Institution: University of Southampton		
Unit of Assessment: 14 Geography and Environmental Studies		
Title of case study: 14-02 Improved mapping of residential populations to target public health planning, service delivery, and development in low and middle income countries		
Period when the underpinning research was undertaken: October 2013 – December 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Andrew Tatem	Professor	January 2013 – present
Alessandro Sorichetta	Senior Research Fellow	January 2014 – present
Edson Utazi	Research Fellow	October 2014 – present
Doug Leasure	Research Fellow	June 2018 – present
Claudio Bosco	Senior Research Assistant	April 2015 – September 2017
Nicola Wardrop	Research Fellow	May 2010 – 2017
Victor Alegana	Research Fellow	May 2015 – October 2018
Warren C. Jochem	Research Fellow	June 2016 – present
Donna Clarke	Research Fellow	September 2016 – August 2020
Heather Chamberlain	Enterprise Fellow	June 2016 – present
David Kerr	GIS Technician	June 2016 – present
Carla Pezzulo	Senior Enterprise Fellow	January 2013 – present
Tomas Bird	Senior Research Fellow	April 2014 – September 2017
Nikolaos Ves	Research Fellow	August 2017 – November 2019
Chris Lloyd	Research Fellow	April 2015 – present
Graeme Hornby	GIS Analyst (GeoData)	February 2013 – present
Natalia Tejedor	Research Fellow	March 2015 – present
Alessandra Carioli	Research Fellow	May 2016 – present
Julia Thorley	GIS Technician	October 2016 – December 2018
Tracy Adole	Research Fellow	September 2017 – September 2019
Nick Ruktanonchai	Research Fellow	September 2014 – present
Claire Dooley	Research Fellow	March 2018 – present
Oliver Pannell	GIS Technician	April 2018 – present
Gianluca Boo	Research Fellow	April 2018 – present
Edith Darin	Research Fellow	July 2018 – present
Period when the claimed impact occurred: November 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

The University of Southampton's WorldPop research programme was established in October 2013. Research within the programme led by **Tatem**, **Sorichetta** and **Utazi** (supported by other WorldPop staff) into the improvement of spatial demographic evidence has led to a series of innovations in the construction of consistent and high resolution population maps through integrating census, survey and satellite-based data. The outputs have formed the basis for estimation of populations at risk of disease, and for planning purposes by governments, UN agencies and others around the world. This includes production of new national statistics used by the government, UN and World Bank in Afghanistan, population maps that have formed the basis of polio elimination in Nigeria, the spatial demographic basis for the World Health Organization's (WHO) malaria burden estimates in Africa, as well as multiple government health information systems and COVID-19 response efforts around the world.

2. Underpinning research

The global human population is growing by more than 80 million a year, with the vast majority of this growth concentrated in low and middle income countries. Detailed spatial data on population distributions and characteristics are a prerequisite for the accurate measurement of impacts of growth, for planning interventions and monitoring progress towards development goals. While high income countries have extensive mapping resources and expertise at their disposal to

create such data, these are either lacking or of poor quality across low income regions, forming a major obstacle to planning of services and intervention targeting.

Southampton's WorldPop research group, led by Tatem, have been developing methods for improving the spatial demographic evidence base in low and middle income countries since October 2013. The underlying research involves development of spatial statistical algorithms for the integration of more 'traditional' sources of demographic data, such as censuses and household surveys, with newer digital datasets derived from GPS, digital boundaries, satellite imagery and elsewhere. WorldPop's algorithms produce estimates of population counts, demographics and characteristics per 100x100m or 1x1km grid squares across countries, together with associated metadata and measures of uncertainty. The benefits of such methods and outputs include: (i) a set of flexible open tools that can be adapted to different environments and levels of data availability; (ii) sufficient spatial detail to support targeting of interventions for meeting the Sustainable Development Goals; and (iii) a flexible format to facilitate summarization at different spatial scales and integration with diverse data sets (e.g. locations of health facilities to estimate catchment population sizes).

Funded by the Bill and Melinda Gates Foundation, Tatem's WorldPop team developed and applied random forests-based machine learning approaches for disaggregating census counts or estimates at administrative unit levels (e.g. for enumeration area or ward boundaries) to high resolution 100x100m gridded population counts structured by age and sex classes [e.g. **3.1**]. These approaches have been scaled to global extents, producing outputs for the 2000-2020 period in collaboration with Columbia University. Funded by the Bill and Melinda Gates Foundation, Wellcome Trust and the United Nations Population Fund (UNFPA), methods have been adapted to map births and pregnancies across low and middle income countries [**3.2**].

Where **census-based population counts are outdated or inaccurate**, WorldPop have developed Bayesian geostatistical methods for the production of gridded population count and age/sex structures through the integration of small area microcensus surveys with geospatial covariate data, in collaboration with various low and middle income country governments [**3.3, 3.4**]. This work has been funded through awards from the Bill and Melinda Gates Foundation, UK Foreign, Commonwealth and Development Office (FCDO) (formerly UK Department for International Development (DfID)) and UNFPA. Additional funding from the Bill and Melinda Gates Foundation and Data2X (a programme promoting data on gender) led to the adaptation of these geostatistical approaches to the high resolution mapping of population characteristics and intervention coverages (e.g. poverty, vaccination coverage, literacy) from GPS-located household survey data and collaboration with governments [**3.5, 3.6**].

3. References to the research

3.1 Sorichetta, A., Hornby, G. M., Stevens, F. R., Gaughan, A. E., Linard, C., & Tatem, A. J. (2015). High-resolution gridded population datasets for Latin America and the Caribbean in 2010, 2015, and 2020. *Scientific Data*, 2, 150045. https://doi.org/10.1038/sdata.2015.45

3.2 James, W. H. M., Tejedor Garavito, N., Hanspal, S. E., Sutton, A., Hornby, G., Pezzulo, C., ... Tatem, A. (2018). Gridded birth and pregnancy datasets for Africa, Latin America and the Caribbean. *Scientific Data*, 5, [180090]. https://doi.org/10.1038/sdata.2018.90

3.3 Wardrop, N., Jochem, W., Bird, T., Chamberlain, H., Clarke, D., Kerr, D., Bengtsson, L., Juran, S., Seaman, V. & Tatem, A. (2018). Spatially disaggregated population estimates in the absence of national population and housing census data. *Proceedings of the National Academy of Sciences (PNAS)* 115 (14) 3529-3537. https://doi.org/10.1073/pnas.1715305115

3.4 Leasure, D., Jochem, W., Weber, E., Seaman, V. & Tatem, A.J. (2020). National population mapping from sparse survey data: A hierarchical Bayesian modeling framework to account for uncertainty. *PNAS* 117 (39) 24173-24179. https://doi.org/10.1073/pnas.1913050117

3.5 Bosco, C., Alegana, V., Bird, T., Pezzulo, C., Bengtsson, L., Sorichetta, A., Steele, J., Hornby, G., Ruktanonchai, C., Ruktanonchai, N., Wetter, E., & Tatem, A.J. (2017). Exploring the high-resolution mapping of gender-disaggregated development indicators. *Journal of the Royal Society Interface* 14: 20160825 https://doi.org/10.1098/rsif.2016.0825

3.6 Utazi, C.E., Wagai, j., Pannell, O., Cutts, F.T., Rhoda, D.A., Ferrari, M.J., Dieng, B., Oteri, J., Danovaro-Holliday, M.C., Adeniran, A., & Tatem, A.J. (2020). Geospatial variation in measles vaccine coverage through routine and campaign strategies in Nigeria: Analysis of recent household surveys. *Vaccine*, 3 38(14): 3062–3071. https://doi.org/10.1016/j.vaccine.2020.02.070

Awards underpinning impact:

This work was underpinned by 40 research awards, including projects totalling more than $20M from the Bill and Melinda Gates Foundation, and other awards from the Wellcome Trust, UNFPA, FCDO, UN Foundation, Belgian Science Foundation and World Bank.

4. Details of the impact

The development and implementation of methods for population mapping ***in the absence of adequate census data*** has resulted in a range of impacts:

-*Service delivery and public health planning in Afghanistan:* Collaboration with UNFPA and the government of Afghanistan in 2015-17 produced new spatially detailed population estimates. These were presented by Tatem in Kabul to President Ghani, his cabinet, heads of UN agencies and multiple diplomats and ambassadors in late 2017. WorldPop's estimates have since been adopted by the UN and many other international organizations in the country and are undergoing cabinet approval to become the new official government population statistics, replacing projections from the last census in 1979 [**5.1**]. The estimates have since been used continuously in planning and implementing polio vaccination in the country by the government and the WHO's polio eradication initiative, as well as by the government and World Bank in designing new household surveys [**5.1**]. In both cases the modelled estimates have replaced 1979 projections to produce more reliable, precise and efficient approaches.

-*Public health and education planning by Nigeria's government*: Similar population modelling in Nigeria has been used to plan polio elimination efforts since 2014, after the 2006 census data proved to be too inaccurate. The switch to the modelled estimates for assessment of needs, planning vaccination strategies and operational implementation contributed to successful delivery of vaccination and the elimination of polio in the country in 2015. Evidence from post-campaign coverage surveys showed that where the modelled estimates were used to plan vaccination in northern Nigeria, no areas were found to have unvaccinated children, compared to the south where children in at least ten of the sampled settlements were found to have been missed [**5.2**]. As the Nigerian National Primary Health Care Development Agency notes [**5.2**] *"Outbreaks fell to zero and have stayed there. These innovations did more than help eradicate polio in northern Nigeria"*. The data are currently used in the national vaccination tracking system [**5.3**], have fed into the National Surgical, Obstetrics, Anaesthesia & Nursing Plan (NSOANP) for Nigeria, and are used by the Ministry of Education (UBEC) to assess school coverage [**5.4**].

-*Uptake by UNFPA and for service delivery in Colombia:* The Afghanistan and Nigeria work resulted in WorldPop's modelling approaches being adopted in the UNFPA census strategy in July 2019 [**5.5**], and the establishment of a new $40M programme, GRID3, where the WorldPop group are funded to support governments in sub-Saharan Africa with modelling and capacity strengthening. As of December 2020, this involves active support to 10 governments, covering 55% of the population of sub-Saharan Africa [**5.6**]. Moreover, through partnerships established with UNFPA, additional modelling efforts continue in collaboration with national governments. This includes the government of Colombia, where the national statistics office, DANE, was unable to complete full enumeration in their 2018 census [**5.1**], depriving many regions of the accurate data required for effective governance and resource allocation. The WorldPop group worked with DANE to develop modelling methods to impute population estimates for unenumerated areas. These were released as national statistics in 2019 [**5.7**]**.** In Colombia and elsewhere, the data saw "*widespread usage within governments for …health system planning, school placement and census planning"* [**5.1**; Dr. Juran, UNFPA].

Following production of the high resolution gridded population datasets produced through **disaggregation of administrative unit-based census or official estimates**, these were made open access through the WorldPop website, and a range of collaborations and uses followed:

-*Disaster relief by UNITAR, FAO and via UN humanitarian data hub:* From November 2013 to present, WorldPop's maps have consistently formed the standard dataset for the Operational Satellite Applications Programme (UNOSAT) of the UN Institute for Training and Research (UNITAR) for assessment of populations impacted by disasters and other events (e.g. the 13.5 million people affected by Cyclone IRMA-17 [**5.8**]), where no other detailed population data exist. They provide the numbers used by response and aid agencies to assess needs and scope budgets. The data also form the core population input to the FAO's geospatial platform [**5.8**], used to plan food security and agricultural operations. From 2017, collaboration with the UN's Humanitarian Data Exchange enabled population total estimates to be produced globally for UN-recognised boundaries. In 2020, the datasets were downloaded 11,883 times by 4,779 individual users to support humanitarian operations such as aid and healthcare delivery, with 155,000 further downloads via the WorldPop web site [**5.9**].

-*Training via UNFPA:* In April 2016, the population mapping work was presented by Tatem to heads and representatives of all national statistical offices of the world as the keynote talk at the UN's Commission on Population and Development [**5.10**]. WorldPop delivered training on data use at UNFPA headquarters in New York, via multiple UN regional workshops for heads of statistical offices, and multiple country capacity strengthening sessions, with cohorts of university staff within GRID3 focus countries trained to deliver future training to governments. This has included co-leading with UNFPA sessions on population modelling for over 50 representatives from the UN and governments in the Arab States region in 2018 and a similar number for the West and Central Africa region in 2019. In 2020, more than 500 government, local university and UN staff attended training run through GRID3. Dr. Juran of UNFPA notes *'the collaborations with WorldPop have helped UNFPA build important new areas to fulfil one of its key missions in supporting population and housing censuses in all low- and middle-income countries'* [**5.1**].

-*International health metrics:* The datasets are widely used in the health metrics field, forming the denominator used for many African countries in the World Malaria Reports by WHO in 2016-2019 [**5.11**], the ongoing Local Burden of Disease work [**5.12**] and from 2014, UNFPA's State of the World's Midwifery series [**5.13**]. Such metrics are used to set international funding allocations, strategic priorities and for global advocacy, and reliable and consistent denominators at subnational scales are vital for their production.

-*Pandemic response:* WorldPop datasets have been widely used in COVID-19 pandemic response. This has included use as the demographic basis for the highly publicised Imperial College and IHME COVID transmission models [**5.14**], which led to the implementation of lockdown measures by the UK and US governments in March 2020. Moreover the datasets form the demographic basis of UNFPA's COVID-19 Vulnerability platform and UN-OCHA's COVID-19 Map Explorer [**5.15**]. Via Grid3, WorldPop datasets have been used by at least three African governments in their response efforts [**5.16**].

The research's impact was recognised in 2020 through the Royal Geographical Society's Back Award to Prof Tatem "*for leading the development of geospatial and demographic data to assist the work of public policy around the globe*". One award is made annually for geographical studies making an outstanding contribution to national or international public policy [**5.17**].

5. Sources to corroborate the impact

5.1 Testimonial from Dr. Sabrina Juran [Regional Technical Adviser, UNFPA], 8th December 2020.

5.2 Web page by the Nigerian National Primary Healthcare Development Agency [NPHDA]: *How Nigeria won the fight against polio*: https://nphcda.gov.ng/how-nigeria-won-the-fight-against-polio/ ;

5.3 Nigeria national vaccination tracking system, built using population data constructed by WorldPop: http://vts.eocng.org/ [see Data export menu / Population Estimates / 'release statement' link];

5.4 Blog by Nigeria NPHDA and UNFPA Nigeria representatives on GRID3 work undertaken by the WorldPop group: https://unstats.un.org/unsd/undataforum/blog/grid3-nigeria-using-geospatial-infrastructure-in-support-of-decision-making/ [e.g. See Figs (a) and (b)]

5.5 UNFPA (2019): *UNFPA Strategy for the 2020 Round of Population & Housing Censuses (2015-2024)* https://www.unfpa.org/pcm/node/20099 [See p. 29, final para]

5.6 GRID3: https://grid3.org/about-us, showing the 10 countries where active support to governments is ongoing.

5.7 Colombia national statistics director presenting imputation methods for missing census data: https://www.facebook.com/DANEColombia/videos/768209593625605/. Released national statistics: https://www.dane.gov.co/files/censo2018/informacion-tecnica/CNPV-2018-Poblacion-Ajustada-por-Cobertura.xls

5.8 Example analysis by UNOSAT/UNITAR using WorldPop data: https://reliefweb.int/report/antigua-and-barbuda/tropical-cyclone-irma-17-population-exposure-analysis-caribbean-4 [p. 2, para 2 of pdf]. FAO's geospatial platform: https://data.apps.fao.org/ [click explore data/socioeconomic and demographic/human population density]

5.9 HDx: https://data.humdata.org/organization/worldpop. WorldPop Spatial Data Infrastructure site showing dataset download statistics: https://sdi.worldpop.org/wpdata/downloads.

5.10 Prof. Tatem's keynote at the UN Commission on Population and Development: http://www.un.org/en/development/desa/population/commission/sessions/2016/index.shtml

5.11 The WHO's 2019 World Malaria report, using WorldPop data as the denominator for burden estimates: https://www.who.int/publications/i/item/9789241565721 [see data sources for Fig 3.1 on p. 87]

5.12 Local Burden of Disease work (http://www.healthdata.org/lbd)

5.13 UNFPA State of the World's Midwifery reports using WorldPop births and pregnancies data: https://www.unfpa.org/sowmy; https://esaro.unfpa.org/en/publications/state-worlds-midwifery-analysis-sexual-reproductive-maternal-newborn-and-adolescent [See page 11; Table 2]

5.14 Use of WorldPop data for the Imperial College COVID model (see 'Copyright and licensing'): https://github.com/mrc-ide/covid-sim; and the IHME COVID model: http://www.healthdata.org/covid/faqs. (see 'Where does IHME obtain its data?').

5.15 UNFPA's COVID-19 Vulnerability platform (https://covid19-map.unfpa.org – click on 'about' top right) and UN-OCHA's COVID-19 Map Explorer (https://data.humdata.org/visualization/covid19-humanitarian-operations)

5.16 Use of WorldPop data by African governments in COVID-19 response as part of the GRID3 program: Sierra Leone COVID-19 hub (press 'explore' under *population within 5km of MCHP;* then see legend): https://coronavirus-response-moic.hub.arcgis.com/; Zambia: https://grid3.org/news/zambia-partners-with-grid3-to-produce-pop-estimates; Nigeria: https://grid3.org/news/taking-on-covid-19-with-data-nigerias-government-collaborates-with-grid3-on-response-and-prevention

5.17 Royal Geographical Society: *2020 medal and award recipients announced*. https://www.rgs.org/geography/news/2020-medal-and-award-recipients-announced/