Population mortality before and during armed conflict in Yemen: geospatial and statistical analysis of cemetery data

Non-technical briefing note

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What was this study about?

Yemen has been affected by widespread armed conflict since late 2014, and more recently by the COVID-19 pandemic. Displacement, epidemics and high food prices are thought to have further compromised the health of Yemenis, but there are few data quantifying this impact.

Over the past three years, we have carried out several studies to try to estimate **to what extent the crisis in Yemen has affected human survival**, or more specifically the population's death rate.

The main challenge in our project was **limited access to affected populations**, which prevented us from doing large-scale ground data collection. To circumvent this, in this specific study we explored the use of very high-resolution satellite imagery to track cemetery burials over time. The study followed a **promising, but smaller-scale experimentation of this method in the city of Aden** (see this paper and web page).

To our knowledge, this is the **first instance** of this approach being used at large scale. As such, a secondary aim of the study was to document how feasible this kind of analysis really is, and what challenges it may present.

How was the study done?

Firstly, we used a variety of sources, including publicly available satellite imagery, online mapping software, networks of contacts and geographers within Yemen, to **identify potential cemeteries** in a random sample of **24 subdistricts** across the country, namely a population of almost 2 million as of 2021.

We then purchased the **highest-resolution satellite images** commercially available for the period from 2011 to 2021, and which covered as many of the cemeteries as we were able to clearly locate. We applied a set of image processing techniques to **improve the visibility** of graves and cemetery boundaries. We kept in the analysis any cemeteries for which we could generate at least two sufficient-quality images from different time points. All these images were annotated by a group of paid citizen analysts, supervised by experts; **annotation** included pinpointing graves and drawing the boundaries of the cemetery (see **Figure 1**).

Lastly, we applied **statistical models** to the remaining data to analyse how the rate of burial changed over time, and how it was affected by specific factors that relate to the crisis, including insecurity, high food prices and forced displacement.

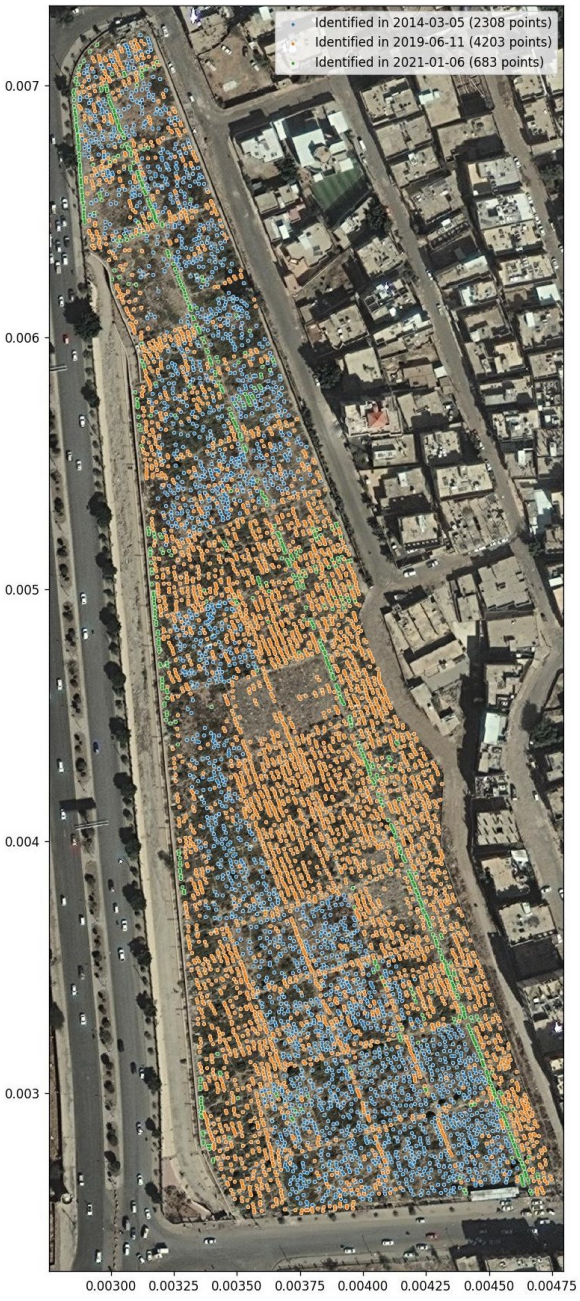

Figure 1. Example of an urban Yemeni cemetery at three different time points: graves are coloured according to when they were identified. Over time, walkways separating different cemetery blocks are filled in with graves, presumably due to space running out. Satellite image ® 2021 Maxar Technologies.

Who did the study, and how was this funded?

The United Kingdom government's Foreign, Commonwealth and Development Office funded the study as part of its humanitarian assistance activities. However, the UK government had no role in designing, implementing or analysing the study. The researchers acted independently.

The study was a **collaboration between the London School of Hygiene and Tropical Medicine**, a public university in the United Kingdom that carries out research and teaches students around the world on diseases and the health of populations, the **Satellite Applications Catapult**, a UK company that specialises in geospatial analysis in support of the private and public sector, and **1715 Labs**, a geospatial consultancy.

The study was authorised by the London School of Hygiene and Tropical Medicine. Unlike those used for military or intelligence purposes, the satellite images we had access to did not enable us to identify individual people.

What were the findings?

A limited final sample of data

While the method was experimental, we were optimistic about its feasibility based on the more limited experience in Aden. However, we encountered a variety of **challenges** with identification of possible cemeteries and the quality of available images, especially in more rural parts of Yemen.

Even where we did have a series of images across time for the same cemetery, image quality issues (see **Table 1**) forced us to exclude the image, or required additional analysis steps.

Table 1. Key issues encountered during image analysis.

Issue
1. Higher quality of recent images reveals previously undetected graves. For some cemeteries (particularly urban), increased image quality over time allowed identification of graves where previously not enough information had been available. For an example, see **Figure 4**.
2. Serious degradation of image quality over time. This made it hard to measure surface area changes and detect new graves.
3. Vegetation growth covers more recent images, partly impeding identification of new graves or surface area expansion.

These challenges greatly reduced our final sample size (see **Figure 2**) to only **35 cemeteries across 10 subdistricts**, only 17% of the cemeteries where we could actually see some graves. As such, the sample was no longer what we would consider representative of Yemen as a whole.

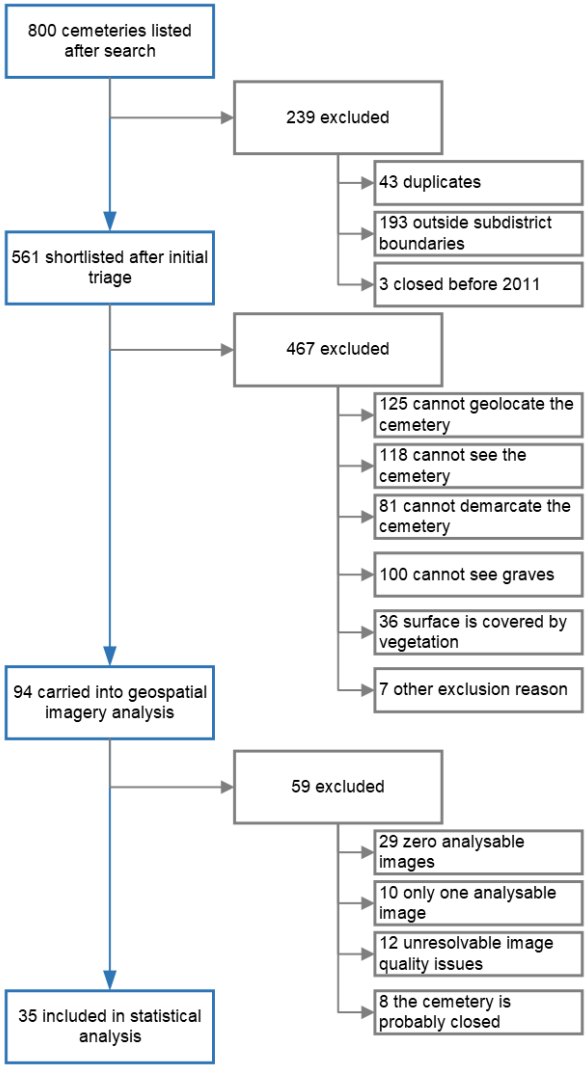

Figure 2. Flowchart of steps leading to final cemetery sample, with reasons for exclusion.

Burial patterns

Across the 35 cemeteries, the general pattern we observed was that the rate (frequency) of burials actually **decreased during 2014-2018** from its initial level in 2011-2013, only to **increase considerably from 2019 onwards**. Whether this pattern reflects the national trend is difficult to say given such a limited sample.

To look more closely at how crisis-related conditions have affected burials, we applied **alternative statistical models** to the data, combining what we saw in terms of burials with a variety of variables including image quality, terrain type, road density, availability of health facilities, etc. Critically, these variables included (i) the occurrence of insecurity events (e.g. battles, bombings), (ii) the price of staple cereal and (iii) the intensity of forced displacement. We then set these **three crisis variables** at the levels they had before the start of the war, and asked the model to predict how many burials would have occurred in this **hypothetical 'counterfactual' (no crisis) scenario**.

As shown in **Figure 3**, for most cemeteries the model predicted that the **burial rate was higher than it would have been in the absence of crisis conditions**, with the average across all cemeteries at 1.7 times higher. An alternative model yielded an average of 1.9. While burials increased in proportion to the occurrence of insecurity, they seemed to decrease as the price of cereal went up, which countered our expectations.

What do the results mean?

The sample of cemeteries we analysed is probably **too limited and unrepresentative** to make general statements about the situation in Yemen as a whole. We can cautiously say that, at least within the cemeteries we had data on, a **fairly consistent pattern** emerges, namely that burials were considerably higher than they would have been in the absence of a crisis.

Because we didn't have data for all cemeteries within the subdistricts, we cannot transform the burial rates we saw into **death rates**, i.e. how many people are passing away within the subdistricts' population, per unit time. We can cautiously assume that, the higher the burial rate, the higher the population death rate, but this might not be true if people in a given locality used different cemeteries preferentially over the ten-year period we analysed.

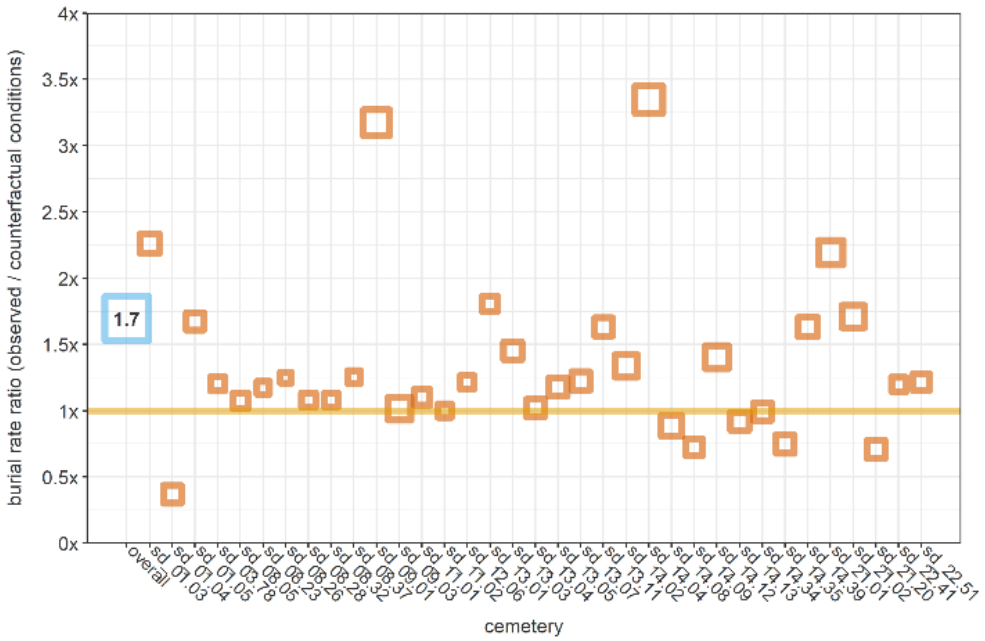

Figure 3. Ratio of model-predicted burials under the observed crisis conditions, versus under hypothetical 'no-crisis' conditions. Each square is a cemetery (square size indicates cemetery size). The overall average is shown in a blue square.

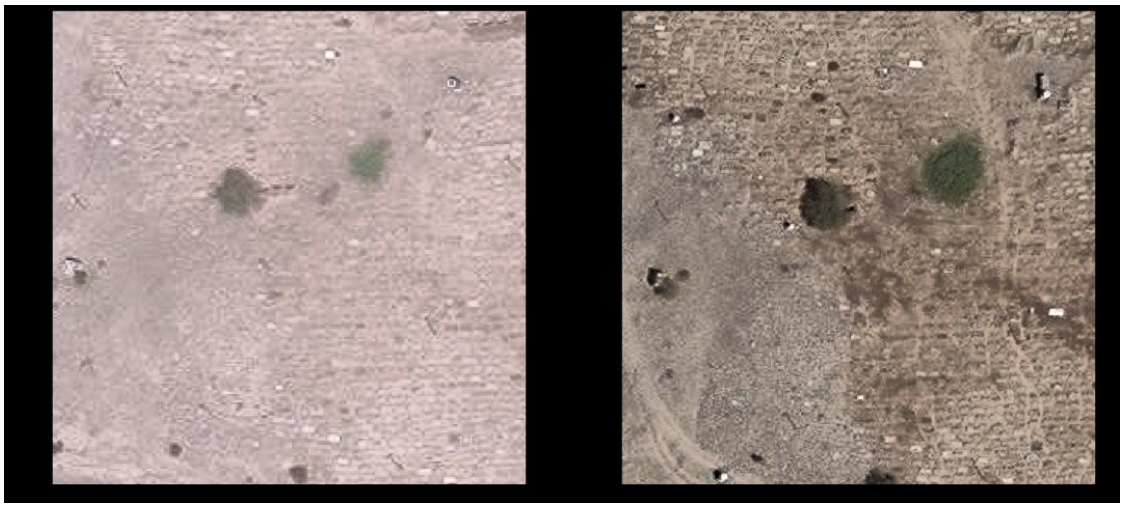

Figure 4. Example of improved image quality resulting in older graves becoming visible. Note how the latter, higher-quality image (right) shows graves that were likely already present when the earlier, lower-quality image (left) was acquired. Satellite image ® 2021 Maxar Technologies.

More broadly, this study produced useful information on **how satellite imagery can be used to analyse death rates at country level**: we now have a much better idea of the main challenges to expect, and how therefore to set up future studies using this source of data.

Questions and feedback

If you would like to share your feedback or ask further questions about the study, please contact Mervat.Alhaffar1@lshtm.ac.uk (Arabic) or Francesco.Checchi@lshtm.ac.uk (English). A **full report** containing more detail on the methods and results is being submitted to a scientific journal.