Refining intra-urban population mapping in sub-Saharan Africa: from land cover to land use

Catherine Linard
Université de Namur, Belgium

Taïs Grippa
Université Libre de Bruxelles, Belgium

PERN Cyberseminar on Application of Gridded Population and Settlement Products in Geospatial Population-Environment Research
14 – 18 October 2019

Introduction

Sub-Saharan Africa (SSA) is expected to face the highest urban growth rates in the next decades. From 33% today, the population living in urban areas is expected to reach 40% by 2030 and 50% by 2050 (1). As a consequence of these rapid transformations, SSA cities are exposed to increasing intra-urban inequalities and urban poverty (2). A large part of the urban population, especially the ones living in deprived and unplanned residential areas are extremely vulnerable to health and disaster risks.

In this context, detailed gridded population data is essential for improving evidence-based decision-making by relevant authorities and organizations, as well as for any application relying on a human population denominator, such as estimating the population at risk, assessing vulnerability, and deriving health or development goals indicators. However, this knowledge is often lacking in SSA. Population data are often outdated or unreliable and large-scale models used to disaggregate population data within administrative units fail to predict population densities with sufficient accuracy (Fig. 1), mainly because the default covariates used in the dasymetric mapping process lack spatial detail.

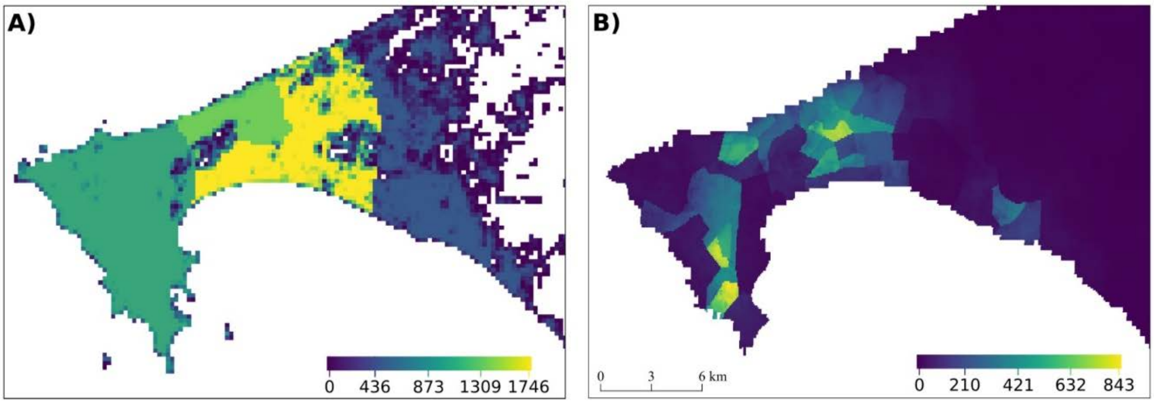

Fig.1: Population count estimates provided by two different gridded population products for the city of Dakar, Senegal. A) GHSL-POP (3), B) WorldPop (4).

This paper presents two ways to improve our intra-urban predictions of population densities in SSA based on remote sensing data. First, land cover data, more specifically the built-up density, was extracted from a fusion of optical and Synthetic Aperture Radar (SAR) in an automatized way. Second, very-high resolution (VHR) satellite data were used to derive land use information. The present paper briefly presents the two methods developed and then discusses the advantages and limitations of using VHR land use data for population mapping in SSA cities.

The city of Dakar, capital of Senegal, is used as a case study and population disaggregation methods are based on machine learning algorithms developed by the WorldPop project (4).

Extracting built-up density for population mapping

Whatever the approach used to model population distribution (expert-based or machine-learning), built-settlement layers are consistently among the most important predictors (5). However, land cover mapping – and especially the built-up class – remains a challenge in SSA cities because of (i) the high intra and inter-urban heterogeneity, (ii) the spectral confusion between built-up and bare soils that is specific to arid climates when using optical imagery, and (iii) the lack of good quality reference datasets. The two first issues can be tackled by using a combination of optical and SAR data. A recent study showed that OpenStreetMap (OSM), a growing volunteered geographic information database, can be used as training data in automated supervised classifications and often provide performances similar to manual approaches (6).

Automatized methods were therefore developed using optical (Landsat suite of satellite sensors), SAR (ERS, Envisat and Sentinel-1) and OSM data to extract the built-up density of 46 SSA urban areas for 5 different years (1995, 2000, 2005, 2010 and 2015) (7). Built-up layers were then used as additional covariates in population models (Fig. 2 A, C).

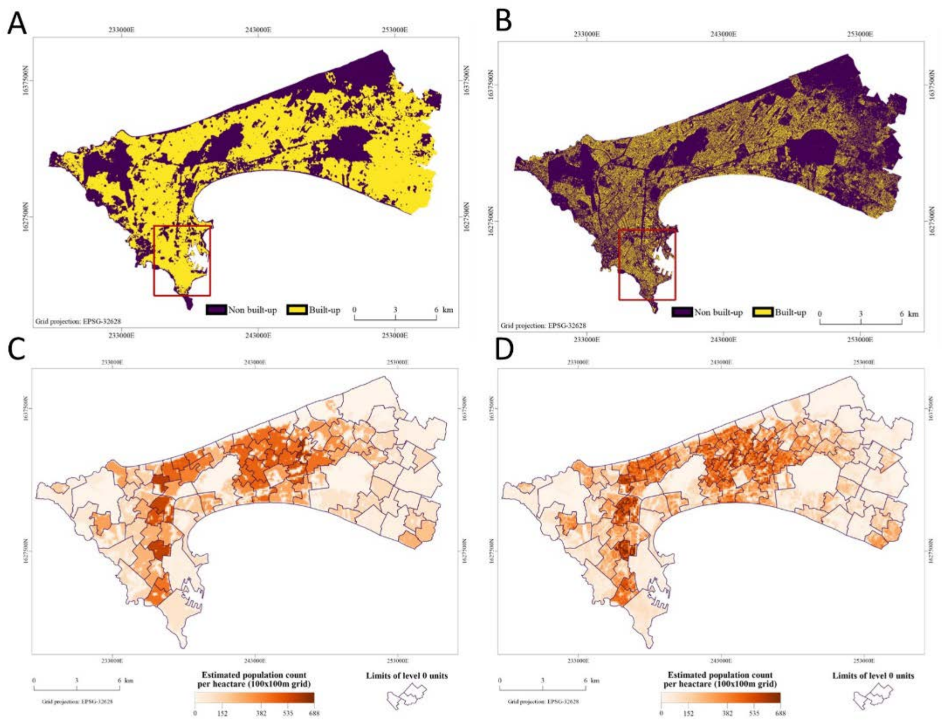

Fig.2: Built-up layers derived from (A) Medium resolution (MR; 10 m) freely available satellite Images and (B) Very-high resolution (VHR; 0.5 m) commercial satellite images, and population density maps derived from (C) MR land cover data and (D) VHR land cover and land use data for the city of Dakar, Senegal.

From land cover to land use

While built-up layers derived from medium resolution (MR) satellite information have proven their contribution to dasymetric population mapping, they still suffer from important limitations when working at the intra-urban level, mainly due to their difficulty in capturing the whole range of variation in terms of built-up densities and patterns. Very-high resolution (VHR) imageries allow to delineate every single building and extract neighbourhood-level spatial metrics, which add crucial information for identifying intra-urban heterogeneities.

A VHR land cover map derived from the Pleiades pan-sharpened tri-stereo images of 2015 (spatial resolution of 0.5 m) (8) was used to extract a set of spatial metrics on the building class and derive a map depicting the dominant land use at the street block level (9). This land use map distinguishes between several building classes: non-residential built-up (administrative, commercial and services), planned residential and deprived residential.

Results showed that accuracies of population maps derived from VHR data dropped significantly compared to population maps derived from MR land cover data (for the details of accuracy assessment methods, see (10)) (Fig. 2, C, D). Also, a combination of VHR land cover and land use data provided better results than VHR land cover or VHR land use only. The distinction made between planned residential areas and deprived residential areas from the LU layer appear among the most important predictors.

Discussion

Census data available for most of African cities suffer from a lack of spatial detail, with the majority of cities having only one administrative unit covering the whole urban area. Several population models have been developed to disaggregate population data from administrative units to finer gridded cells. Existing large-scale population distribution models typically use freely available remote sensing products, usually with a global coverage. This allows the models to be easily replicable, but often limits their use in applications covering small geographic extents such as urban areas. VHR remote sensing is known for its ability to better capture small variations in built-up densities and to derive detailed urban land use, which is – as expected – highly valuable for population mapping at the intra-urban level. Given the heterogeneities observed in rapidly growing African cities, being able to distinguish between high-density deprived areas, high/low density planned residential and commercial or administrative areas is key for health or vulnerability assessments and interventions at the neighbourhood level.

However, even if the price of VHR remote sensing data tends to drop slowly, it is still an important limiting factor for using such images in large-scale applications. In addition, VHR images require a much higher cost of processing, even if the automatization of methods has greatly improved in recent years. While the added value of VHR products is clear for population modelling in SSA cities – especially because of its ability to go from land cover to land use information –, the quantification of these benefits is important when evaluating the cost effectiveness of VHR data. Future research should look at the potential of the newly available Sentinel data, which could provide an interesting cost-efficient compromise between MR and VHR.

References

1. United Nations, *World Urbanization Prospects: The 2018 Revision* (United Nations Population Division, 2018).
2. United Nations Human Settlements Programme, ICLEI-Local Governments for Sustainability, United Cities and Local Governments of Africa, *The state of African cities, 2014: re-imagining sustainable urban transitions* (2014).
3. S. Freire, K. MacManus, M. Pesaresi, E. Doxsey-Whitfield, J. N. Mills, "Development of new open and free multi-temporal global population grids at 250 m resolution" in *Geospatial Data in a Changing World*, Springer Berlin Heidelberg, (2016).

4. F. R. Stevens, A. E. Gaughan, C. Linard, A. J. Tatem, Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data. *PLoS ONE* **10**, e0107042 (2015).
5. J. J. Nieves, *et al.*, Examining the correlates and drivers of human population distributions across low- and middle-income countries. *J. R. Soc. Interface* **14**, 20170401 (2017).
6. Y. Forget, C. Linard, M. Gilbert, Supervised Classification of Built-Up Areas in Sub-Saharan African Cities Using Landsat Imagery and OpenStreetMap. *Remote Sens.* **10**, 1145 (2018).
7. Y. Forget, M. Shimoni, M. Gilbert, C. Linard, Complementarity Between Sentinel-1 and Landsat 8 Imagery for Built-Up Mapping in Sub-Saharan Africa (2018) https:/doi.org/10.20944/preprints201810.0695.v1 (October 7, 2019).
8. T. Grippa, *et al.*, An Open-Source Semi-Automated Processing Chain for Urban Object-Based Classification. *Remote Sens.* **9**, 358 (2017).
9. T. Grippa, *et al.*, Mapping Urban Land Use at Street Block Level Using OpenStreetMap, Remote Sensing Data, and Spatial Metrics. *ISPRS Int. J. Geo-Inf.* **7**, 246 (2018).
10. T. Grippa, *et al.*, Improving Urban Population Distribution Models with Very-High Resolution Satellite Information. *Data* **4**, 13 (2019).