Can we estimate sub-Saharan Africa's population from remote sensing images and land cover mapping?

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Suivre les densités et la distribution spatiale de la population à distance est un rêve qui devient presque réalité. Il est très utile de connaitre la population de localités spécifiques pour la gestion ex-post des catastrophes, ou la planification nationale, en particulier dans des contextes où il est impossible d'accéder aux habitants pour une enquête ou un recensement - des situations de violence par exemple. C'est aussi précieux quand la population change rapidement - pour suivre l'ouverture d'un front pionnier ou l'expansion urbaine. Alors que le nombre de satellites ne cesse d'augmenter et que les initiatives de données ouvertes livrent un volume de plus en plus important de données satellitaires quotidiennes, les bases de données concernant la population et l'empreinte urbaine se multiplient également.

Monitoring population densities and distribution from afar is a dream almost come true. Knowing how many people reside in specific localities is useful in post-catastrophy management as well as for national planning, especially in contexts where access to population with surveys and censuses is impossible -situations of violence for instance. It is also precious when population changes fast – to monitor the opening of new frontier land, or the spread of fast-growing cities. As satellite numbers increase and open data initiatives deliver an increasing amount of remote sensing data on a daily basis, urban footprint and population databases multiply.

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Figure 1: Sentinel-2 satellite – high-resolution optical images.
Source: ESA, 2015 - www.copernicus.eu

Satellite data

According to the database compiled by experts from the Union of Concerned Scientists, a MIT related non-profit organisation[1], there are more than 5,465 satellites currently orbiting Earth used for communications, earth observation and monitoring or technology development. This number will keep increasing as launching costs and satellite sizes are getting lower. Among them, Earth Observation (EO) satellites have applications in defense, weather, environmental change or natural disaster monitoring. We list here some satellites commonly used for Earth monitoring. A useful and more comprehensive list is available online[2].

1 https://www.ucsusa.org/resources/satellite-database
2 https://en.wikipedia.org/wiki/List_of_Earth_observation_satellites

- Optical imagery (visible domain and near infrared)
  - Pléiades Neo[3], Airbus: multispectral imagery with up to 0.3m resolution, commercial with an academic program.
  - PlanetScope[4], Planet Lab: multispectral imagery with up to 3.7m resolution, commercial with an academic program. Launched in 2016.
  - Sentinel-2[5], ESA (Figure 1): multispectral imagery with up to 10m resolution with a high refresh rate. Launched in 2016.
  - Landsat[6], NASA: multispectral imagery with up to 30m resolution with a high refresh rate. Launched in 1972.
  - NightTimeLights (NTL)[7]: visible infrared for low-light emission sources to see the lights during the nights. Available since 1992.

- SAR Imagery (radar)
  - TerraSAR-x[8], DLR : SAR imagery up to 0.5m resolution.
  - Sentinel-1[9], ESA : SAR imagery up to 5m resolution.
- Spectrometer
  - Sentinel-5[10], ESA : atmospheric variables such as air quality.

Each type of imagery can have different applications linked to their characteristics, notably their spatial resolution. For example, Spot-5 and Sentinel-2 images can be used for mapping and long-term land use monitoring (Figure 2.a and Figure 2.c present such images of the district of Abidjan, the economic capital city of Ivory Coast, with inverted colours – vegetation in red). In the same way, Pléiades images are very high resolute products available on request for tasks requiring more accurate observation such as natural disaster monitoring.

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3 https://www.intelligence-airbusds.com/imagery/constellation/pleiades-neo/
4 https://www.planet.com/products/planet-imagery/
5 https://sentinel.esa.int/web/sentinel/missions/sentinel-2
6 https://landsat.gsfc.nasa.gov/
7 https://www.earthdata.nasa.gov/learn/backgrounders/nighttime-lights
8 https://earth.esa.int/eogateway/missions/terrasar-x-and-tandem-x#instruments-section
9 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1
10 https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5

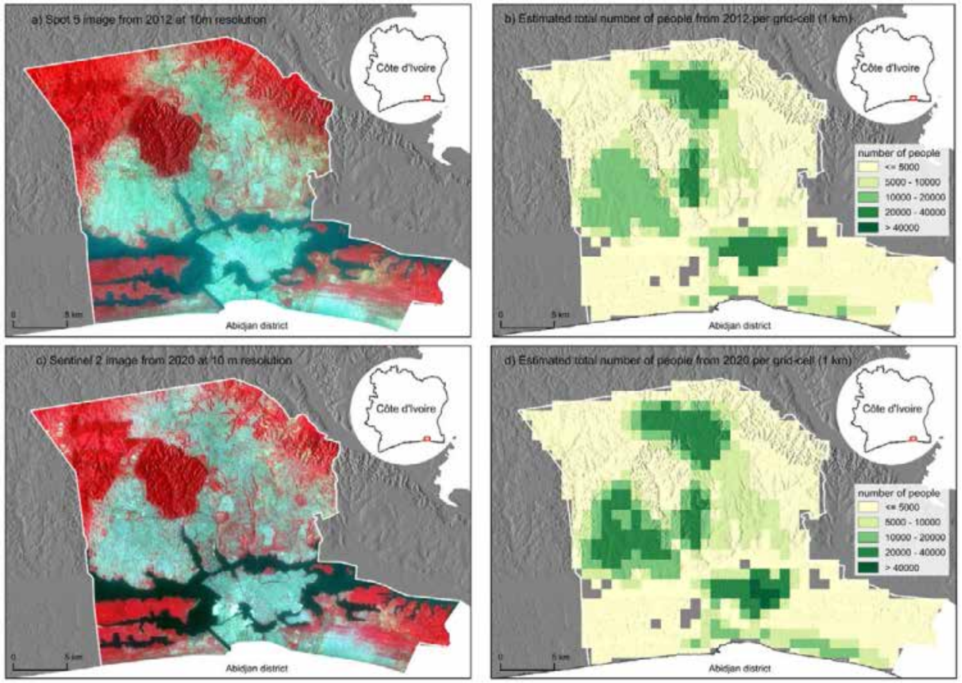

Figure 2 : Views of Spot-5 (a) and Sentinel-2 (c) images and WorldPop population data in Abidjan, a Sub-Saharan African city, in 2012 (b) and 2020 (d).
Source: analysis by the authors from openly accessible Copernicus and Worldpop data

Land use/Land cover mapping in sub-Saharan Africa

Land use refers to the management and modification of natural environment whereas land cover refers to physical material at the surface of Earth. Those types of mapping are essential for monitoring rapid urbanisation. Most of the works on land cover mapping use optical sensors as spectral data is highly correlated with the Earth's surface and such products' availability is very high.
In remote sensing, the detection of urban footprint is not trivial and depends strongly on the image characteristics and the target areas. Urban footprint is characterised by impervious surfaces which are all hard surfaces that water cannot infiltrate such us a transport related land (roads, streets, parking lots) and building rooftops (commercial, residential, industrial areas). The characteristics of this urban footprint (perimeter, area, height, width) are generally detectable with very high (<10m) and high (>10m) spatial resolution images. Teillet et al. (2021) have demonstrated that urban footprints are best detected with Sentinel-2 images, while Pleaide images allow to distinguish the texture of urban objects in Brasilia (Brazil) and Bouake (Ivory Coast). In order to improve the detection of urban footprint in France, the experts of THEIA's Centre d'Expertise Scientifique «Urbain» (Urban SEC) (Puissant et al., 2022) combine images from optical sensors (Sentinel-2) and SAR images (Sentinel-1). Achieving accurate mapping of urban footprint remains a challenge in sub-Saharan African countries where the use of remote sensing data is limited. NightTimeLights data are an example of remote sensing data not suitable for use in sub-Saharan countries, as the distribution of electricity in towns and villages is very limited. The second challenge in urban footprint detection is the characterisation of buildings:

- Horizontal buildings, to detect areas covered by buildings. The presence of vegetation and changing weather patterns in addition to the similarity materials between buildings and vegetation may alter the mapping accuracy. It is even more difficult to detect mud or straw houses in rural areas, as they blend in with barren land.

- Vertical buildings, to detect the height of buildings. The feature can be difficult to detect as it is not well visible in optical images, leading to underestimation of the population (Lu, Weng, Li, 2006).

Application: Combining demographic and satellite data to estimate population: the example of WorldPop and top-down and bottom-up techniques

The WorldPop program was initiated in 2013 to combine AfriPop, AsiaPop, and AmeriPop population mapping projects. Today, WorldPop is the global reference project for providing open access spatial population data.

According to WorldPop (2024), «human population maps have found use in disease burden, epidemic modelling, resource allocation, disaster management, accessibility modelling, transportation and city planning, poverty mapping and environmental impact assessment among others".

The use of geo-spatial variables is paramount because they allow for a logical distribution of population in areas that appear similar. To estimate local population counts and population densities Worldpop uses variables related to the built-up area footprint (density, building type, area, etc.), variables from population surveys (household size, employment rate, etc.) and spatial variables (land cover, roads, school density, etc.). Then, WorldPop divides the study area into 100X100 meter tiles and gives a population estimate at that level. The advantages of this format are that it is consistent and comparable with their other products and that it allows for easy aggregation of the entire population of the administrative area because it is only necessary to add up the entire population of the estimated tiles. Two estimation techniques exist however. The most reliable and accurate is the top-down approach (Stevens, Gaughan, Linard, Tatem, 2015). It requires reliable and recent census data but gives very good results thanks to random-forest algorithms. This reliability can be lacking in some sub-Saharan African countries. The second method is «bottom-up» and is used when there has been no recent census, as in the Democratic

Republic of Congo where the last census dates back to 1984. Here, the idea is to take micro-censuses or to use the results of previous surveys (DHS, MICS, etc.) to create statistical models of the population using Bayesian methods. These methods have the advantage of quantifying uncertainty very well, which is essential in regions where the population is not known precisely. Figure 2.b and figure 2.d show an illustration of the WorldPop population estimates for the district of Abidjan.

Conclusion

Urban footprint data offer scientists the possibility to estimate the sizes and densities of populations in countries where census data are unavailable, inaccurate or missing. Obtaining an accurate mapping of the urban footprint in urban as well as in rural areas is a guarantee for better population estimates. Satellite imagery and remote sensing techniques should be chosen according to local contexts, depending on the characteristics of the study area (especially urban or rural). However, image analysis requires accurate and reliable field data in order to validate spatial products. Finally, it remains to be specified how remote sensing data limits are reflected in the population estimate models.

BIBLIOGRAPHIE

Lu D., Weng Q., Li G.
- 2006, “Residential population estimation using a remote sensing derived impervious surface approach”, International Journal of Remote Sensing, Vol.27, N°16, 3553-3570.

Puissant A., Catry T., Cresson R., Dessay N., Demagistri L., Gadal S., et al.
- 2022, “Products and services of the ”Urban” THEIA Scientific expertise Centre”, https://hal.science/hal-03678980

Stevens F. R., Gaughan A. E., Linard C., Tatem A. J.
- 2015, “Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data” (L. A. N. Amaral, Éd.), PLOS ONE, Vol.10, N°2, e0107042.

Teillet C., Pillot B., Catry T., Demagistri L., Lyszczarz D., Lang M., et al.
- 2021, “Fast Unsupervised Multi-Scale Characterization of Urban Landscapes Based on Earth Observation Data”, Remote Sensing, Vol.13, N°12, 2398.

WorldPop
- 2024, “About us”, WorldPop. https://www.worldpop.org/about/

Publier ou périr ("publish or perish"), c'est l'équation à laquelle sont confronté.e.s tous, toutes les chercheur.e.s, ingénieur.e.s de recherche. Pas de financement ou de promotion possibles sans une bonne évaluation de son travail, et pas de bonne évaluation sans un nombre conséquent de publications dans des revues reconnues, à impact factor. Ne pas publier c'est ne pas exister. Cela induit une forte concurrence entre chercheur.e.s, ingénieur.e.s et favorise l'émergence de revues scientifiques avec des modèles économiques abusifs (les revues prédatrices). Pour répondre à cette injonction de publication, les chercheur.e.s, ingénieur.e.s se plient aux exigences des revues. Les formats des articles sont imposés (le plan, le nombre de mots…), l'anglais est devenu dans certaines disciplines la seule langue de publication reconnue. Les articles sont parfois retravaillés pendant plusieurs années avant d'être finalement publiés (ou refusés). Il est de plus en plus fréquent que les revues fassent payer les laboratoires de recherche, les institutions de recherche pour la publication. Une fois publiés, les articles n'appartiennent plus aux auteur.e.s, et très souvent encore, ils ne sont accessibles aux lecteurs et lectrices (individus ou institutions) que moyennant paiement ou abonnement.

Vous l'aurez compris, publier n'est pas une mince affaire. Une des conséquences de ce système est que nous, chercheur.e.s, ingénieur.e.s de recherche nous avons tous dans nos tiroirs et dans nos disques durs des articles de très bonne qualité que nous ne publierons peut-être jamais. Certains ont été soumis et refusés malgré leur qualité: la sélection est rude, le nombre de soumissions pour une même revue est bien supérieur à celui des places possibles dans un numéro de revue. Certains articles ont un format qui ne conviennent pas aux revues : ils sont trop pointus, trop interdisciplinaires, écrits dans une langue qui ne se publie pas faute d'audience…. D'autres ont été soumis, acceptés, relus, corrigés et jamais publiés, faute de financement.

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