here. Current and spatially referenced administrative boundaries (at the country, provincial, and district scale) can be downloaded from the Global Administrative Areas website in shapefile format for nearly all nations in the world [33].

Imagery in the Google Earth™ platform is used in the second stage of the sampling method. Google Earth

™ maps the earth by the superimposition of images obtained from satellite imagery and aerial photography (images from airplanes, kites and balloons) [34]. This is a particularly useful tool for public health and conflict epidemiology as it has no financial cost, is easy to use, and can interact with other mapping technologies. Although the resolution, quality, and age of the imagery varies across the globe, it is generally possible to identify individual household rooftops.

#### Gridded Population Dataset Selection

We selected the 2008 LandScan™ gridded population dataset to depict the population of Iraq. The 2008 LandScan™ population data were obtained from the Oak Ridge National Laboratory [24]. This dataset was selected over others for these reasons:

- *Theory:* We preferred the “smart interpolation” approach over the areal weighting approach for the disaggregation of sub-national population counts to grid units. Smart interpolation uses numerous sources of ancillary data (i.e. land cover, road network, slope, etc.) and does not assume that populations are uniformly distributed across space within administrative units [35].
- *Timeliness:* The 2008 LandScan™ dataset offered the most up to date spatial population dataset available. Both GRUMP and GPW were released in 2000. Since a census has not been conducted in Iraq for decades, all population datasets are based on out-dated census information. However, the ancillary data used to disaggregate population data, land cover data for example, is most recent for the LandScan™ dataset.

**Table 1 Overview of gridded population datasets currently available**

Dataset	Provider (website)	Spatial resolution	Input population data source	Interpolation method	Ancillary data	Year(s)
GPWv3.0	CIESIN ( <a href="http://sedac.ciesin.columbia.edu/gpw/">http://sedac.ciesin.columbia.edu/gpw/</a> )	2.5' (~5 km <sup>2</sup> )	UNPD census data	Areal weighting <sup>1</sup>	-None	1990,1995, 2000, 2005 (projection), 2010 (projection), 2015 (projection)
GRUMPv1	CIESIN ( <a href="http://sedac.ciesin.columbia.edu/gpw/">http://sedac.ciesin.columbia.edu/gpw/</a> )	.5' (~1 km <sup>2</sup> )	UNPD census data	Dasymetric mapping <sup>2</sup>	-Night-time light imagery -Populated places	2000
LandScan™	ORNL ( <a href="http://www.ornl.gov/sci/landscan/">http://www.ornl.gov/sci/landscan/</a> )	.5' (~1 km <sup>2</sup> )	Population Division of the U.S. Census Bureau	Smart interpolation <sup>3</sup>	-Land cover -Road networks -Digital elevation models -Slope -Satellite imagery	2008

Adapted from [27].

<sup>1</sup> Areal weighting overlays a grid onto sub national administrative unit population data and distributes the population across space according to the proportion of the administrative unit area that is contained within the grid cell [28].

<sup>2</sup> Dasymetric mapping disaggregates sub national population estimates into grid units using ancillary data such as road networks [28,29].

<sup>3</sup> Smart interpolation disaggregates sub national population estimates to grid cells according to likelihood co-efficients of population occurrence derived from ancillary data such as proximity to roads, slope, land cover [30].

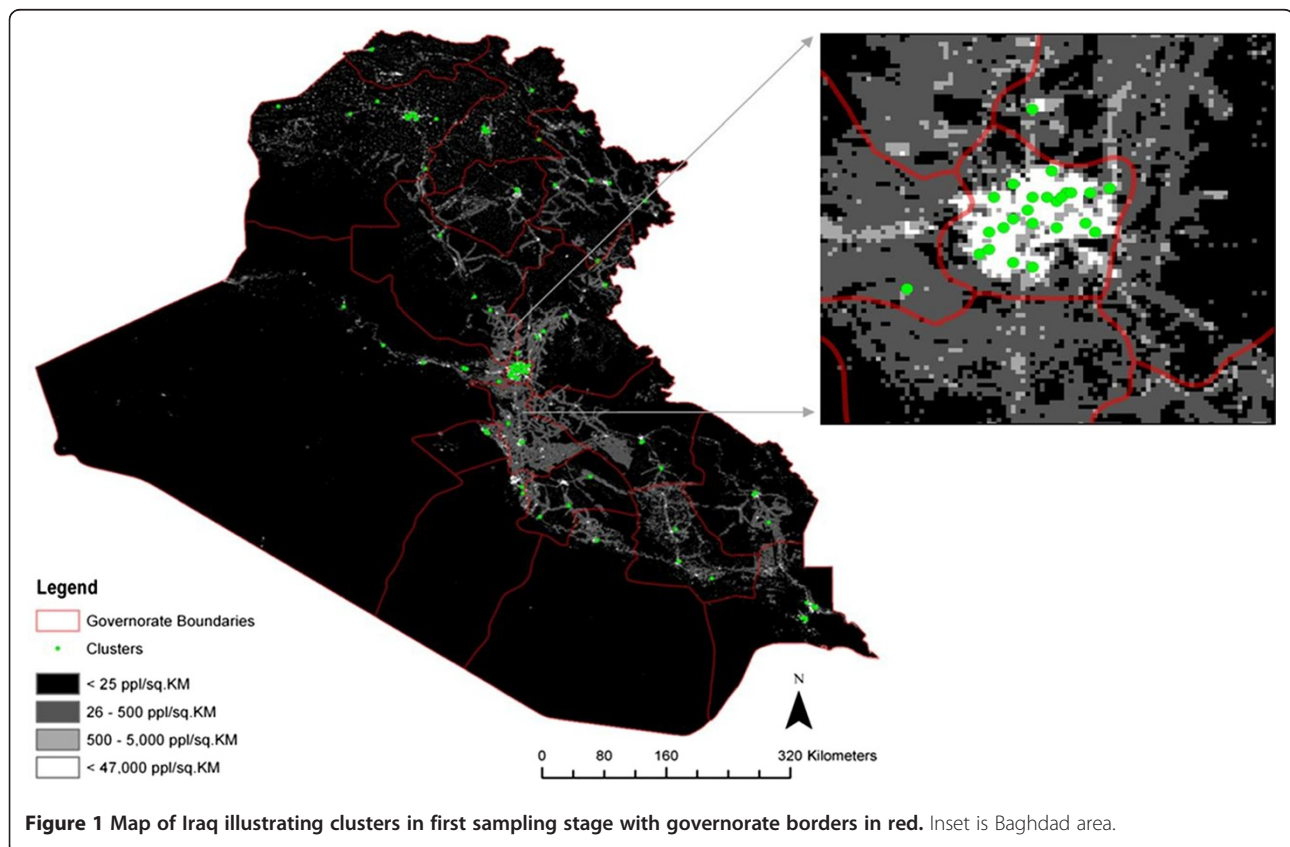
- *Validation in study area:* Mubareka's 2008 study conducted in Northern Iraq found the LandScan™ dataset correlated with settlements and population distribution on the ground [36].
- *Validation in other conflict settings and limited resource areas:* A review entitled "Tools and Methods for Estimating Populations at Risk from Natural Disasters and Complex Humanitarian Crises" recommended that the LandScan™ population estimates tend to be better than other population sources in countries where the census data are spatially coarse and not recent, which is the case in Iraq [37].

### Stage 1- Cluster Selection

In the first stage of sampling, we used the 2008 LandScan™ gridded population dataset and the CSBP tool to randomly select a sample of clusters weighted by estimated population size. The 2008 LandScan™ gridded population dataset was downloaded in ESRI Grid format at the global scale, masked to the spatial extent of the Iraq administrative boundary and converted to a density grid. Using this raster (see Figure 1), we identified those grid cells with 25 people per km<sup>2</sup> or fewer. These grid cells were assigned a probability of zero

as they were unlikely to contain the minimum 20 households required for the survey design. For all other grid cells, we standardized the population dataset to create a probability surface. The probability surface is a raster layer with values ranging from 0 to 1, indicating the probability of inclusion for each grid cell. Higher values indicate a higher probability of inclusion. Here the probability of inclusion is based on population estimates according to LandScan™ 2008 data.

We then used the CSBP tool to randomly generate 125 points according to the probability surface and the RRQRR algorithm. The grid cells containing one of the 125 points were then selected as possible clusters and numbered 1–125. Next, the 125 selected clusters were exported as a KML (Keyhole Markup Language) file for use in the Google Earth™ platform. Using the Google Earth™ satellite imagery, we visually examined all 125 clusters to identify any that were clearly not residential areas. Among these original 125 clusters, 12 were obviously either industrial areas, commercial areas, or otherwise not residential and were thus excluded from the initial sample set. Using the remaining 113 suitable clusters, we numbered the first 100 and held the remaining 13 clusters as a set of "backup" clusters that could replace any cluster



**Figure 1** Map of Iraq illustrating clusters in first sampling stage with governorate borders in red. Inset is Baghdad area.

deemed unsafe or otherwise inaccessible at the time of the survey.

### Stage 2- Starting Household Selection

In the second stage of sampling, we needed to select a starting household in each of the first-stage clusters. The starting households were randomly selected using a sampling grid superimposed over satellite imagery in the Google Earth™ platform (see Figure 2). Sampling grids were generated in ArcGIS at a resolution of 10 meters by 10 meters (10 m by 10 m) that corresponded to the spatial extent of each cluster. A resolution of 10 m by 10 m was selected for the sampling grid to approximate the extent of a single rooftop. These sampling grids were exported as KML files and subsequently superimposed onto satellite imagery in Google Earth™. We assigned each 10 m by 10 m cell within the sampling grid a unique number, enabling the selection of a single grid cell using a random number generator. If that grid cell contained a household, ascertained through visual assessment of satellite imagery, that household was marked using the “Add Placemark” tool. If the grid cell did not contain a household, we moved to the next randomly selected grid cells until a cell containing a household was selected. In the event that more than a single rooftop existed within the selected grid cell, the household with a greater proportion of its rooftop contained within the cell was selected. The same steps were followed to select “back-up” starting households in each cluster in the event that a household no longer existed, was not a residential building, or was not accessible for security reasons.

## Results and Discussion

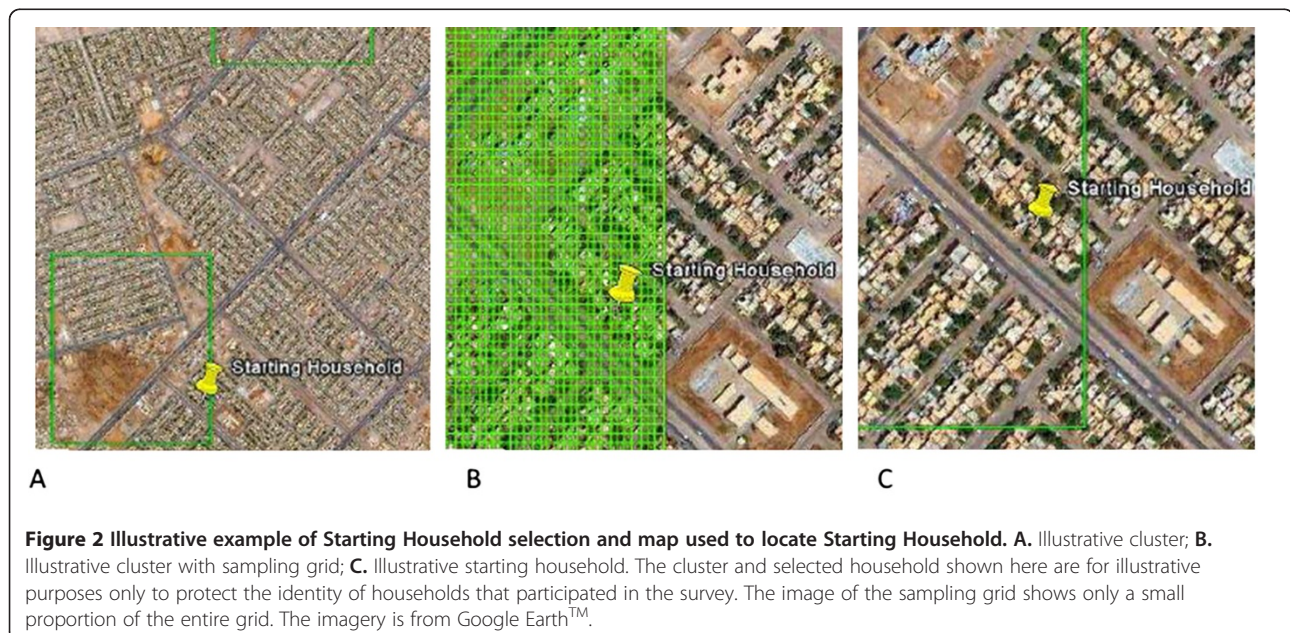
### Application: Iraq 2011 University Collaborative Mortality Study

This sampling method was designed for a retrospective population-based study aimed at estimating mortality in Iraq: the Iraq 2011 University Collaborative Mortality. This study was carried out in 2011 and was designed to update and extend earlier mortality estimates published in 2004 [9], 2006 [8], and 2008 [38]. The 2011 Iraq mortality study used a standard household demographic method and a sibling survival technique [15,39]. Results of the Iraq 2011 University Collaborative Mortality Study are expected in 2012. A power calculation informed the original sampling design, leading to the selection of 100 clusters with 20 households per cluster, for a plan to sample 2,000 households.

### Survey Preparation and Implementation

GPS devices could not be used to locate starting households as laws prohibiting the use of this technology by Iraqi civilians made this an unacceptable security risk. Consequently, printed maps were used. For each cluster, we created maps at different scales. To help survey teams locate households efforts were made to produce maps that included easily identifiable structures such as water towers, highways, or mosques. As part of five day initial field training, two days were spent in map reading and orienteering. Teams quickly became adept at locating clusters and households using maps, which was verified in a second training session.

The 2011 Iraq mortality survey was carried out between May and July 2011 by four teams of Iraqi medical



doctors with training in family medicine and community medicine and previous household survey experience. There were two supervisors each managing and monitoring the work and progress of two of the survey teams. We were fortunate that one of our project supervisors was particularly enthusiastic and adept in the use of maps. We also employed a person in each governorate who had local knowledge of the landscape. Only one (0.01%) of the 100 clusters selected for the original sample could not be visited because of safety concerns; this cluster was replaced with one of the remaining 13 “back-up” clusters from the same governorate.

### **Feasibility and Methodological quality**

In designing a cluster survey trade-offs and contextual factors must be considered to balance feasibility and methodological quality [40]. As there are few alternatives to cluster samples in conflict situations our goal was to improve methodological quality in a practical and feasible field approach. We believe that this adapted two-stage cluster sampling method meets these goals.

#### **Feasibility**

The feasibility of doing research in conflict-settings is always balanced by the requirement for rigorous protocols [41]. Factors influencing feasibility include survey team safety, time required for research, resources and expertise needed, and financial costs.

*Safety of survey team:* Safety of the survey team is not merely related to feasibility but is also an important ethical consideration [41]. In our study, the use of GPS to identify starting households was viewed as a significant safety threat; this is likely to be the case in other conflict settings. The maps allowed teams to move directly to the starting household without the extended exposure needed for the “random walk” method. Using a local facilitator to help locate starting households can reduce risk to the survey team.

*Time:* The element of time must be considered in terms of both preparation time (generating a sample selection prior to field work) and the amount of time in the field. Selection of the clusters, which included gathering and preparing the data used, took approximately 1 week for a single researcher. The process of selecting households and preparing the maps required approximately 2 weeks for a single researcher. Time needed in the field tended to vary depending on the setting. If the starting household was located in an urban setting or near an identifiable landmark, the household was identified quickly and with ease. This task was more time consuming and difficult for remote settings. The use of a local person with knowledge of the territory facilitated the task of locating a starting

household. The ability to examine cluster and household locations before going into the field using Google Earth™ proved helpful to field teams, and in areas where access was restricted by checkpoints and barriers permitted scouts to locate the site a day in advance and guide the survey teams the following day. *Resources and expertise:* All of the datasets used are free and publically available for research purposes. The same is true for the Google Earth™. ArcGIS however, requires a purchased licence. While expertise in GIS software is needed to carry out the steps in the two first stages of sampling, comparably less training is required to orientate survey teams in map reading and orienteering. We recommend employing at least one ground-level supervisor with a knack for geography and maps.

*Financial cost:* The financial costs related to the implementation of this sampling method are not large. Although the costs associated with the GIS software can be substantial, most institutions have some access to GIS software. Additionally, free or low-cost alternatives to ArcGIS could be considered (e.g. GRASS) [42,43]. Free and high-quality imagery from Google Earth™ produces substantial savings over commercial imagery providers. Additionally, using maps rather than purchasing GPS units is a cost savings approach. Even in situations where GPS units are not a security concern the use of printed maps is a low-cost alternative for localizing sites [44].

#### **Methodological quality**

Tapp et al. [2008] present quality indicators for retrospective mortality surveys in complex emergencies [45]. Two of the five indicators, coverage and bias, are specifically related to sampling design and are discussed below in relation to the method presented here.

*Coverage:* Is the sample sufficiently representative of the underlying population of interest [45]? To answer this question, we examined the coverage of our sample in terms of regional distribution across administrative units and urban–rural status in comparison to the Iraqi population in general (see Table 2). Regional distribution and urban–rural status are important factors, as violence and therefore mortality risk are presumably influenced by both. We examined the percentage of total clusters and households in each governorate (an administrative unit akin to a province or state) compared to the percentage of the Iraqi population in each governorate. These comparisons suggest that our sample sufficiently captures the regional distribution of the underlying Iraqi population. The extent of urban–rural coverage of our sample was assessed by identifying those clusters located in urban

regions and those located in rural regions and comparing the urban–rural proportion of our clusters to the national urban–rural proportion. We classified clusters as urban or rural based on local knowledge of survey team supervisors as there were no adequate data available identifying urban–rural status at the local level. Urban regions are defined here as metropolitan cities, towns, or peri-urban areas while rural areas are defined as remote communities with low population density. Based on best available estimates, the urban–rural divide in Iraq is approximately 66 percent urban to 34 percent rural (UN population data [46], US census Bureau [47], and Iraq’s Central Organization for Statistics and Information [48] all provide estimates between 66 percent and 67 percent) According to our classification of clusters as urban or rural, 31 percent of the sample is rural while 69 percent is urban. Our sample has slightly over-sampled the urban population, which is to be expected as we excluded the very remote areas in our sampling strategy to ensure that cluster locations had at least 20 households. Nonetheless, the urban–rural coverage in our study is very close to the estimated national average.

*Bias:* As Tapp et al. (2008) highlight [45] an important quality consideration for retrospective surveys is whether the population was sampled to avoid bias.

The sampling method presented here was designed to reduce the potential for sampling bias by randomly-selecting both clusters and households prior to field work. We also took into account criticisms regarding the sampling strategy used in the 2006 Iraq mortality study, especially what some authors have referred to as a “main street bias.” Using sampling grids enables simple random selection of households to minimize the possibility of systematic selection of certain regions and further removes the possibility of conscious or unconscious interviewer bias by selecting households a priori.

Nevertheless, the sampling method described here does have several potential sources of bias, mostly stemming from the population size from which clusters were defined [17]. The LandScan 2008™ population data for Iraq is not based on official 2008 census data, but rather uses estimated population figures derived from the most recent national census. A complete national census has not been conducted in Iraq since 1987 (although a partial census excluding Kurdish regions was carried out in 1997). A full Iraqi census has been planned since the early 2000’s but has been repeatedly postponed [48]. Both internal and external displacement have been significant in Iraq since the US-led invasion in 2003; it is unlikely that any extrapolated population estimate has

**Table 2 Sample selection clusters across Iraqi governorates for 2011 Iraq mortality study, compared to Iraq population estimates**

Governorates	Estimated population <sup>1</sup>	Percentage of Iraqi population	No. of clusters	Percentage of sample	Difference (pop% - sample%)	No. of individuals <sup>2</sup>	Percentage of sample	Difference (pop% - sample%)
Al-Anbar	1,451,583	4.52	7	7	-2.48	990	9.28	-4.76
Al-Muthanna	719,824	2.24	1	1	1.24	142	1.33	0.91
Al-Najaf	1,180,681	3.68	2	2	1.68	200	1.88	1.80
Al-Qadisiya	1,121,782	3.49	4	4	-0.51	580	5.44	-1.95
Babil	1,727,032	5.38	3	3	2.38	353	3.31	2.07
Baghdad	7,180,889	22.37	23	23	-0.63	2,347	22.01	0.36
Basrah	2,555,542	7.96	8	8	-0.04	882	8.27	-0.31
Diala	1,370,537	4.27	5	5	-0.73	463	4.34	-0.07
Duhouk	968,901	3.02	2	2	1.02	284	2.66	0.36
Erbil	1,471,053	4.58	9	9	-4.42	803	7.53	-2.95
Kerbala	1,003,516	3.13	2	2	1.13	219	2.05	1.08
Kirkuk	1,290,072	4.02	2	2	2.02	201	1.89	2.13
Missan	1,009,565	3.14	3	3	0.14	308	2.89	0.25
Ninevah	3,237,918	10.09	13	13	-2.91	1,298	12.17	-2.08
Salahuddin	1,259,298	3.92	3	3	0.92	312	2.93	0.99
Sulaimaniya	1,551,974	4.83	7	7	-2.17	663	6.22	-1.39
Thi Qar	1,846,788	5.75	3	3	2.75	308	2.89	2.86
Wasit	1,158,033	3.61	3	3	0.61	310	2.91	0.70

<sup>1</sup> Estimated 2009 population According to Central organization for statistics and Information Technology [COSIT] estimates.

<sup>2</sup> Total number of individuals based on reported household members.

accurately captured the complex patterns of population movement [49]. It is estimated that there are up to 2.5 million Iraqis who have fled Iraq to neighbouring countries and at least that number who have internally migrated principally due to violence [50]. It is difficult to estimate how the use of out-dated population figures and migration affects sampling and the potential for bias. It is likely that there are important implications, perhaps with mortality in the most violent regions underestimated, and violence in areas receiving internally displaced being overstated.

The construction method of the LandScan<sup>TM</sup> dataset may also introduce bias. The smart interpolation approach employed by LandScan<sup>TM</sup> uses ancillary data such as road networks and satellite imagery to define occupation probabilities for all grid cells in a raster grid [51]. Assumptions made in generating these grid cell occupation probabilities, that people are most likely to live along roads for example, may not reflect true population distribution on the ground in some areas. In the field we did not encounter problems due to this theoretical limitation.

Lastly, the use of Google Earth<sup>TM</sup> imagery may also introduce bias as images can be out-dated, thereby excluding recent development. This is especially problematic if the newly developed communities have differential mortality experiences. In our study, imagery dates range from 2002 to 2011, with the majority (70%) from late 2004. It is possible that households not captured in older imagery could be families fleeing more violent areas and therefore families with higher probability of mortality events. Google Earth<sup>TM</sup> satellite imagery may thereby select households that underestimate mortality. It is also important to note that Google Earth<sup>TM</sup> satellite imagery does not cover every region of the globe with high resolution images such that individual rooftops may not be identifiable. If this is the case, alternative sources of imagery may be needed.

We should note the measures of bias are both objective and subjective. Our own surveyors expressed concerns that this study sample appeared to minimize the enumeration of mortality events by the choice of too many clusters in remote areas and potentially protected populations (such as oil worker company enclaves) and not capturing mortality events among families that fled the country.

## Conclusion

For a variety of political and economic failures, conflict affects many populations around the world. Given increasing resource constraints, economic instability, dwindling oil supplies, and food and water stress due to climate change, global conflicts are not likely to decrease. There is a dearth of published work regarding both the population impacts of conflict and appropriate

methods for studying the public health effects of conflict [41]. Although subject to certain limitations, retrospective population-based mortality studies are an important tool in conflict epidemiology. Sampling is a challenge in such studies and alternatives that improve on the conventional cluster approach are needed. As Morris & Nguyen note in their review of cluster sampling used in humanitarian emergencies, we need to “look beyond the standard methods for measuring mortality” [6]. Adapting conventional cluster sampling and using novel data sources, tools, and technologies can improve the overall validity of retrospective survey estimates and support the feasibility of research in challenging conflict settings. The sampling strategy presented here was designed to generate a sample representative of the Iraqi population. We sought to reduce the potential for bias while considering the context specific challenges of the study setting. When designing sampling methods for retrospective population-based mortality surveys, researchers must consider all available methods, options for improving and adapting these methods for a particular setting and endpoint, and the implications for feasibility and study validity. This sampling strategy, or variations on it, are adaptable and should be tested in other conflict settings.

## Competing interests

The authors declare that they have no competing interests with regards to this manuscript.

## Authors' contributions

All authors participated in the design and conceptualization of the sampling method. LPG carried out the sampling steps and wrote the initial draft of the manuscript. All authors provided valuable feedback on the method and contributed to the writing of the manuscript. All authors read and approved the final manuscript.

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## Author details

<sup>1</sup>Faculty of Health Sciences, Simon Fraser University, Blusson Hall 8888 University Drive, Burnaby B.C Canada V5A 1 S6, USA. <sup>2</sup>Department of Surgery, University of British Columbia, West Mall, Vancouver BC, Canada. <sup>3</sup>Human Development and Training Center, Iraqi Ministry of Health, Iraq. <sup>4</sup>School of Public Health, University of Washington, Seattle WA, USA. <sup>5</sup>School of Public Health, Johns Hopkins University, Baltimore MD, USA.

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