National Aeronautics and Space Administration

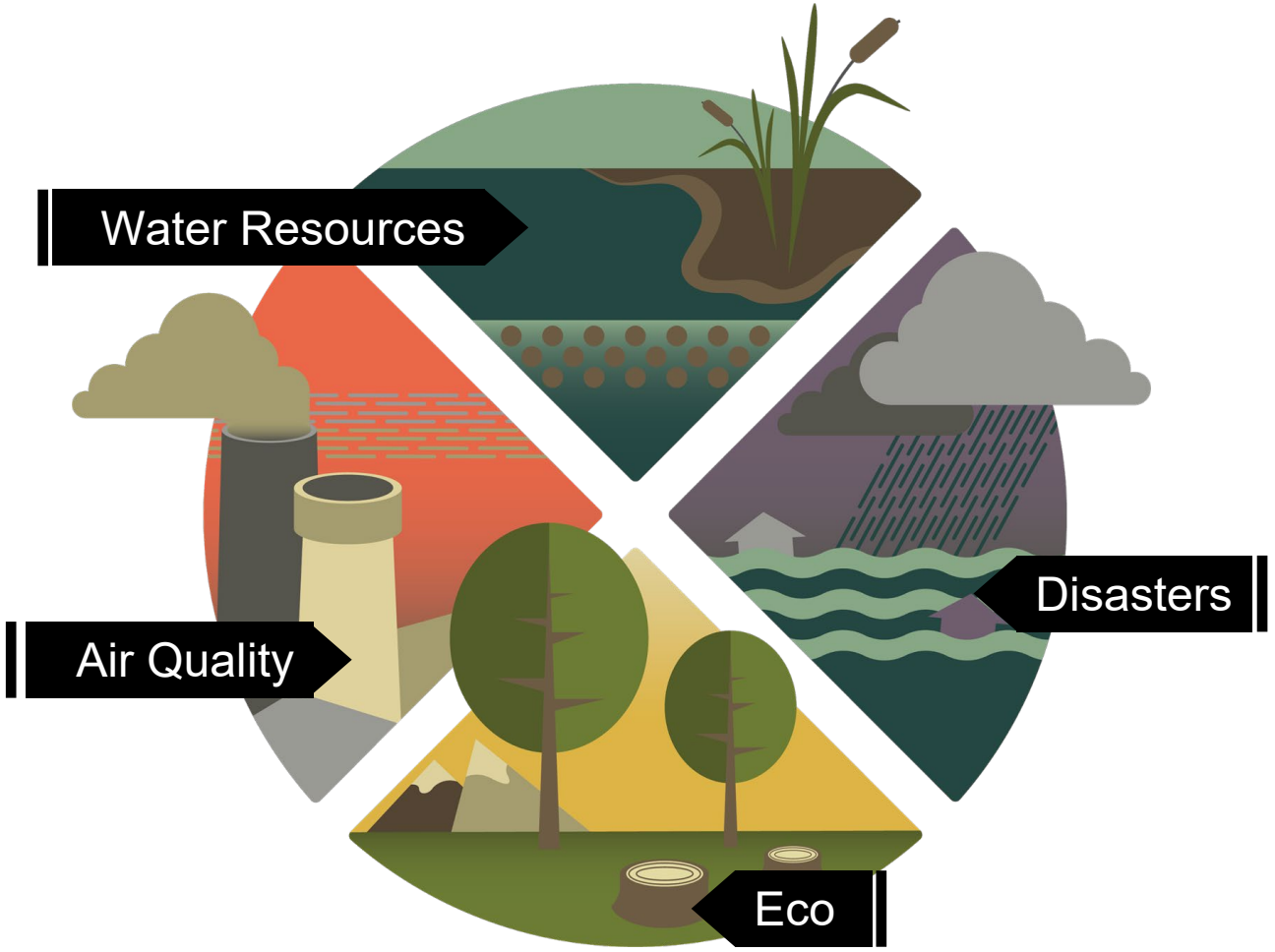
Introduction to Population Grids and their Integration with Remote Sensing Data for Sustainable Development and Disaster Management

March 30, 2021

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset/about-arset

- Part of NASA's Applied Sciences Program
- Empowering the global community through remote sensing training
- Seeks to increase the use of Earth science in decision-making through training for:
  - Policy makers
  - Environmental managers
  - Other professionals in the public and private sector



The POPGRID Data Collaborative

https://www.popgrid.org/about-us

BILL & MELINDA GATES foundation

NASA

TRENDS
Thematic Research Network on Data and Statistics

Global Partnership for Sustainable Development Data

Center for International Earth Science Information Network
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Course Structure and Materials

- Two, 2-hour sessions on March 30 and April 6
- The same content will be presented at two different times each day:
  - Session A: 10:00-12:00 EDT (UTC-4)
  - Session B: 15:00-17:00 EDT (UTC-4)
  - **You only need to attend one session per day.**

- Webinar recordings, PowerPoint presentations, and the homework assignment can be found at:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-population-grids-and-their-integration-remote

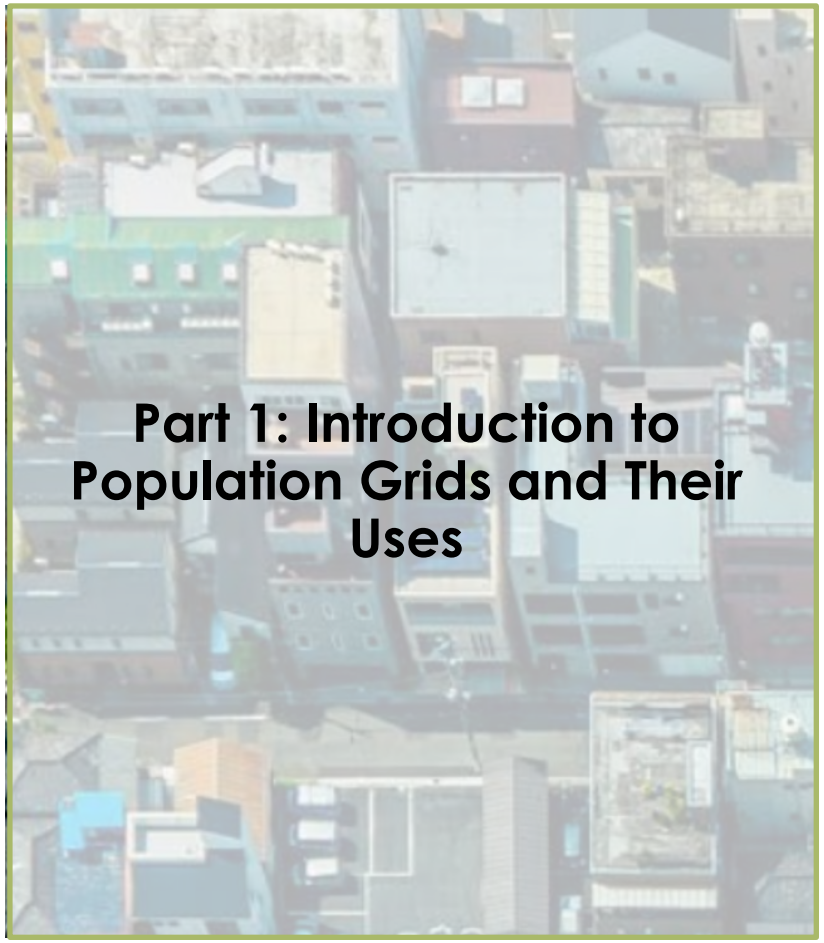
  - Q&A following each lecture and/or by email at:
    - brock.blevins@nasa.gov
    - nasa.arset@gmail.com

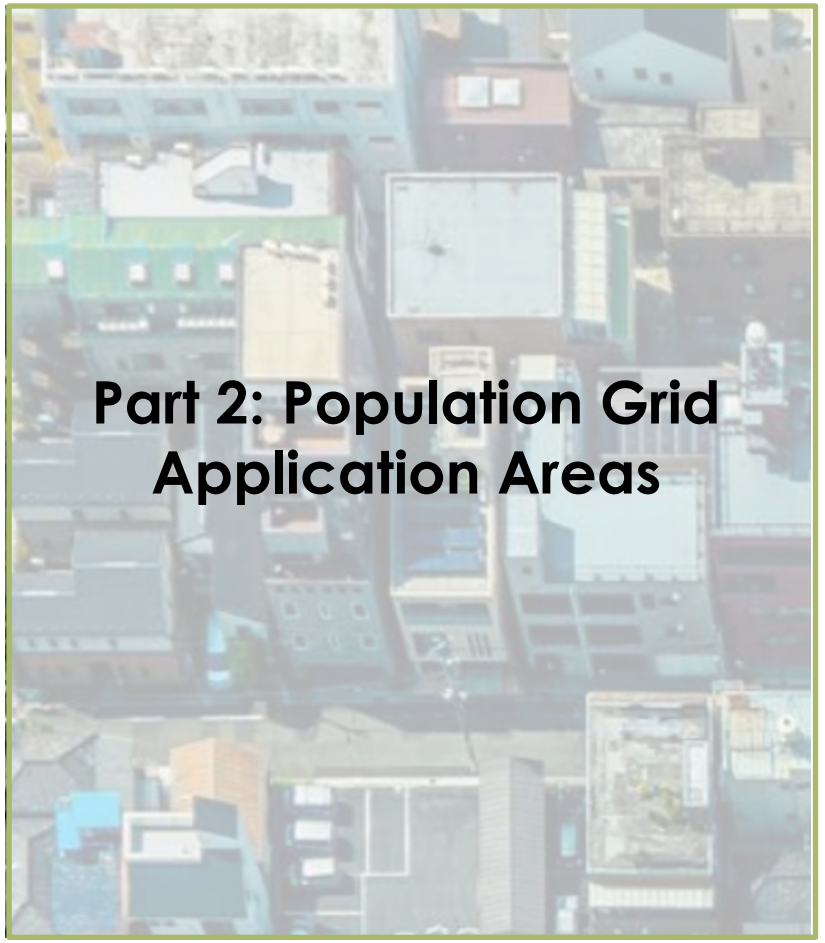
Homework and Certificates

- **Homework:**
  - One homework assignment given after Part 2
  - Answers must be submitted via Google Forms
  - **HW Deadline: Tuesday April 27**

- **Certificate of Completion:**
  - Attend both live webinars (March 30 and April 6)
  - Complete the homework assignment by the deadline (access from ARSET website)
  - You will receive certificates approximately three months after the completion of the course from: marines.martins@ssaihq.com

Course Outline





National Aeronautics and Space Administration

An Introduction to Population Grids and Their Uses

Stefan Leyk & Greg Yetman

March 30, 2021

An Introduction to Population Grids and Their Uses

A. The POPGRID Data Collaborative
B. The Motivation for Gridded Population Data
C. Methodological Frameworks for Population Allocation
D. Global Gridded Population Layers
E. POPGRID's Goals Moving Forward
F. POPGRID Website and the POPGRID Viewer
G. Application Areas for Population Grids
H. Data Uncertainty and Fitness for Use

A. The POPGRID Data Collaborative

https://www.popgrid.org/about-us

Mission: "Data for everyone"

Bring together and expand the international community of **data providers, users, and sponsors** concerned with georeferenced data on population, human settlements, and infrastructure to:

- Improve data **access**, timeliness, consistency, and utility;
- Support data **use** and interpretation, reduce confusion;
- Identify and address pressing **user needs**;
- Encourage **innovation** and cross-disciplinary use.

Center for International Earth Science Information Network
EARTH INSTITUTE | COLUMBIA UNIVERSITY

A. The POPGRID Data Collaborative

https://www.popgrid.org/about-us

Objectives: "Cooperation for technical & data advancement"

Channel **expertise** from natural, social, health, & engineering sciences and from government, academia, private industry, & NGOs.

Promote **cooperation** in producing & harmonizing high-quality data and services

- Improve accessibility and documentation of data sets and services
- Compare and contrast methods and implications of different data sources
- Convene experts from the geospatial and demographic communities
- Provide online tools and services to facilitate visualization & intercomparison

A. The POPGRID Data Collaborative

Data Providers

- CIESIN
- CUNY-CIDR
- Connectivity Lab at Facebook
- Esri
- German Aerospace Center
- Joint Research Centre
- ImageCat, Inc.
- Oak Ridge National Laboratory
- U.S. Census Bureau
- The WorldPop Program

https://www.popgrid.org/data-providers

Center for International Earth Science Information Network
Earth Institute | Columbia University

CUNY Institute for Demographic Research

internet.org by facebook

esri
The Science of Where

DLR Deutsches Zentrum für Luft- und Raumfahrt

European Commission
Joint Research Centre

ImageCat

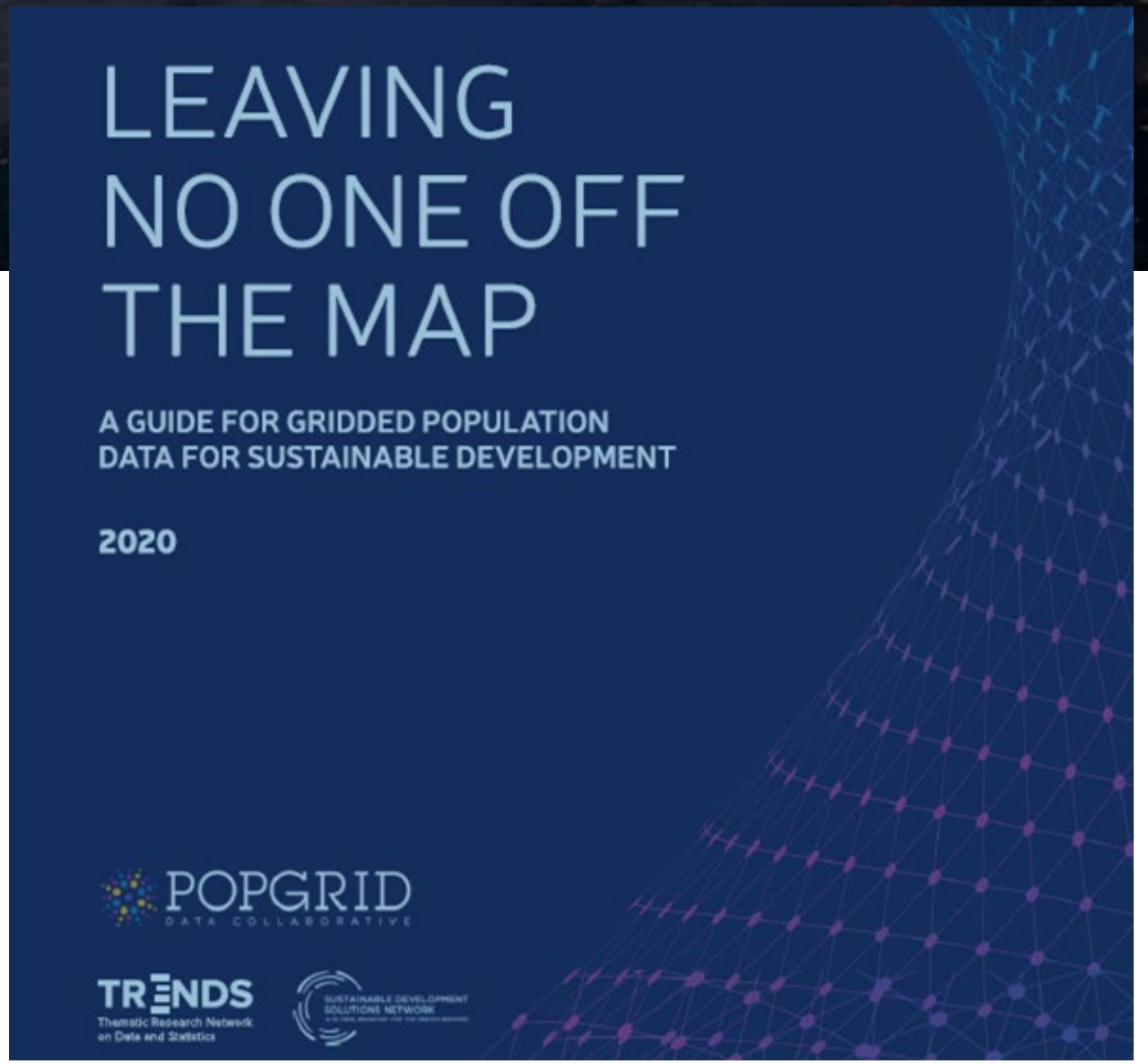
Oak Ridge National Laboratory

United States Census Bureau

worldpop

A. The POPGRID Data Collaborative

Leaving no one off the map



A GUIDE FOR GRIDDED POPULATION DATA FOR SUSTAINABLE DEVELOPMENT

A Report by the Thematic Research Network on Data and Statistics (TReNDS) of the UN Sustainable Development Solutions Network (SDSN) in Support of the POPGRID Data Collaborative

2020

Maryam Rabiee & Hayden Dahmm

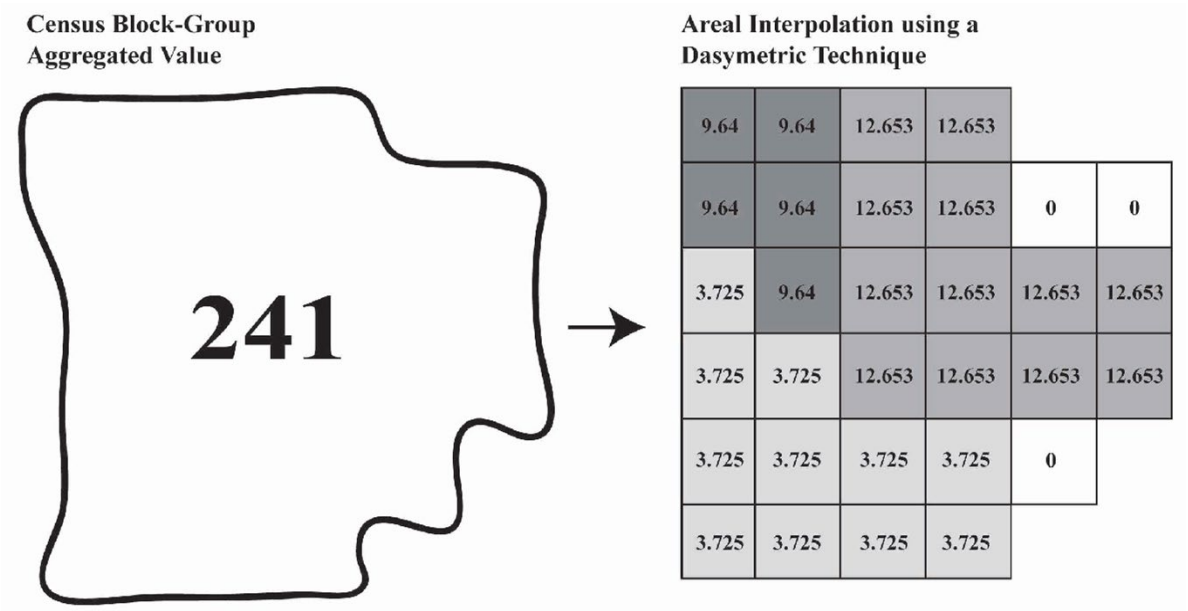
Thematic Research Network on Data and Statistics of the UN SDS Network (SDSN TReNDS)

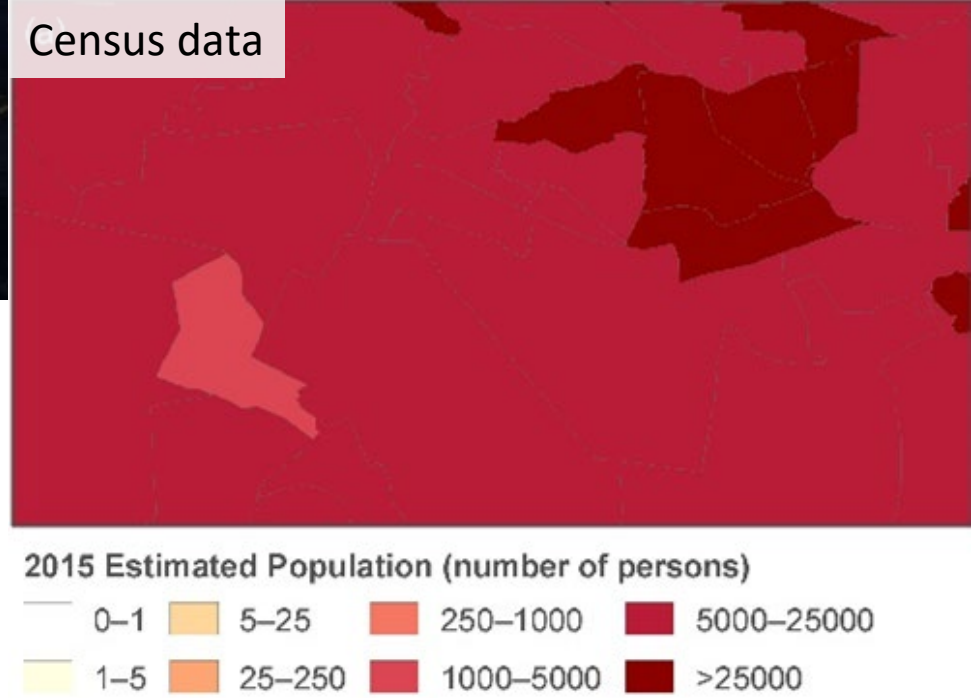
Also available in Spanish and French:
https://www.unsdsn.org/leaving-no-one-off-the-map-a-guide-for-gridded-population-data-for-sustainable-development

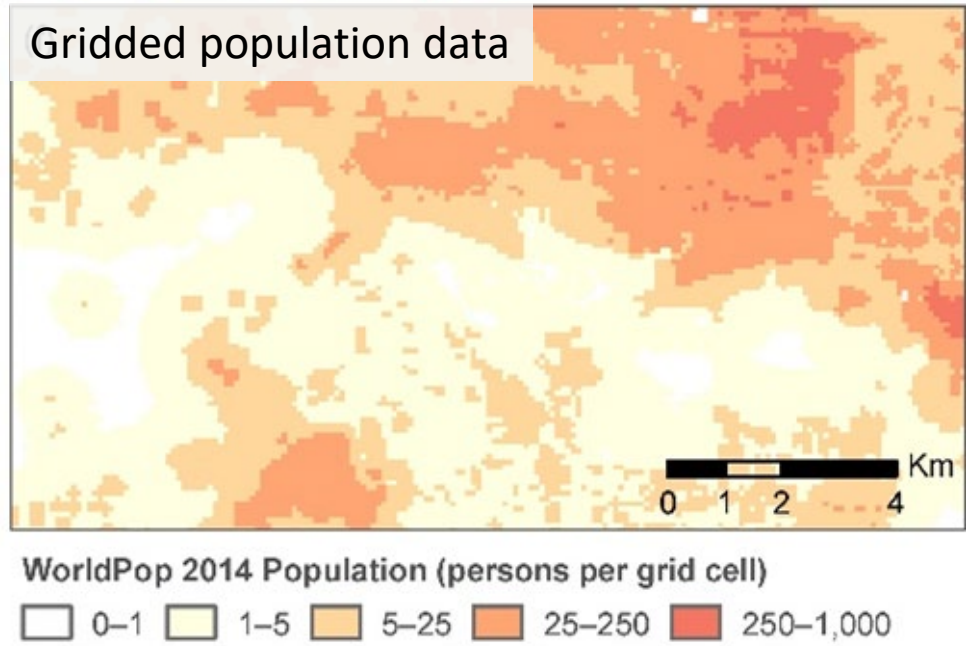
B. The Motivation for Gridded Population Data

Gridded what…?

- Tesselations: rasterized representation of population
- Grid cells that carry population counts
- Partitioning counts summarized within census boundaries



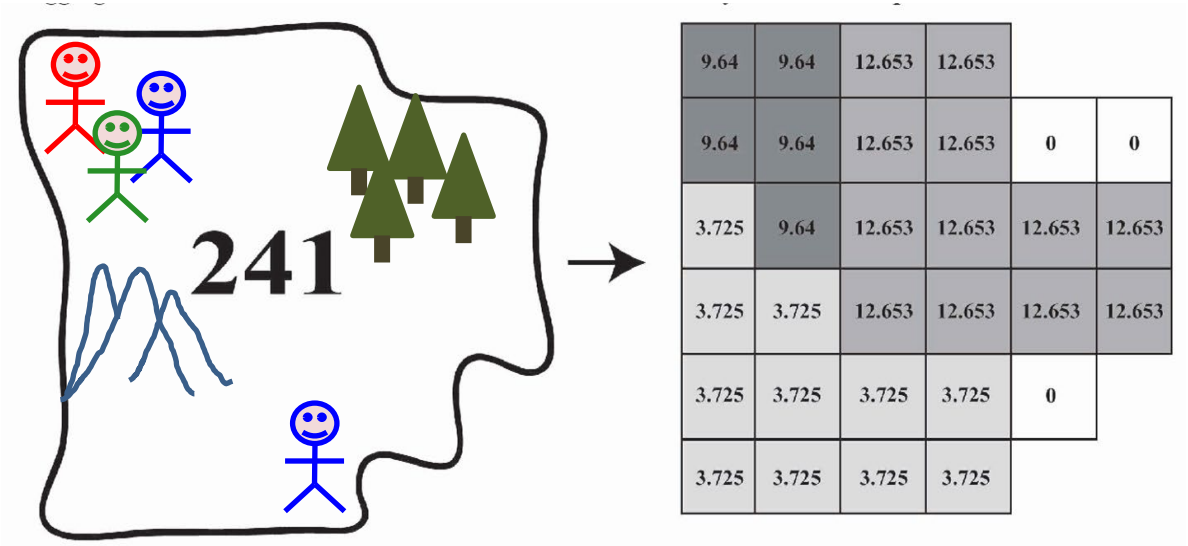


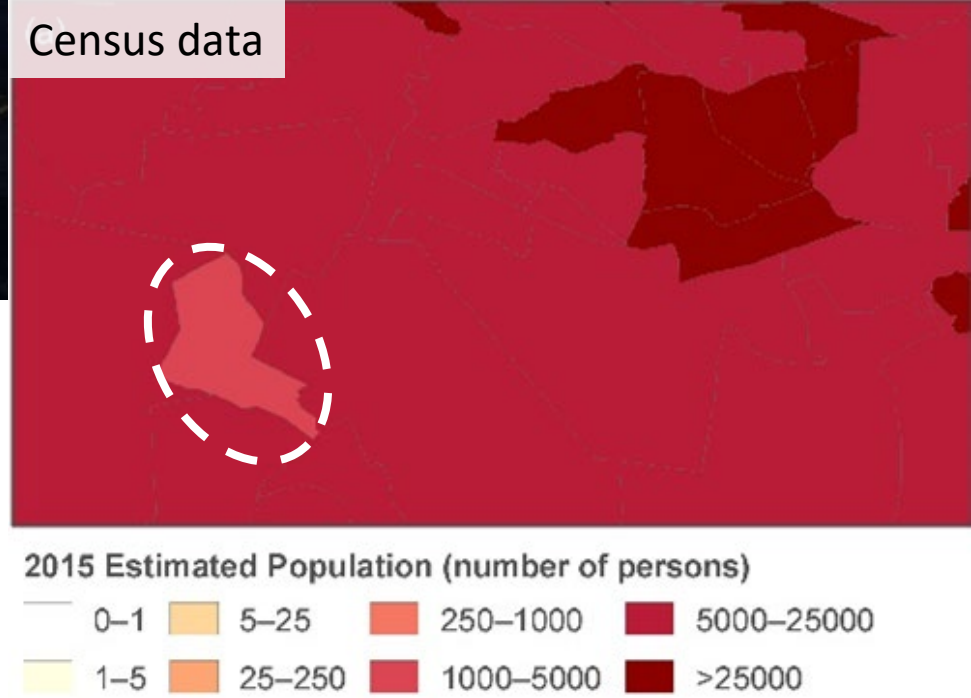


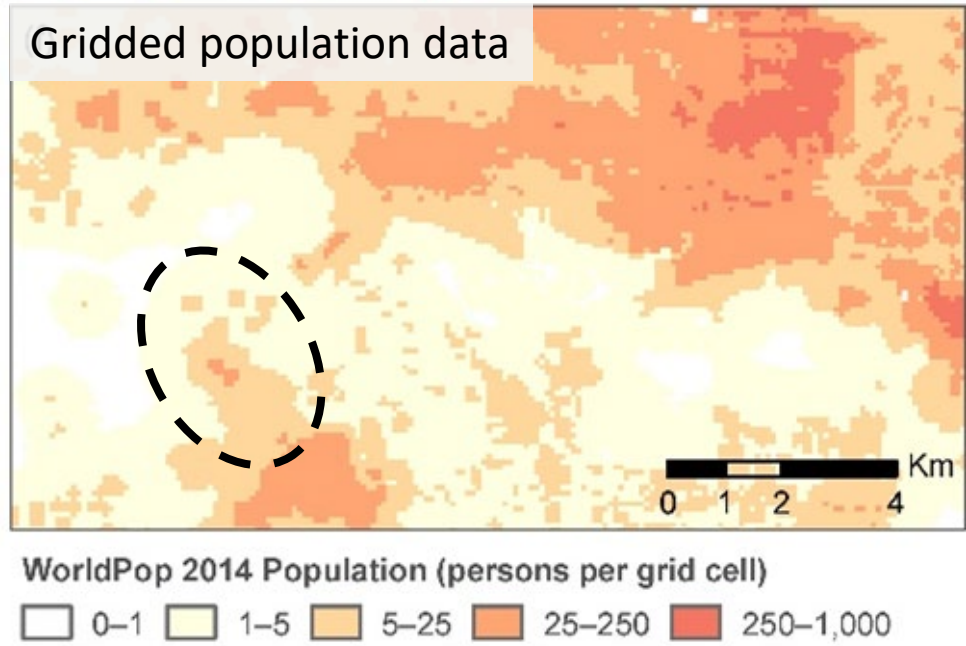
B. The Motivation for Gridded Population Data

Leaving no one off the map?

- Many applications related to population at various scales, but…
- Census data can create obstacles for such applications, as they:
  - Are infrequent
  - Miss people (inaccessibility, social constraints, language)
  - Are summarized for large areas that change over time



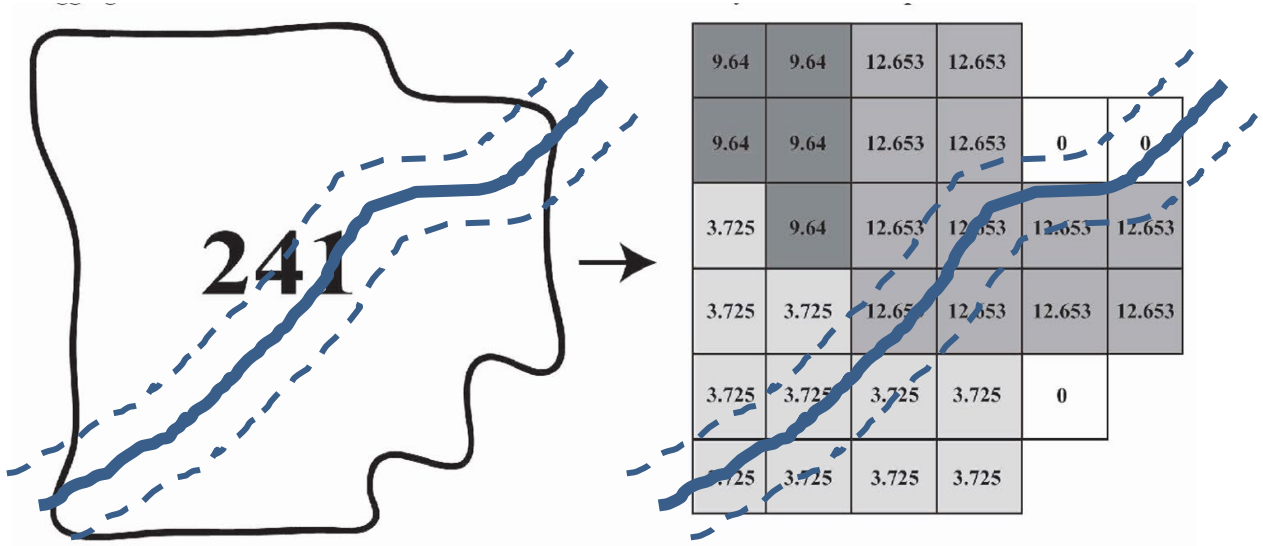




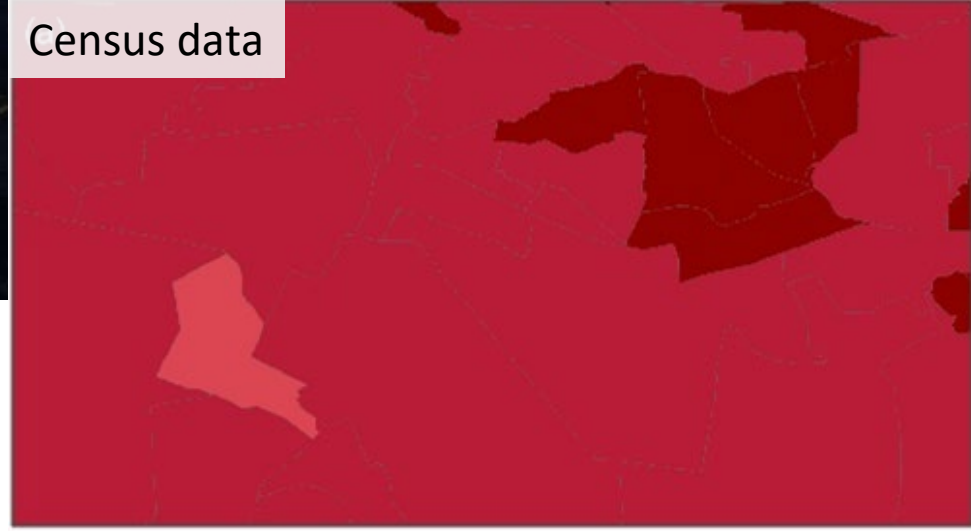
B. The Motivation for Gridded Population Data

Putting everyone on the map…

- Adv. GIS/remote sensing & the geospatial data revolution
- Complement (not replace) census data, fill in the gaps
- Estimates for non-administrative (and consistent) geographies at fine scale
- Policy-Making: Population growth, monitor change, plan interventions



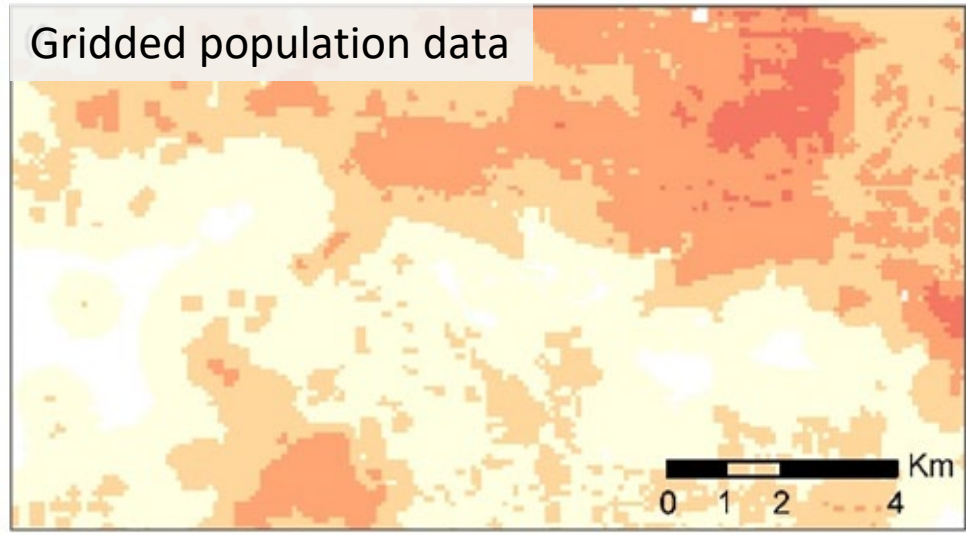
Census data



2015 Estimated Population (number of persons)

0–1 5–25 250–1000 5000–25000
1–5 25–250 1000–5000 >25000

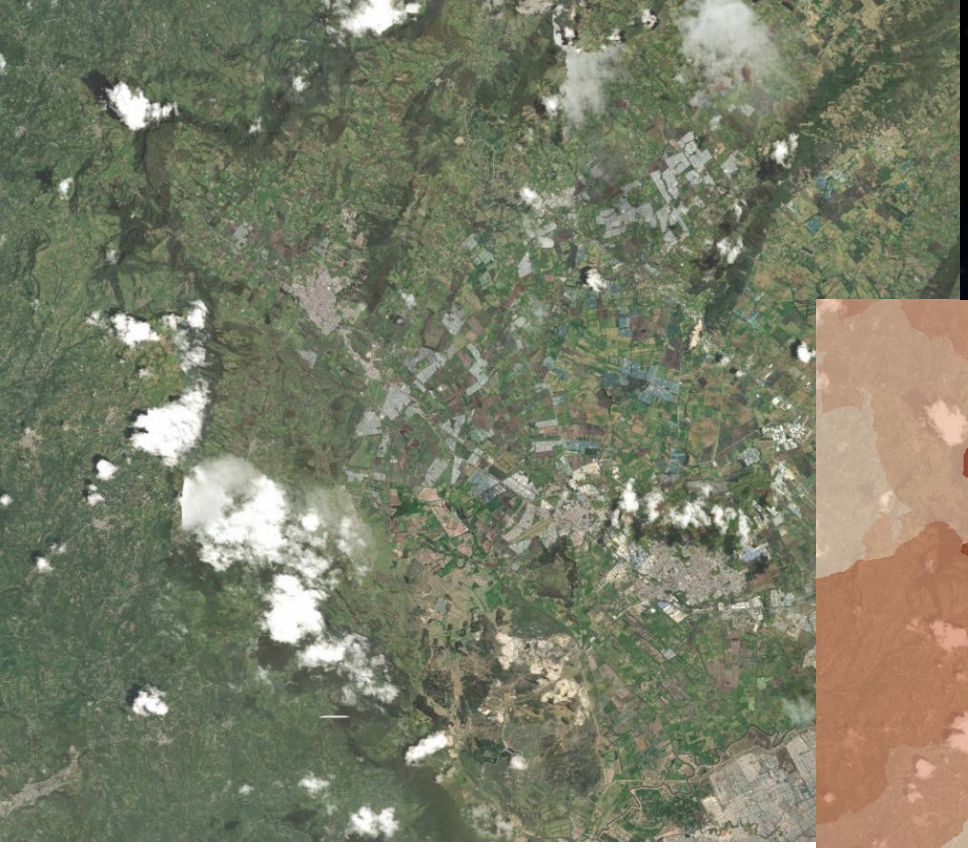
Gridded population data

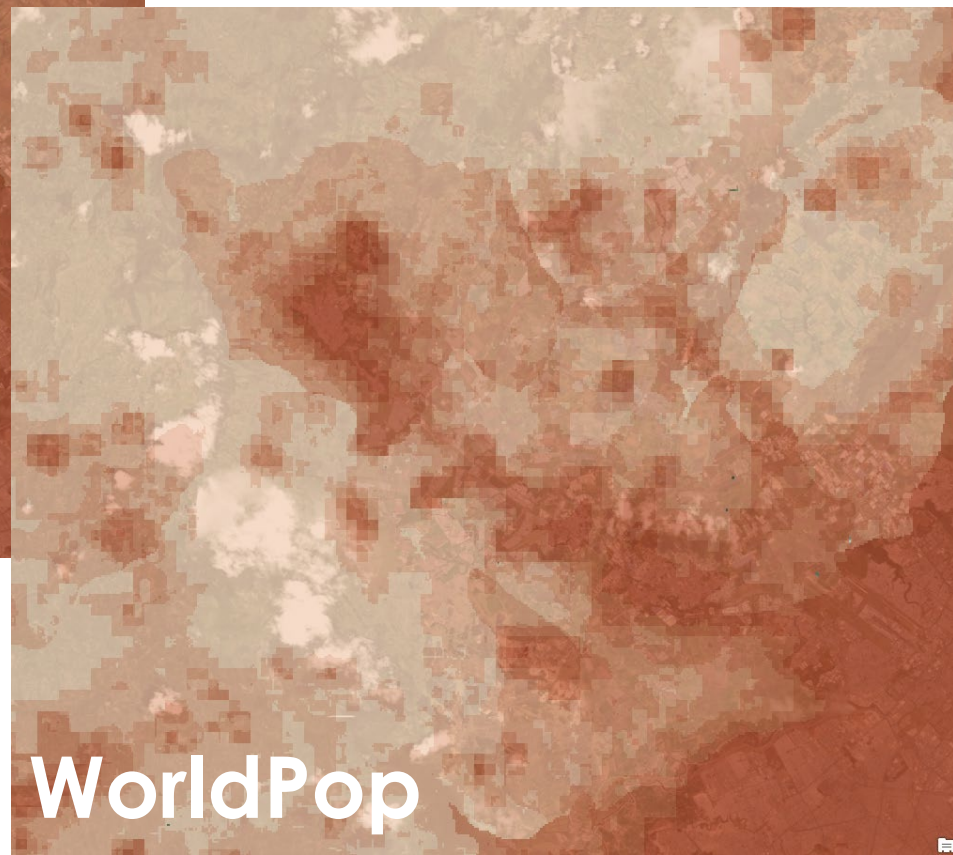


WorldPop 2014 Population (persons per grid cell)

0–1 1–5 5–25 25–250 250–1,000

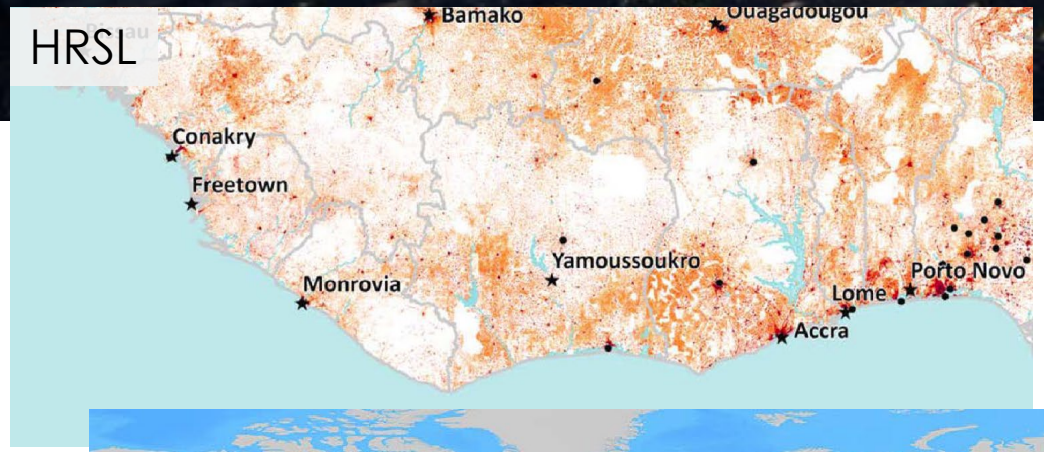
B. The Motivation for Gridded Population Data

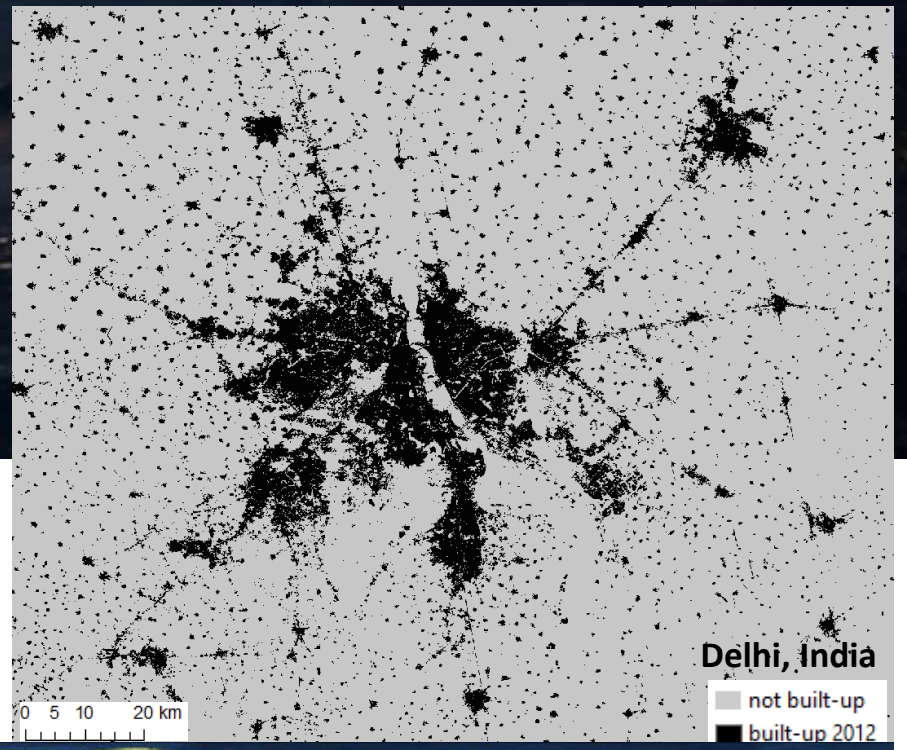


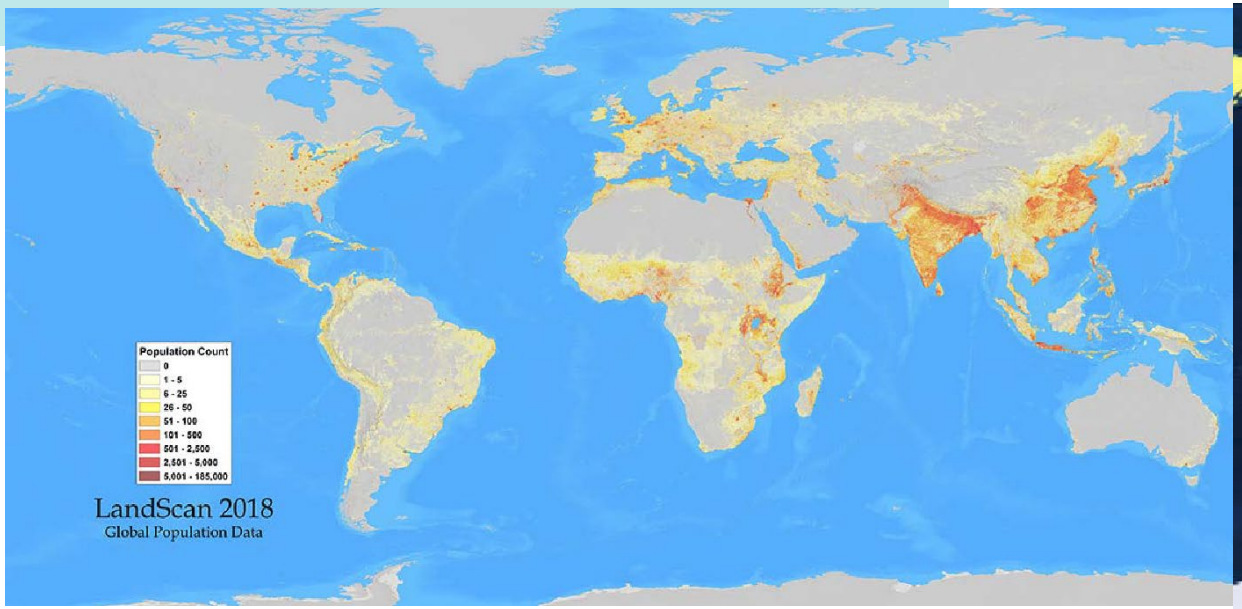


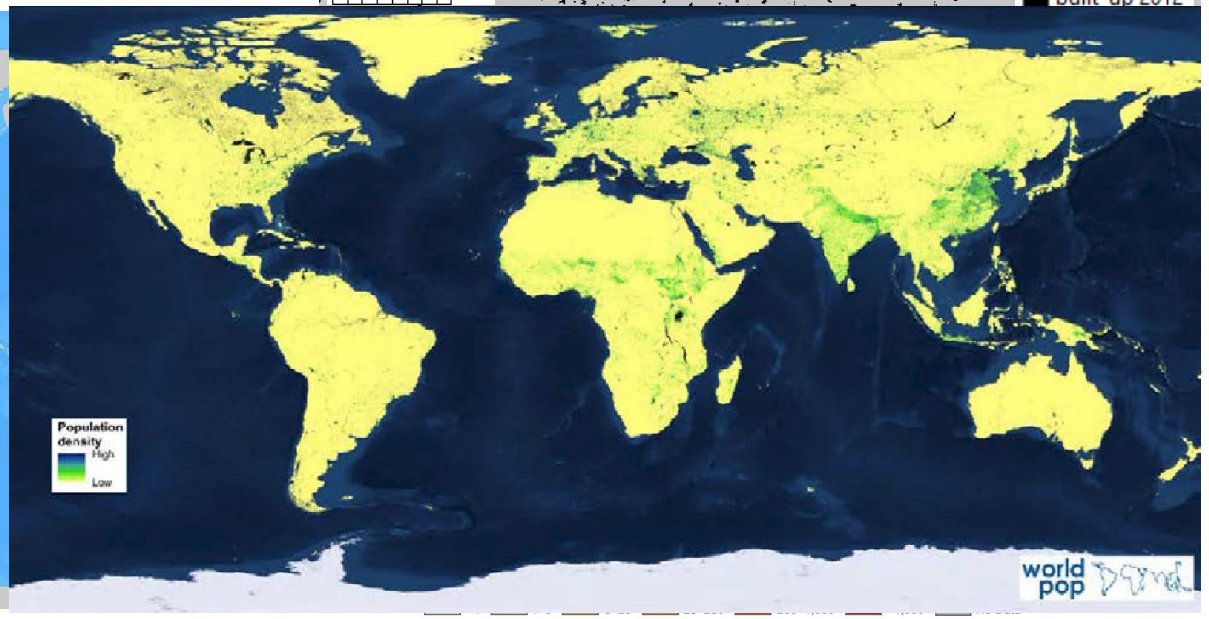
B. The Motivation for Gridded Population Data

A Geospatial Data Revolution







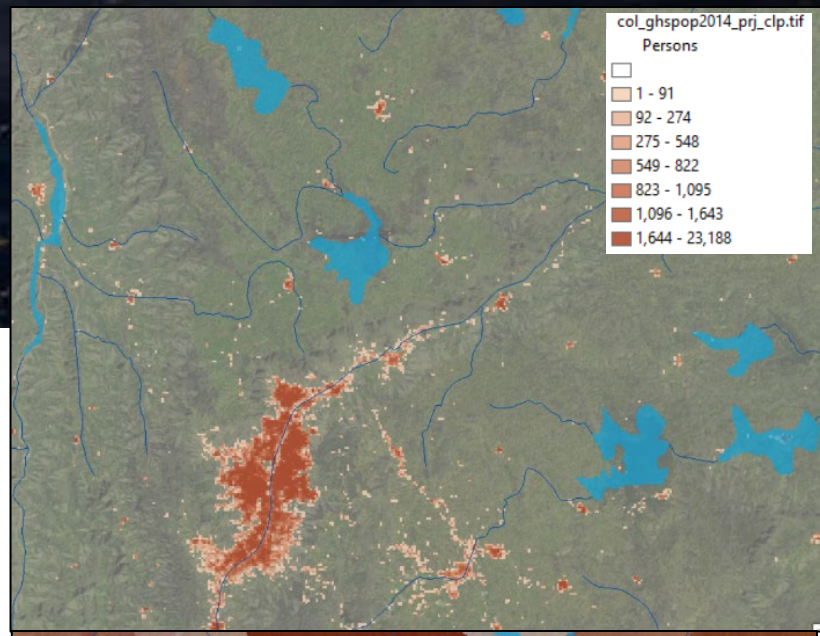


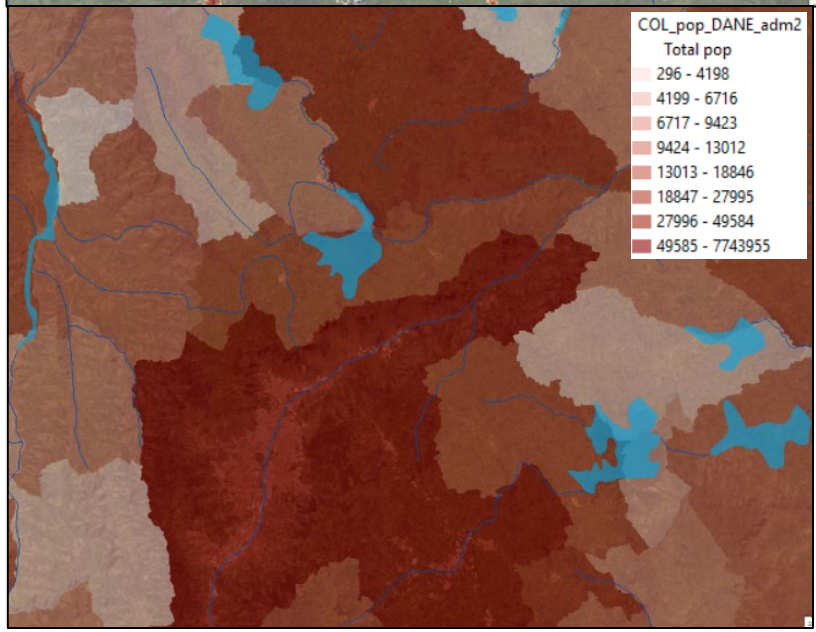
B. The Motivation for Gridded Population Data

A Wide Range of Applications in the Interdisciplinary Community

- Land use and urban planning
- Measurement of economic development
- Transportation infrastructure
- Management and rural access
- Resource allocation and accessibility
- Disaster risk mitigation,
- Management and reduction
- Climate change research
- Sampling design for household surveys
- Public health campaigns and assessments
- Sustainable resource management
- Intern. frameworks for development and sustainability

https://sdgs.un.org/goals

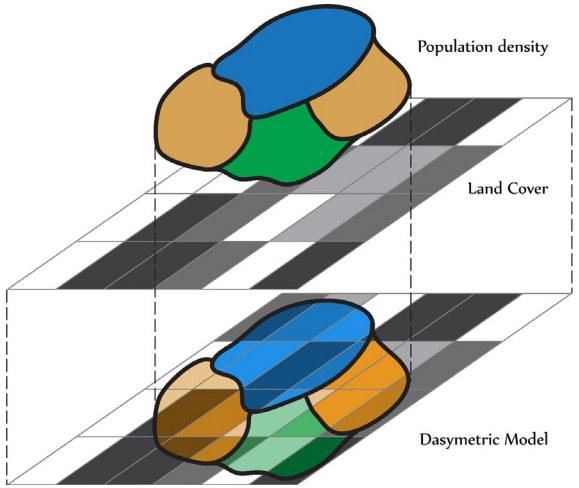




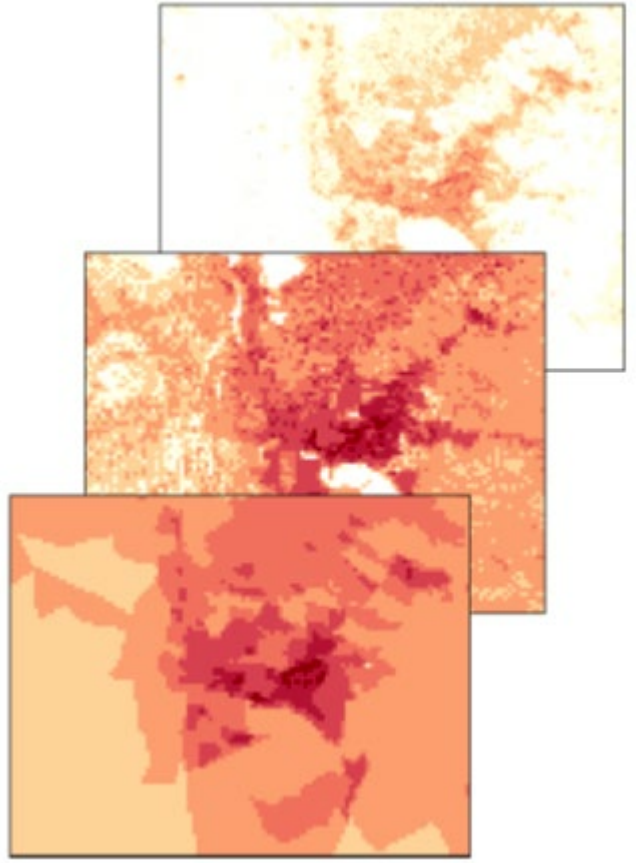
C. Methodological Frameworks for Population Allocation

Data **integration/allocation** through forms of areal interpolation

- **Areal Weighting**
- **Dasymetric Modeling**
  - Binary
  - Empirical
- **Statistical-Dasymetric Modeling**
- **Hybrid Modeling**
  - Machine learning/ensemble prediction
  - Population weights for dasymetric refinement



Nagle et al. 2014



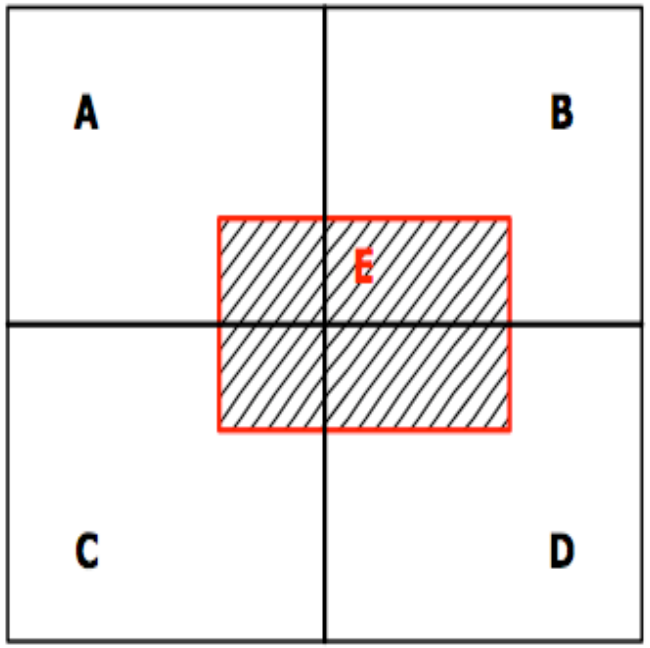
C. Methodological Frameworks for Population Allocation

Areal Interpolation to Address Zonation Incompatibility

Example **Areal Weighting**: Estimation of source populations within target zones is based on the proportion of area overlap between target zones (E) and source zones (A-D). Based only on geometry!

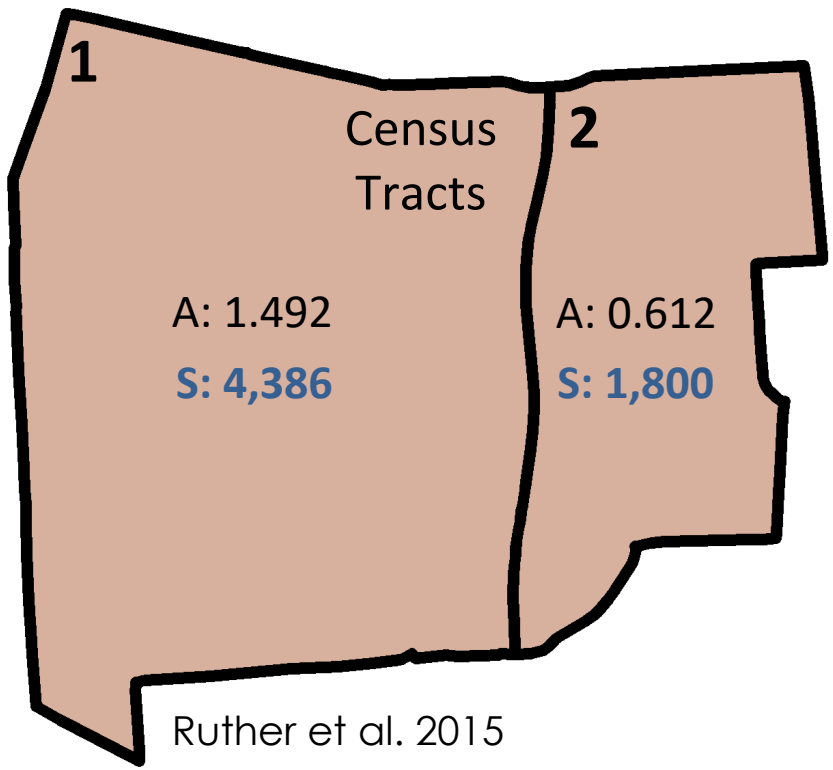
$$\hat{y}_t = \sum_s \frac{Area_{st}}{Area_s} y_s$$

st – intersection between source *s* and target *t*
y – variable of interest (e.g., population)

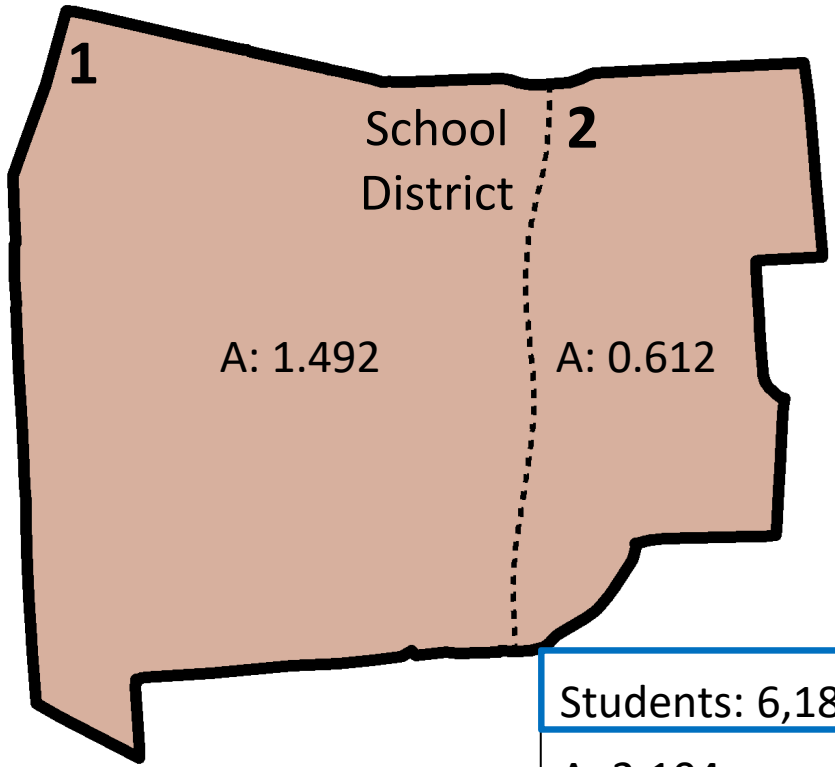


C. Methodological Frameworks for Population Allocation

Areal Weighting



Ruther et al. 2015



Students: 6,186

A: 2.104

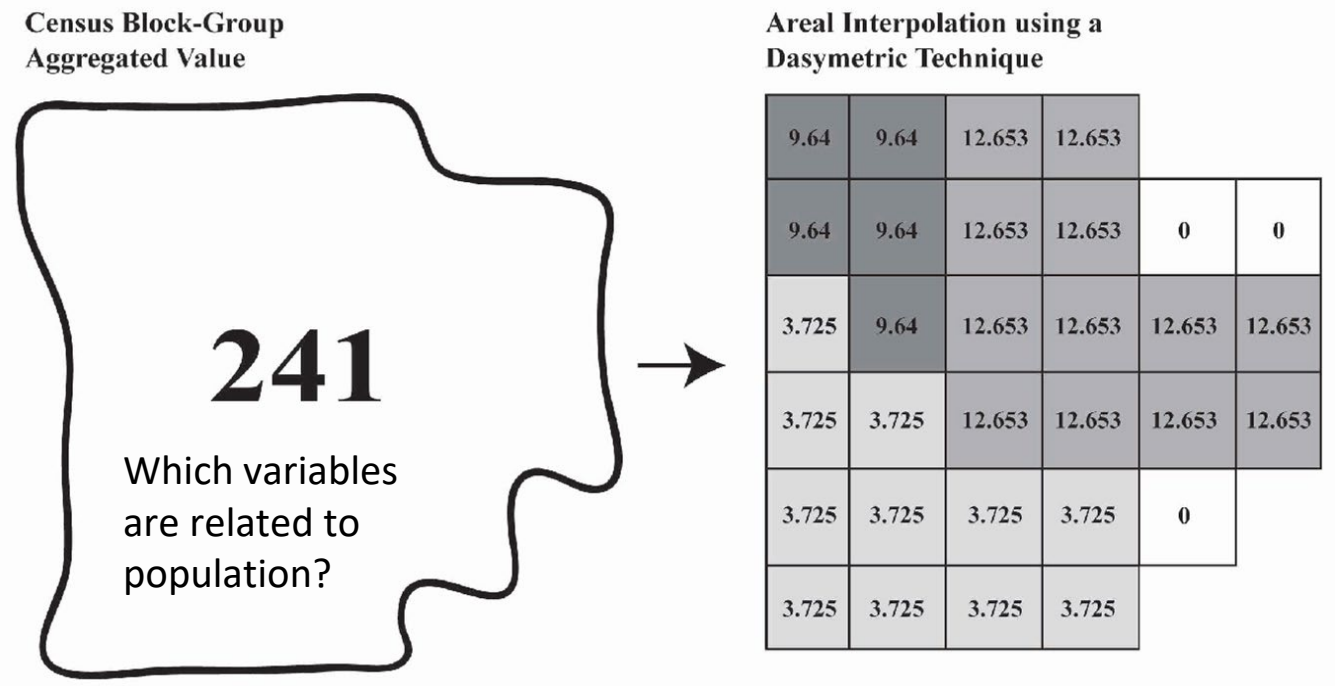
Sector 1: $1.492/2.104 = 0.709$ $0.709 \times 6186 = \mathbf{4386}$

Sector 2: $0.612/2.104 = 0.291$ $0.291 \times 6186 = \mathbf{1800}$

C. Methodological Frameworks for Population Allocation

Dasymetric Mapping

- Type of **areal interpolation** to address zone incompatibility and **aggregation** (in choropleth maps)
- Re-allocating population to mapping zones that better reflect population distributions
- **Limiting** and **related** ancillary variables
- **Volume-preserving (pycnophylactic)** approach

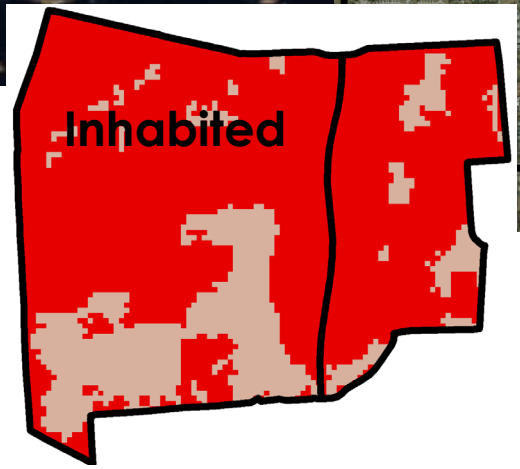


From: http://geography.wr.usgs.gov/science/dasymetric/methods.htm

C. Methodological Frameworks for Population Allocation

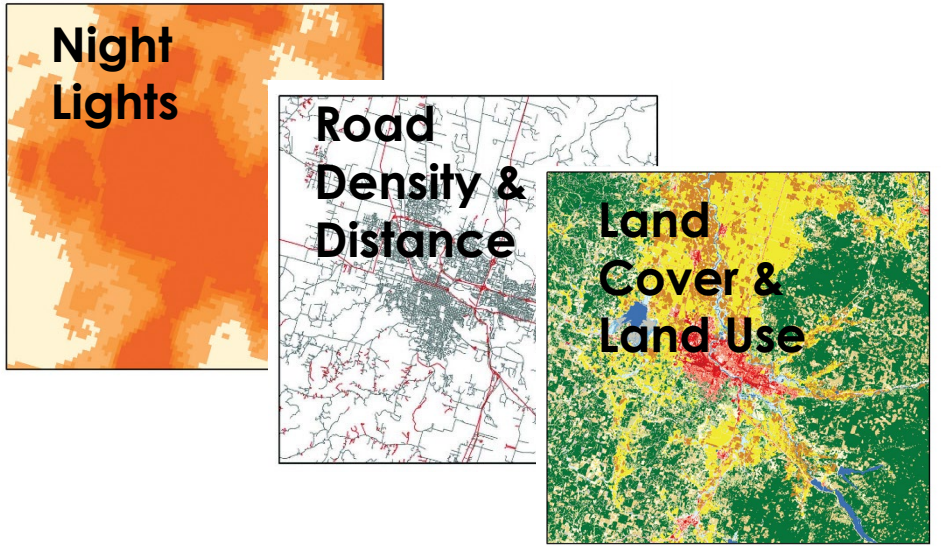
Limiting Ancillary Variables:

Restrict possible occurrences in the original unit (**limit** the **area proportion** within the same unit)



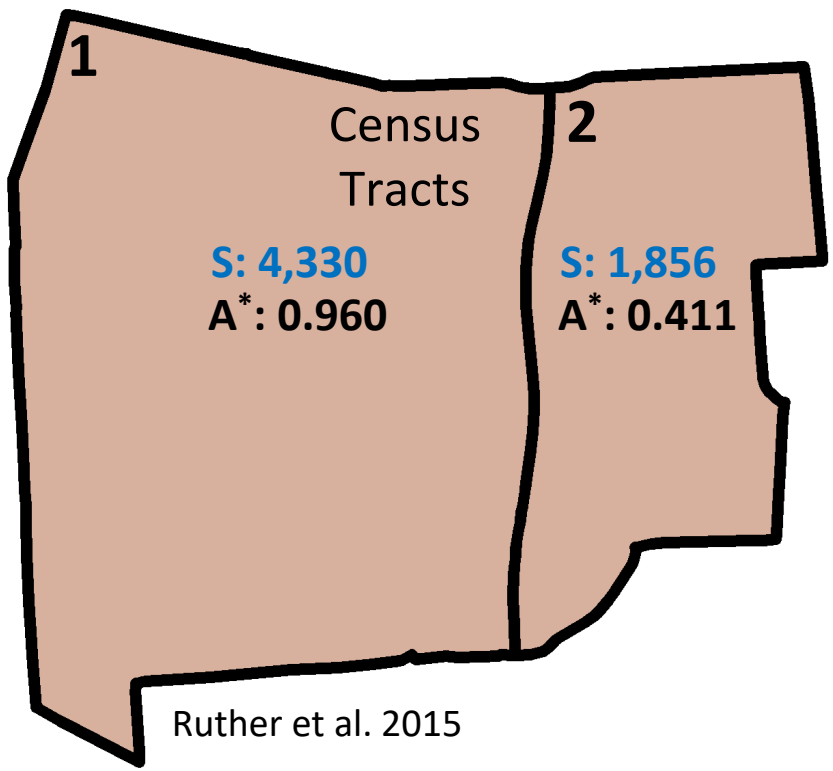
Related Ancillary Variables:

Associated with the variable of interest:
a) **Set of rules** how the variable will influence our variable in what way…
b) **Statistical relationships** (economy, terrain, road distance)

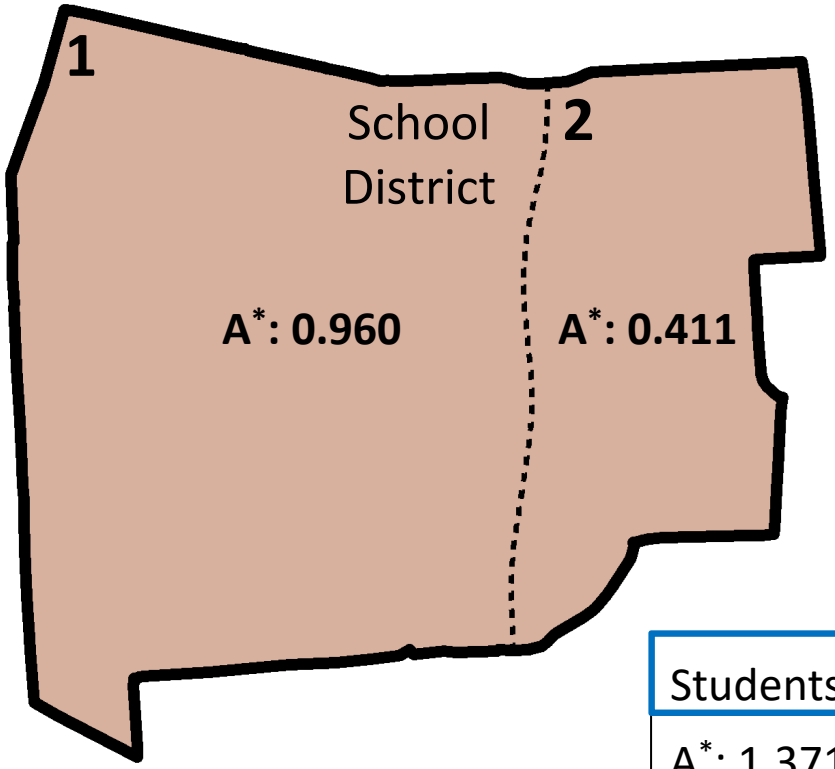


C. Methodological Frameworks for Population Allocation

Dasymetry with Limiting Ancillary Data



Ruther et al. 2015



Students: 6,186

A*: 1.371

Sector 1: $0.960/1.371 = 0.700$ $0.700 \times 6186 =$ **4330** **(before: 4386)**

Sector 2: $0.411/1.371 = 0.300$ $0.300 \times 6186 =$ **1856** **(before: 1800)**

C. Methodological Frameworks for Population Allocation

Areal Weighting

Unit A, n=54			Unit B, n=36		
6	6	6	4	4	4
6	6	6	4	4	4
6	6	6	4	4	4

Dasymetric: Binary weights

grey: built-up land
hashed: no built-up

Unit A, n=54			Unit B, n=36		
0	0	0	0	0	0
0	13.5	13.5	18	0	0
0	13.5	13.5	18	0	0

Dasymetric: Empirically derived weights e.g., land use classes (different grey tones)

Unit A, n=54			Unit B, n=36		
4	4	4	3	3	3
4	8.5	8.5	7.5	3	3
4	8.5	8.5	7.5	3	3

Dasymetric: Statistically derived weights (informed by multiple ancillary variables): $\hat{Y} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$

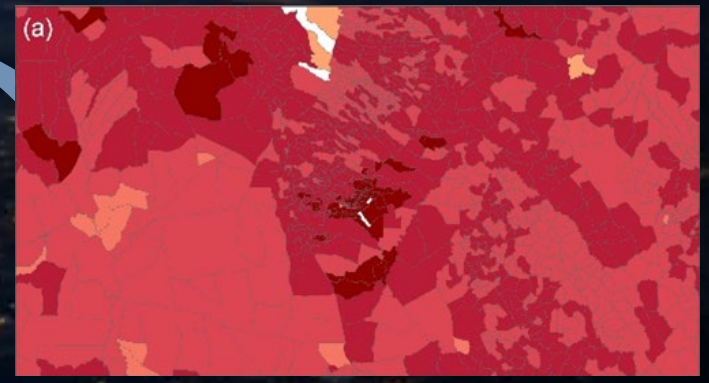
Unit A, n=54			Unit B, n=36		
5	5.5	5.5	3	2	2
5	7	7	9	3	2
5	7	7	9	3	3

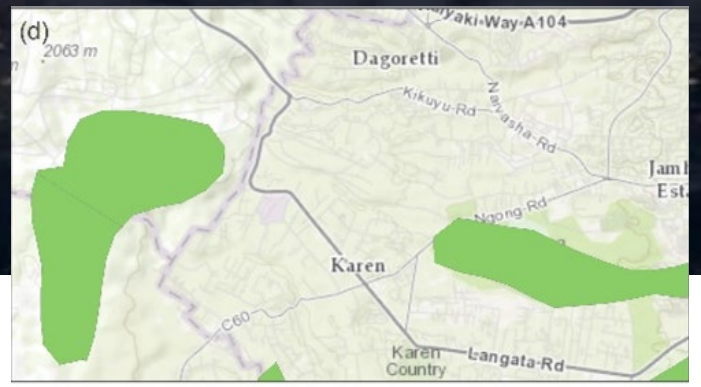
C. Methodological Frameworks for Population Allocation

Ancillary Variables

Relationship to Population
Temporal Mismatches
Spatial Granularity

- Roads
- Land Cover
- Built structures
- Cities or Urban areas
- Night-time lights
- Infrastructure
- Environmental data
- Protected areas
- Water bodies





WDPA Protected Areas

Protected Areas

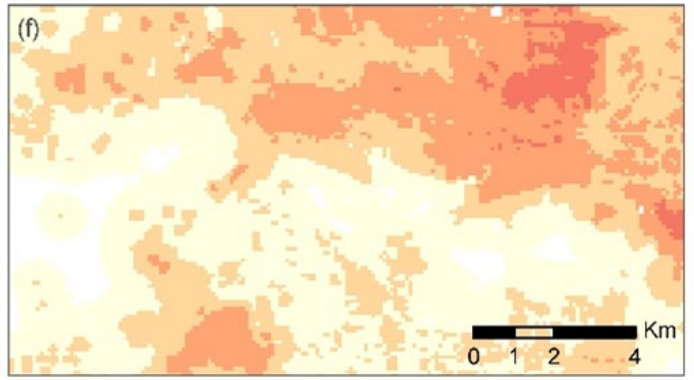
OpenStreetMap Roads

motorway — secondary — trunk

Elevation (meters)

<1800 | 1851–1900 | 1951–2000 | >2051

1801–1850 | 1901–1950 | 2001–2050



WorldPop 2014 Population (persons per grid cell)

0–1 | 1–5 | 5–25 | 25–250 | 250–1,000

C. Methodological Frameworks for Population Allocation

Gridded population dataset	Population	Ancillary data layers								
		Roads	Land cover	Built structures	Cities or urban areas	Night-time lights	Infrastructure	Environmental data[b]	Protected areas[a]	Water bodies
GPW	x								a	x
GRUMP	x				x	x			a	x
LandScan	x	x	x	x	x		x	x	x	x
GHS-POP	x			x						
WPE	x	x	x		x					x
WorldPop	x	x	x	x	x	x	x	x	x	x
HYDE 1950–2015	x							x		x

[a] Protected areas were not masked out, but national statistical offices often assign no data or 0 (zero) to protected areas. [b] Climate, topography, elevation.

Have a look at the data distributions…

D. Global Gridded Population Grids

Many Global (and near-global) Gridded Population datasets are available!

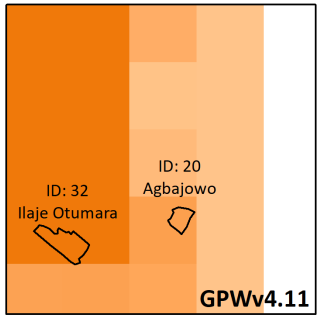
Name	Resolution	Years	Organization	Model
Global Human Settlement Layer Population (GHS-POP)	250m (projected) 9 arc-seconds	1974, 1990, 2000, 2015	Joint Research Centre (JRC)	Machine Learning + weighted allocation
Gridded Population of the World (GPW)	30 arc-seconds (~1km)	2000, 2005, 2010, 2015, 2020	CIESIN/SEDAC	Proportional allocation
High Resolution Population Density Maps (HRSL)	1 arc-second (~30m)	2020	Facebook	Machine learning + weighted allocation
LandScan	30 arc-seconds (~1km)	2019 (annual release)	Oak Ridge National Laboratory	Multivariate Dasymetric
World Population Estimate (WPE)	5 arc-seconds (~150m)	2016 (periodic release)	Esri	Multivariate Dasymetric
WordPop	3 arc-seconds (~90-100m)	2000-2020 (annual estimates)	WorldPop	Machine Learning (Random Forest)

E. POPGRID's Goals Moving Forward

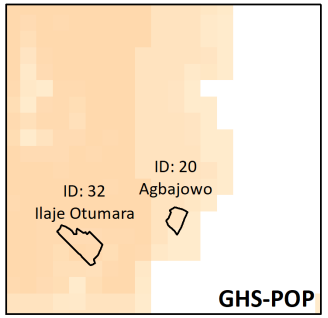
- Improving accessibility and documentation of data sets and data services
- Comparing and contrasting methods and implications of different data sources
- Convening technical experts from the geospatial and demographic communities at events and conferences worldwide
- Providing online tools and services to facilitate user visualization and intercomparison for specific regions and types of data of interest
- Developing an intercomparison report that clarifies how different data sets are useful for different applications and research

E. POPGRID's Goals Moving Forward

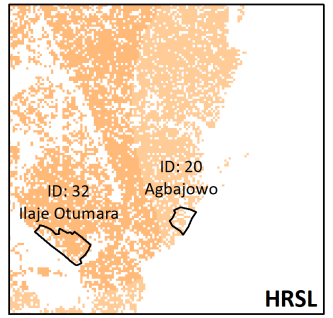
- Example Paper (Preprint): Evaluating the Accuracy of Gridded Population Estimates in Slums: A Case Study in Nigeria and Kenya
- D. Thomson et. al, 2021 https://www.preprints.org/manuscript/202102.0521/v1



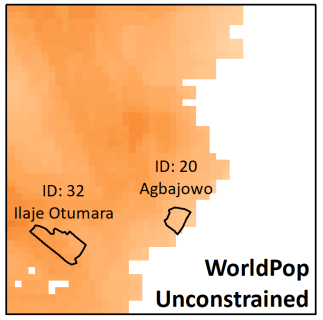
Top-down
Un-modelled
Unconstrained
~1x1 km



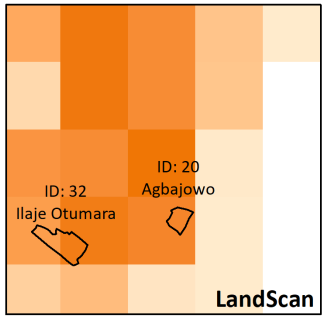
Top-down
Lightly modelled
Constrained
~250x250 m



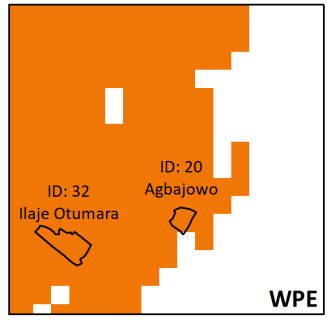
Top-down
Lightly modelled
Constrained
~30x30 m



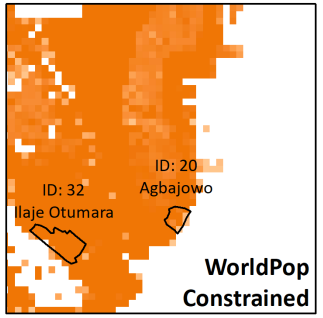
Top-down
Highly modelled
Unconstrained
~100x100 m



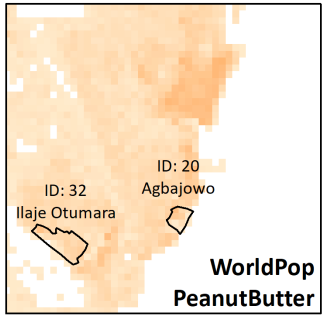
Top-down
Highly modelled
Constrained
~1x1 km



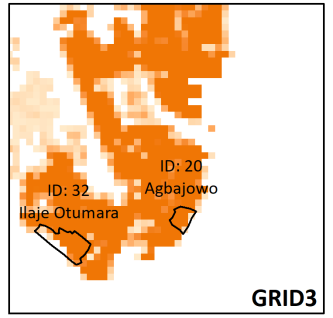
Top-down
Highly modelled
Constrained
162x162 m



Top-down
Highly modelled
Constrained
~100x100 m



Bottom-up
Un-modelled
Constrained
~100x100 m



Bottom-up
Highly modelled
Constrained
~100x100 m

F. POPGRID Website and the POPGRID Viewer

https://popgrid.org

POPGRID DATA COLLABORATIVE

Home | About | Events | News | Data Providers | Explore Data | Resources | •••

Global Population Grids: Summary Characteristics

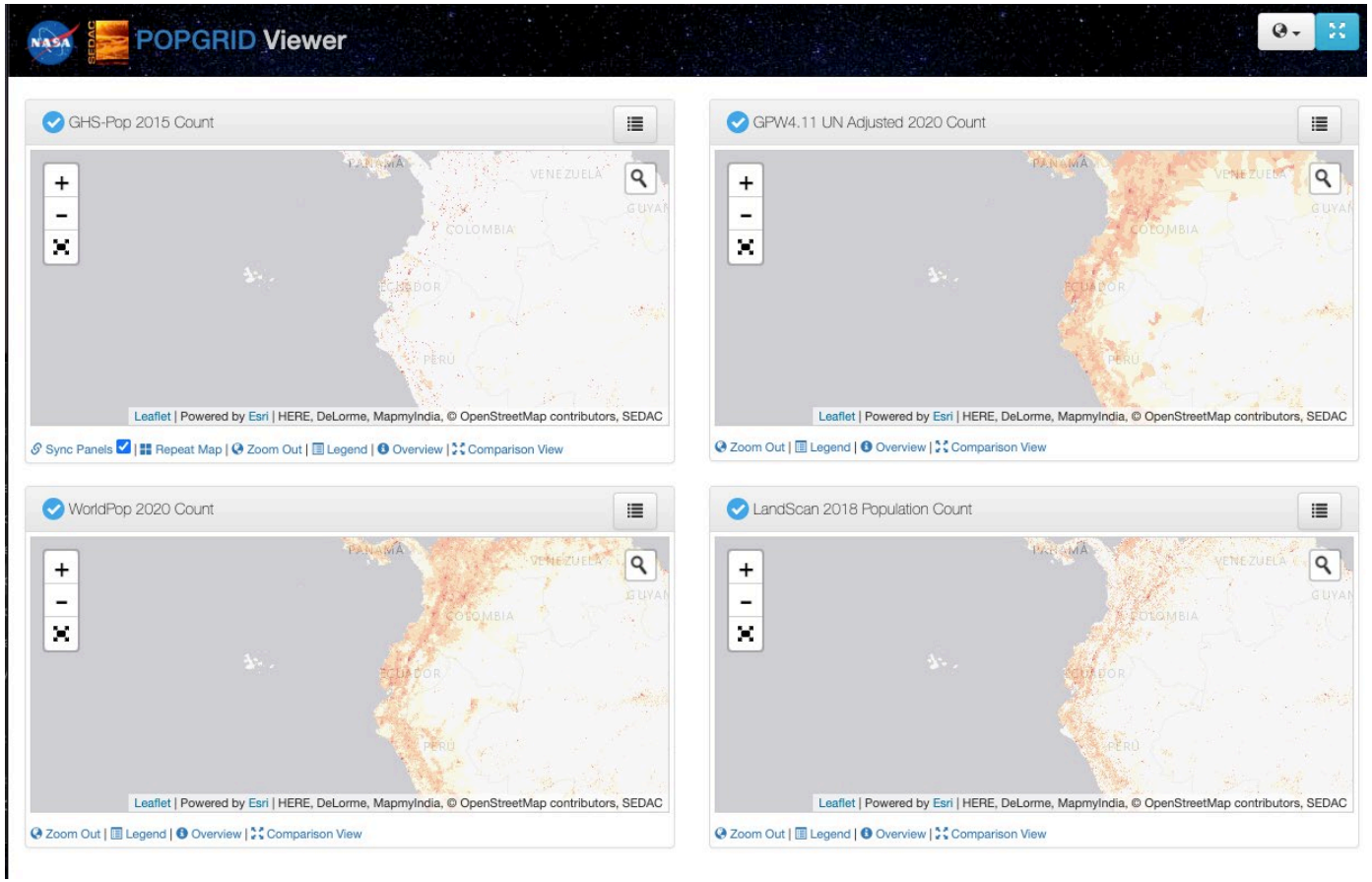
Dataset	Source	Concept	Method	Grid Cell Size	Year(s) Represented	Source for National Level Population Totals	Distribution Policy
Unmodeled Population Grids							

POPGRID DATA COLLABORATIVE

Home | About | Events | News | Data Providers | Explore Data | Resources | •••

Global And Continental Urban Extent / Settlement Layers: Summary Characteristics

Dataset	Source	Concept	Method	Imagery Used	Spatial Resolution	Year(s) Represented	Distribution Policy
Global	NASA Goddard	Extent of	Integrates spatial texture	Landsat	30 meter,	2010	Open access



F. POPGRID Website and the POPGRID Viewer GitHub Demo

https://popgrid.org

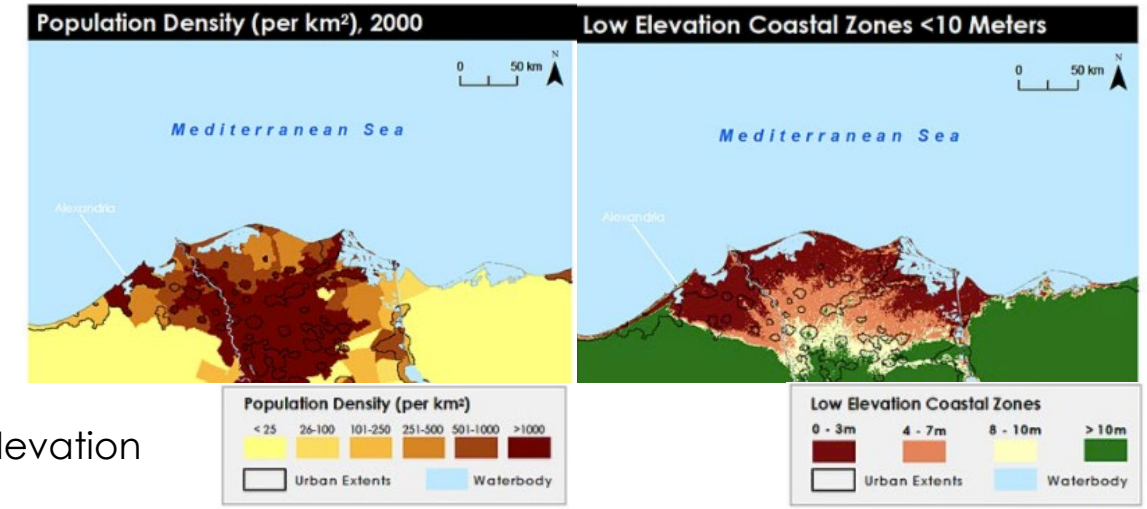
GitHub Demo

https://github.com/gyetman/popgrid_service_demo/

G. Application Areas for Population Grids

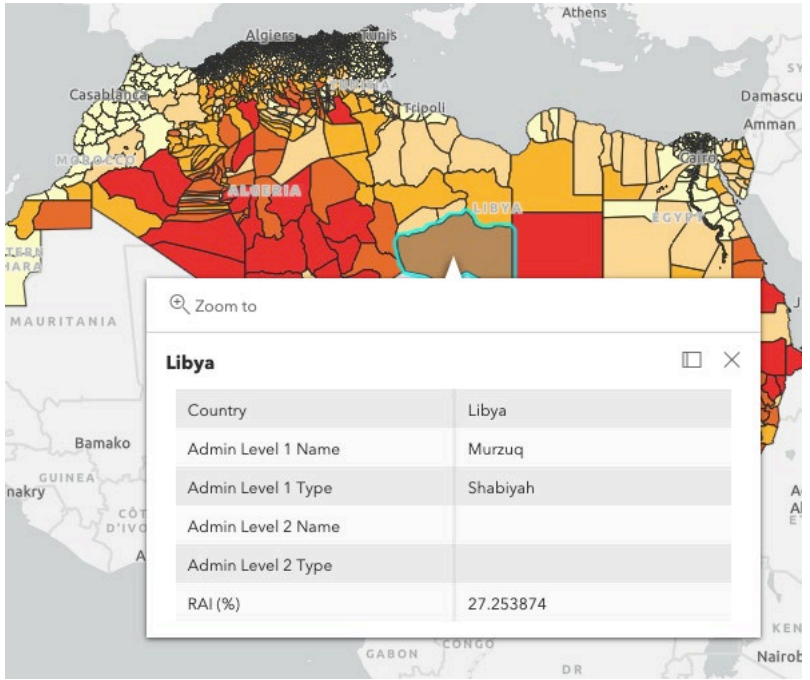
Common Applications:

- Exposure to hazards
- Health service delivery; health facility planning / access
- Monitoring (SDG goals, population change)
- Commercial applications (cell phone networks, new market estimation)
- Human-environment research



Population in the Low Elevation Coastal Zone (LECZ)

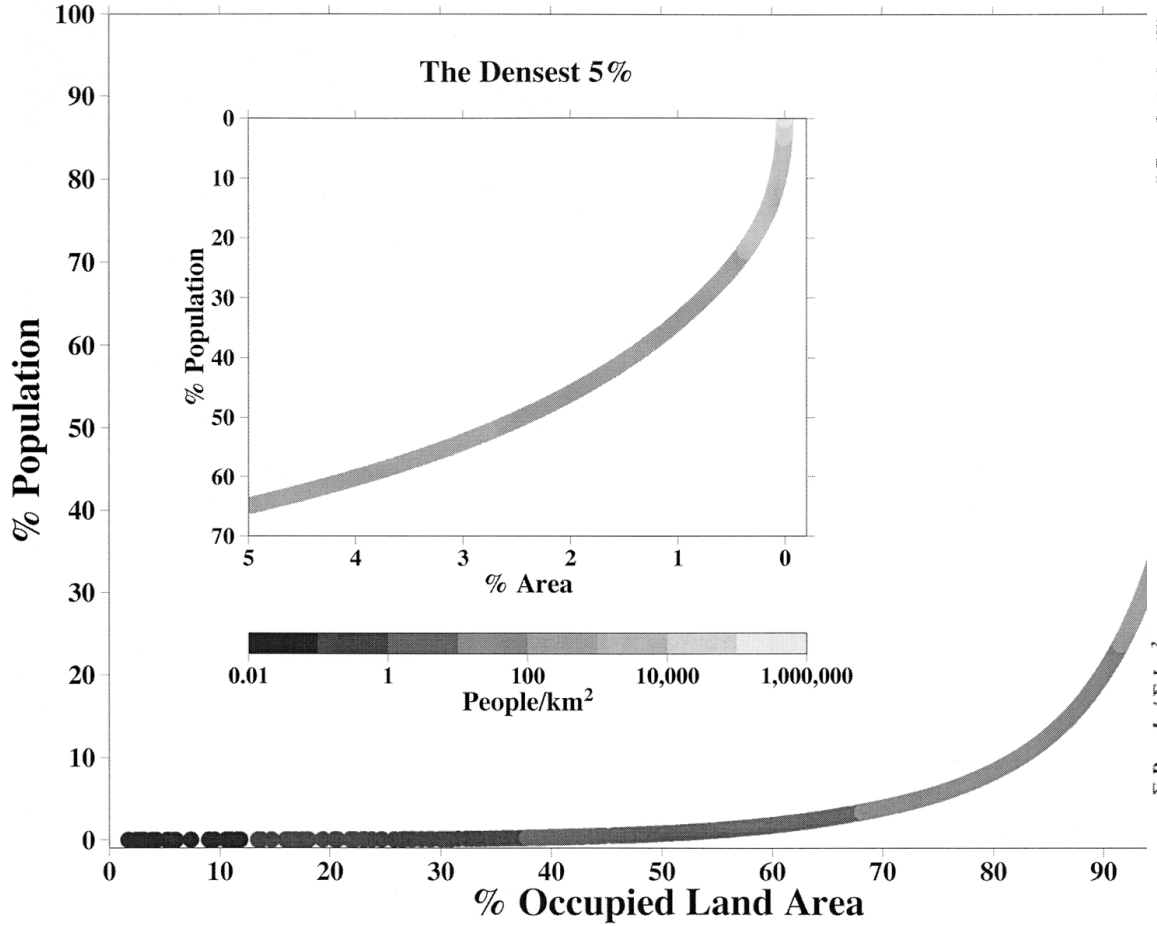
SDG 9.1.1: Rural Access to Roads

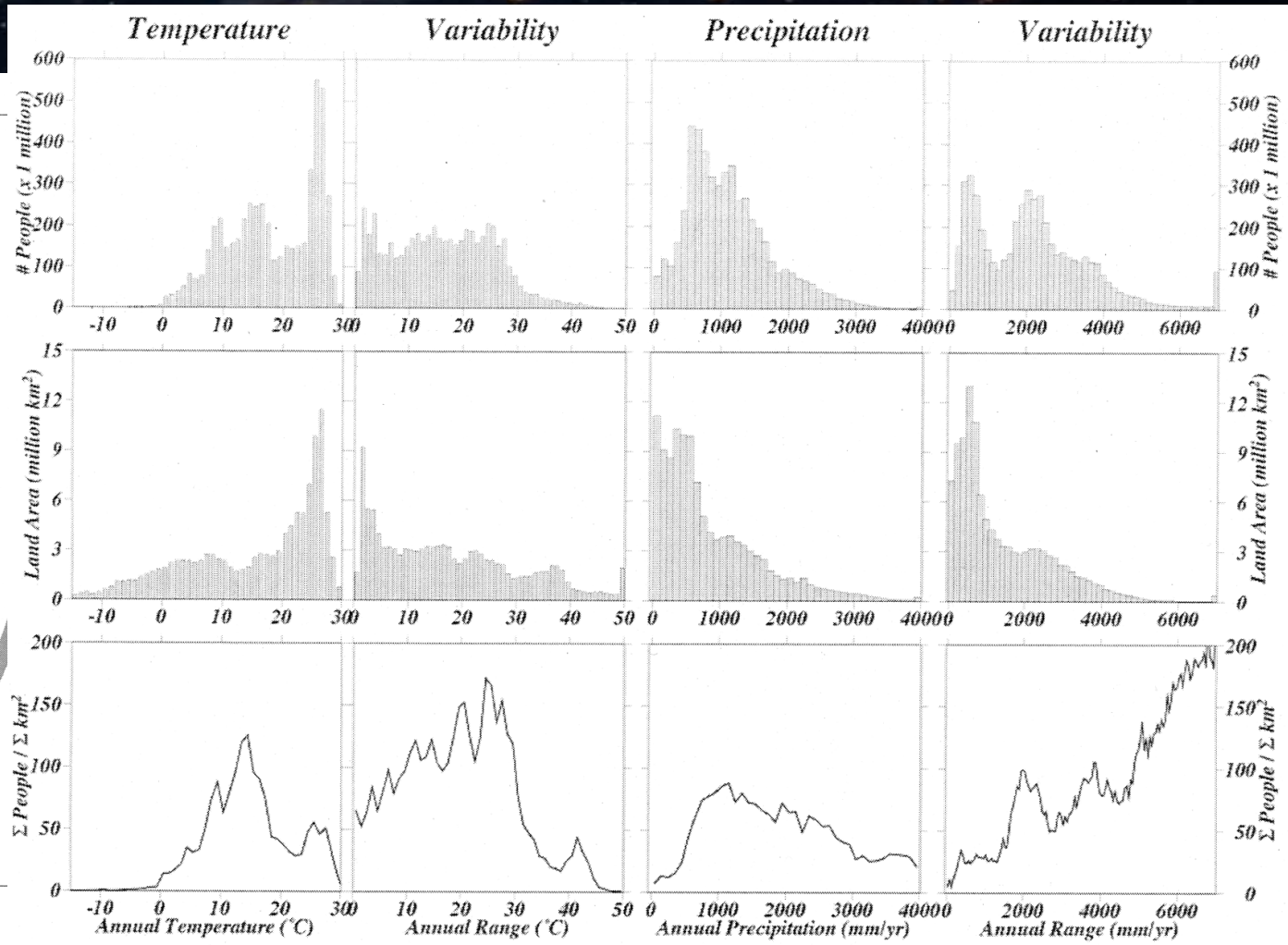


G. Application Areas for Population Grids

Continental Physiography, Climate, and the Global Distribution of Human Population

Small and Cohen, 2004. Current Anthropology, Volume 45, Number 2





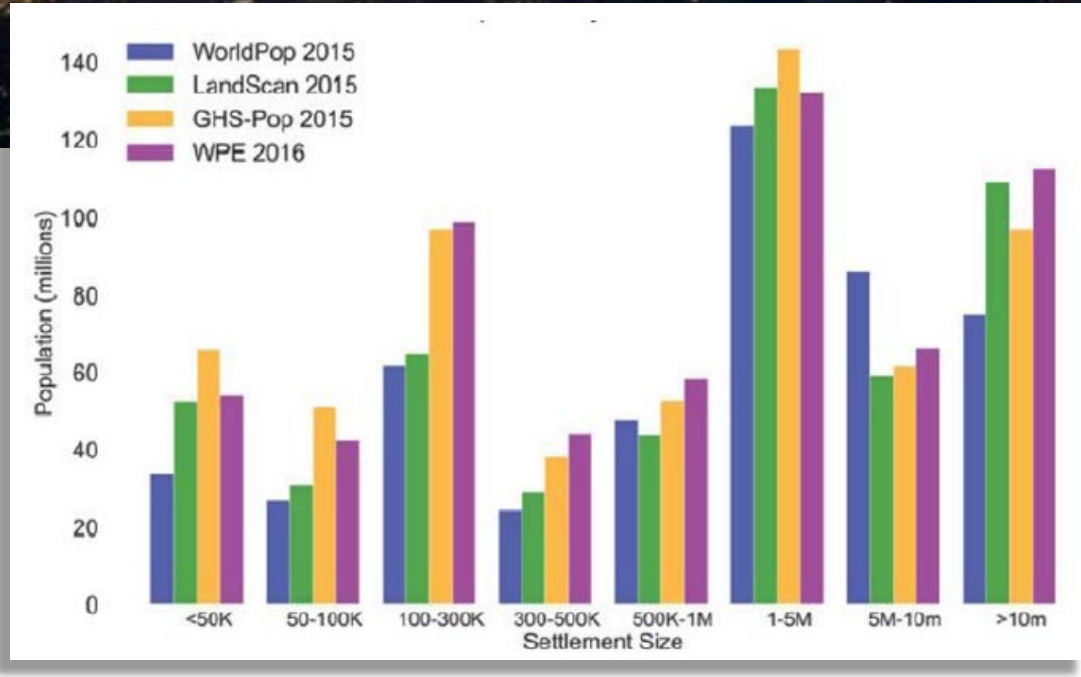
H. Data Uncertainty and Fitness for Use

Inter-comparison of existing population grids

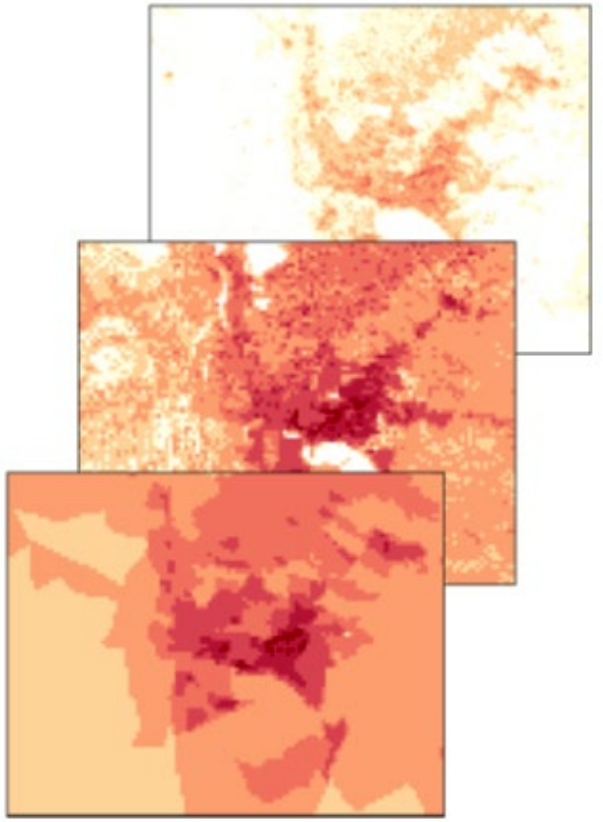
Validation efforts and their challenges

Fitness for Use: Context of target applications

Inform users about forms of **appropriate**, **uncertainty-aware** use



Tuholske et al. (2019): Total urban population by settlement size for Africa



H. Data Uncertainty and Fitness for Use

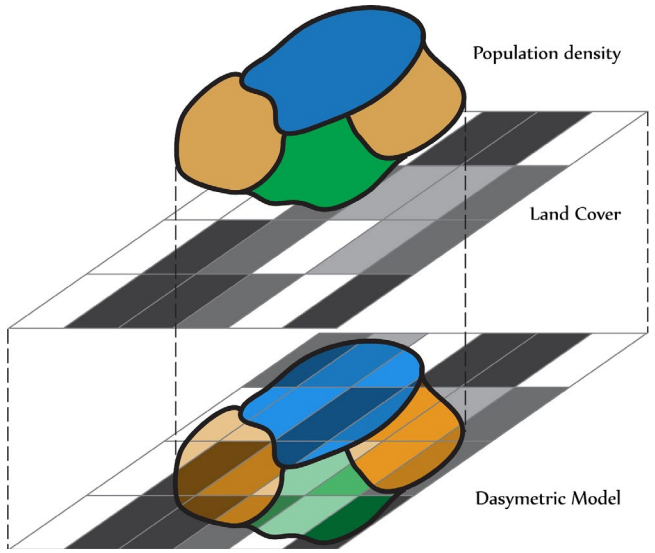
Concept of **"relative data quality"** (Tayi & Ballou 1998)

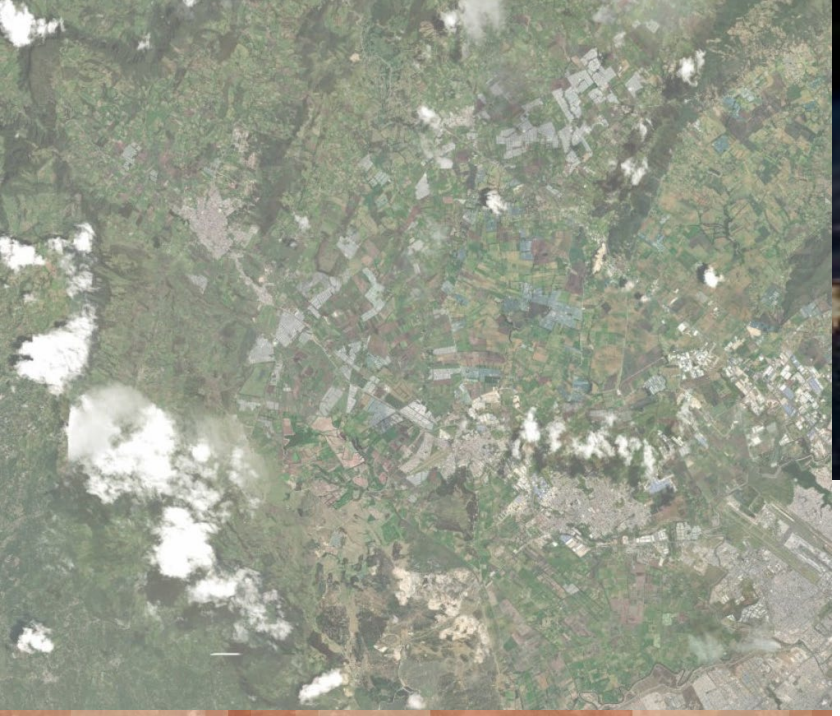
Assess the **appropriateness** of a given dataset for an **intended purpose**

Guide user community in making **informed decisions** by better understanding:

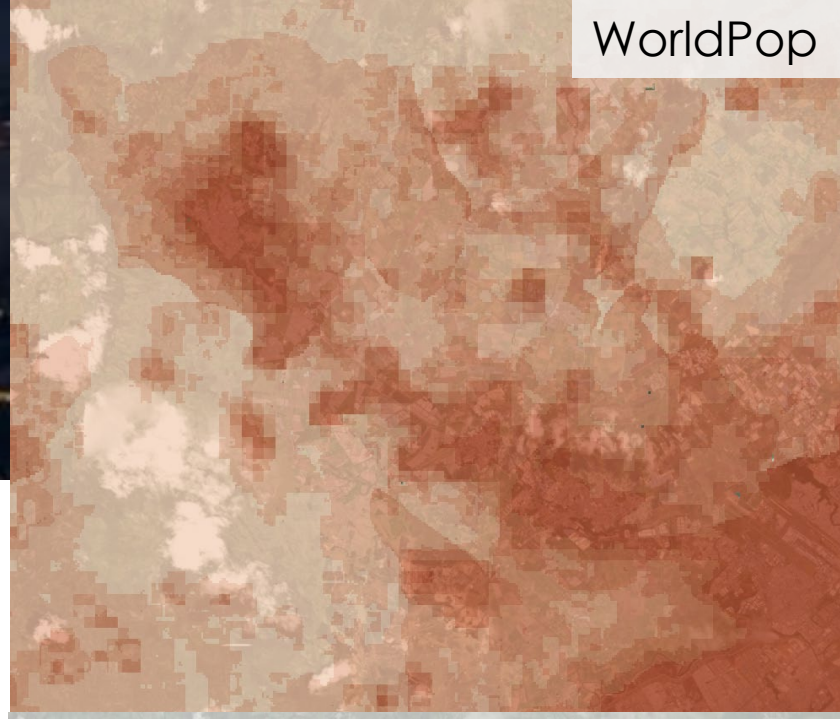
Spatial, thematic and temporal **accuracy** in relation to the intended use, driven by…

(1) Input population data properties
(2) Modeling assumptions behind products
(3) Ancillary data

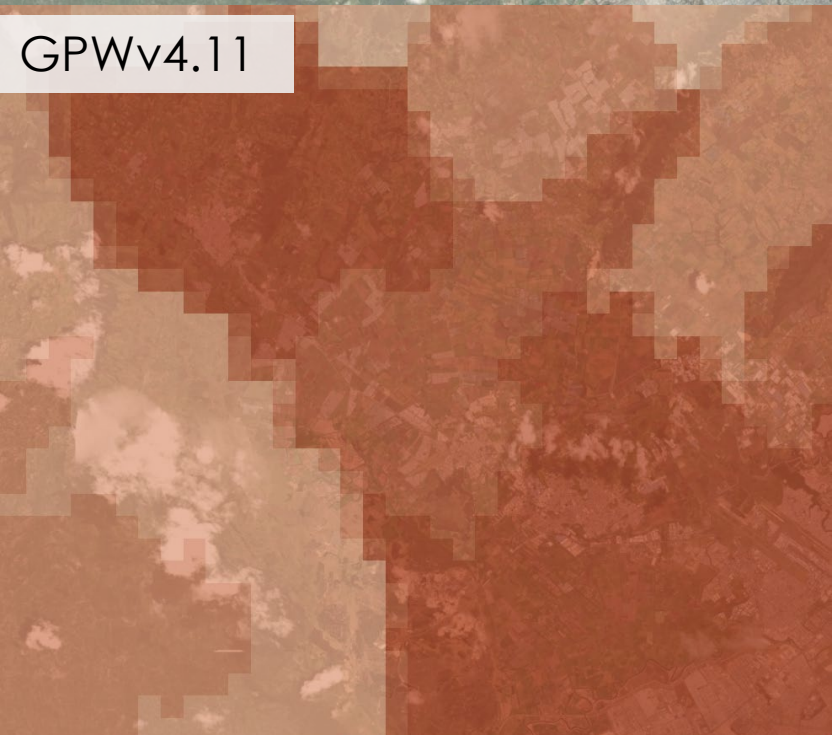


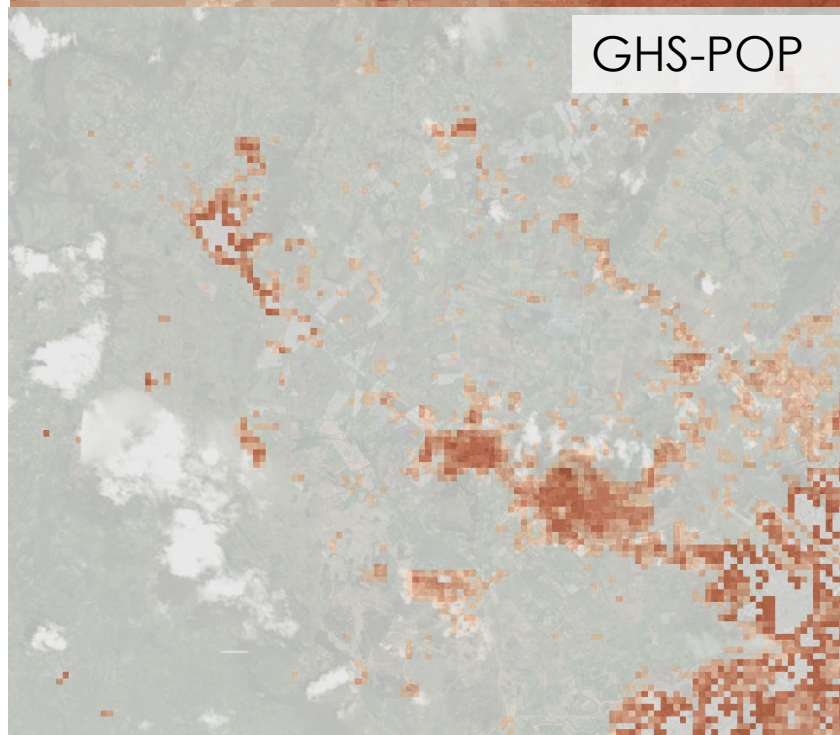


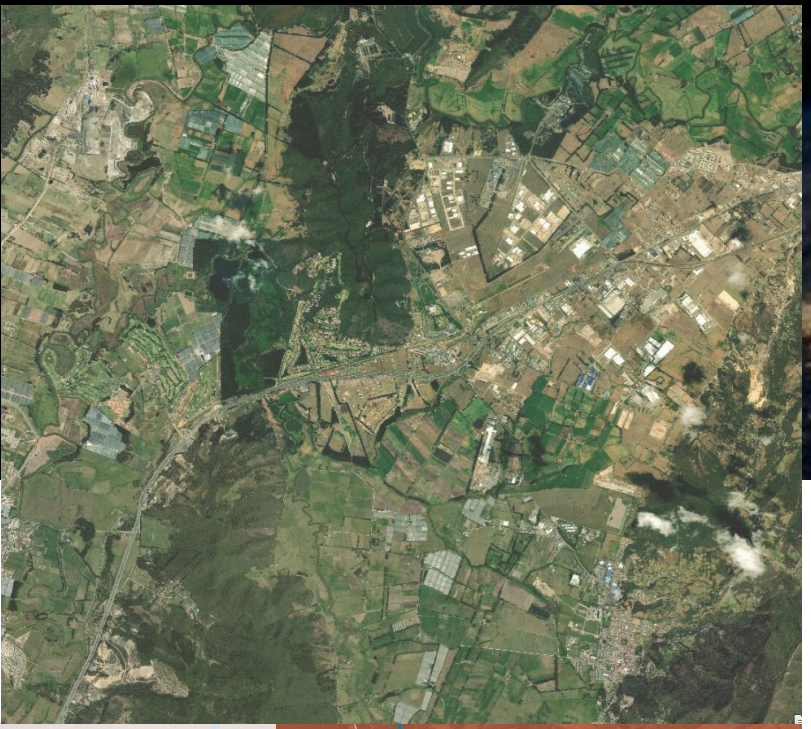
H. Data Uncertainty and Fitness for Use



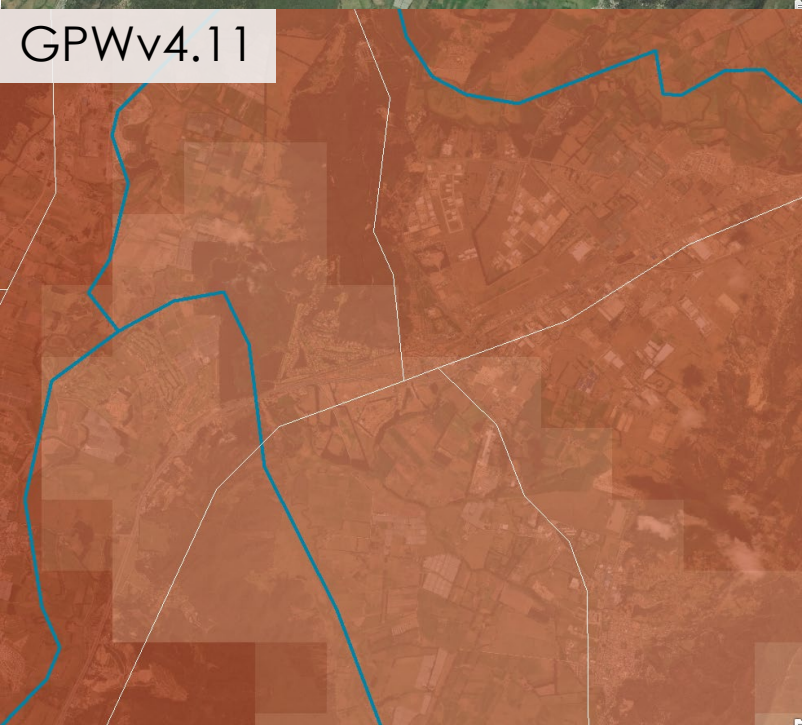
Data Aspects of **Relative Quality** & their Interrelations:







H. Data Uncertainty and Fitness for Use

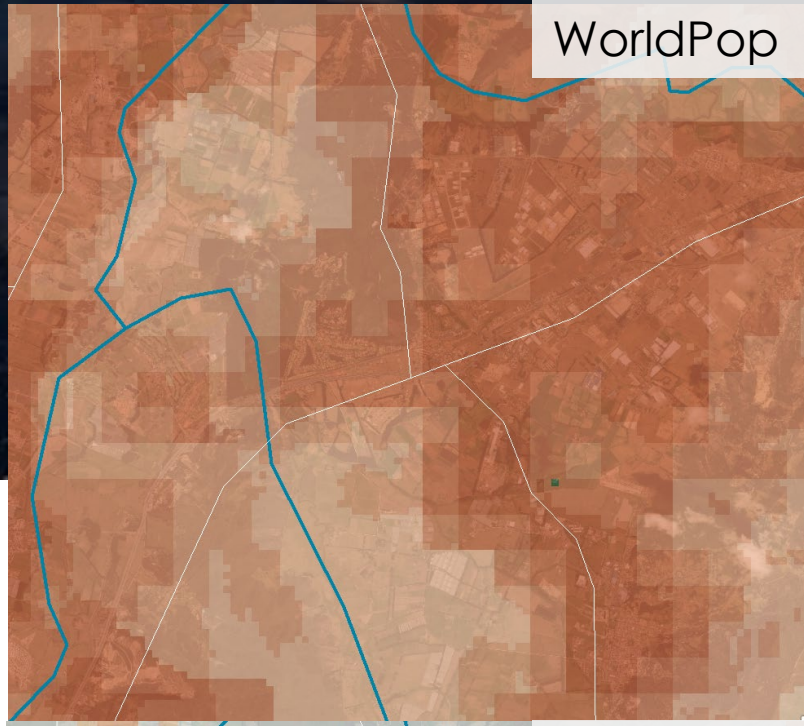


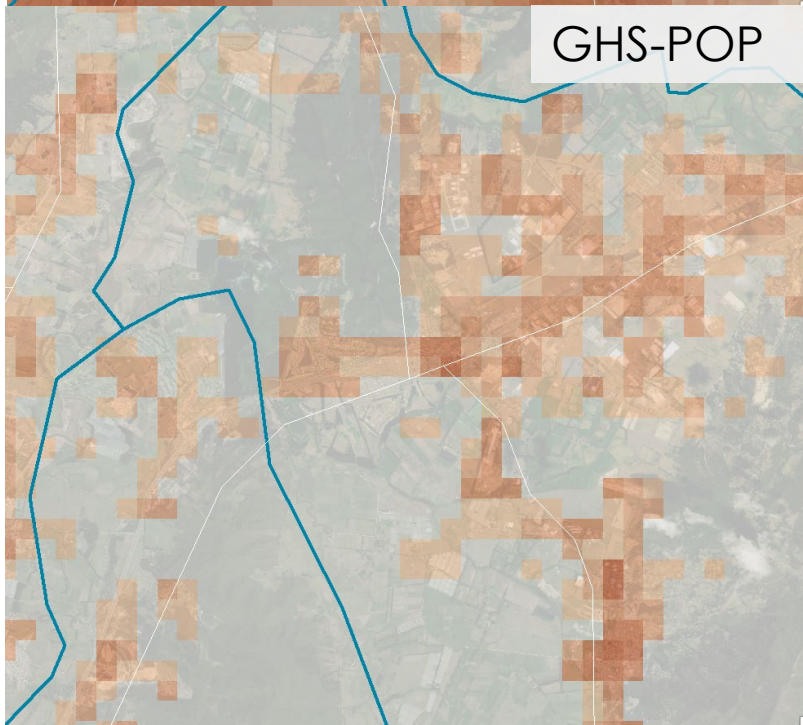
Data Aspects of **Relative Quality** & their Interrelations:

- Aggregation, mismatch, variation w/ regard to…
  - Scale
  - Currency
  - Semantics (populations)

Processing- & **Model-Related** Implications of **Uncertainty**:

- Integration/allocation
- Modeling intensity
- Uncertainty propagation

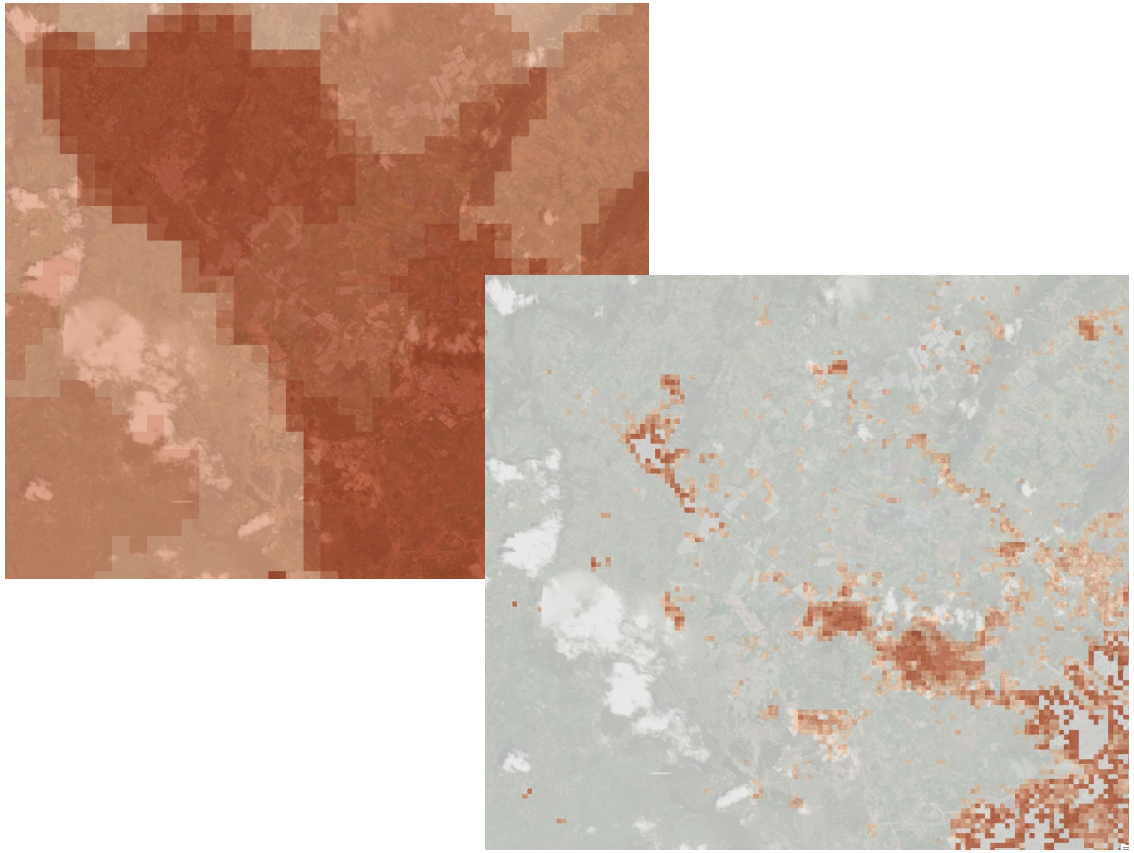




H. Data Uncertainty and Fitness for Use

Guiding questions to inform the user:

- How important is **spatial refinement** of the population grid to be used?
- Does the analysis focus on **urban** populations?
- What is the **target population** for the question at hand?
- Is the population grid being used to model **other outcomes**?
- Are you analyzing **change** over time?
- How have these datasets been used **previously**?



Earth Syst. Sci. Data, 11, 1385–1409, 2019
https://doi.org/10.5194/essd-11-1385-2019
© Author(s) 2019. This work is distributed under
the Creative Commons Attribution 4.0 License.

Open Access Earth System Science Data

The spatial allocation of population: a review of large-scale gridded population data products and their fitness for use

Stefan Leyk[1,11], Andrea E. Gaughan[2,10], Susana B. Adamo[3], Alex de Sherbinin[3], Deborah Balk[4], Sergio Freire[5], Amy Rose[6], Forrest R. Stevens[2,10], Brian Blankespoor[7], Charlie Frye[8], Joshua Comenetz[9], Alessandro Sorichetta[10], Kytt MacManus[3], Linda Pistolesi[3], Marc Levy[3], Andrew J. Tatem[10], and Martino Pesaresi[5]

[1]Department of Geography, University of Colorado Boulder, Boulder, CO 80309, USA
[2]Department of Geography and Geosciences, University of Louisville, KY 40292, USA
[3]CIESIN, Columbia University, Palisades, NY 10964, USA
[4]CUNY Institute for Demographic Research, and Marxe School of Public and International Affairs, Baruch College, City University of New York, New York City, NY 10010, USA
[5]European Commission, Joint Research Centre (JRC), Ispra, Italy
[6]Human Dynamics Group, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[7]Development Data Group, World Bank, Washington, D.C. 20433, USA
[8]Environmental Systems Research Institute, Redlands, CA 92373, USA
[9]U.S. Census Bureau, Washington, D.C. 20233, USA
[10]WorldPop, School of Geography and Environmental Sciences, University of Southampton, Southampton, SO17 1BJ, UK
[11]Institute of Behavioral Science, University of Colorado Boulder, Boulder, CO 80309, USA

Correspondence: Stefan Leyk (stefan.leyk@colorado.edu)

Received: 21 May 2019 – Discussion started: 6 June 2019
Revised: 23 July 2019 – Accepted: 25 July 2019 – Published: 11 September 2019

Further Recommended Reading

Sorichetta, A., Hornby, G., Stevens, F. et al. High-resolution gridded population datasets for Latin America and the Caribbean in 2010, 2015, and 2020. Sci Data 2, 150045 (2015). https://doi.org/10.1038/sdata.2015.45

Nelson, A., Weiss, D.J., van Etten, J. et al. A suite of global accessibility indicators. Sci Data 6, 266 (2019). https://doi.org/10.1038/s41597-019-0265-5

Balk, D., Deichmann, U., Yetman, G., Pozzi, F., Hay, S. I., and Nelson, A.: Determining Global Population Distribution: Methods, Applications and Data, ADV PARASIT, 62, 119–156, https://doi.org/10.1016/S0065-308X(05)62004-0, 2006.

Bhaduri, B., Bright, E., Coleman, P., and Dobson, J.: LandScan: Locating people is what matters, Geoinformatics, 5, 34–37, 2002.

CIESIN: Gridded Population of the World, Version 4 (GPWv4): Population Count Adjusted to Match 2015 Revision of UN WPP Country Totals, Revision 11, NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY, https://doi.org/10.7927/H4PN93PB, 2018b.

Dobson, J. E., Bright, E. A., Coleman, P. R., Durfee, R. C., and Worley, B. A.: LandScan: A Global Population Database for Estimating Populations at Risk, Photogramm. Eng. Rem. S., 66, 849–857, 2000.

Eicher, C. L. and Brewer, C. A.: Dasymetric Mapping and Areal Interpolation: Implementation and Evaluation, Cartogr. Geogr. Inf. S., 28, 125–138, https://doi.org/10.1559/152304001782173727, 2001.

Esch, T., Heldens, W., Hirner, A., Keil, M., Marconcini, M., Roth, A., Zeidler, J., Dech, S., and Strano, E.: Breaking new ground in mapping human settlements from space – The Global Urban Footprint, ISPRS J. Photogramm., 134, 30–42, https://doi.org/10.1016/j.isprsjprs.2017.10.012, 2017.

Frye, C. and Gilbert, M.: World Population Estimated 2016, Esri, https://doi.org/10.13140/RG.2.2.12996.48007, 2018a.

Frye, C., Wright, D. J., Nordstrand, E., Terborgh, C., and Foust, J.: Using Classified and Unclassified Land Cover Data to Estimate the Footprint of Human Settlement, Data Science Journal, 17, p. 20, https://doi.org/10.5334/dsj-2018-020, 2018.

Leyk, S., Gaughan, A. E., Adamo, S. B., de Sherbinin, A., Balk, D., Freire, S., ... & Comenetz, J.: The spatial allocation of population: A review of large-scale gridded population data products and their fitness for use. Earth System Science Data, 11(3), doi:10.5194/essd-11-1385-2019, 2019.

Lloyd, C. T., Sorichetta, A., and Tatem, A. J.: High resolution global gridded data for use in population studies, Scientific Data, 4, 170001, https://doi.org/10.1038/sdata.2017.1, 2017.

Nagle, N. N., Buttenfield, B. P., Leyk, S., and Speilman, S.: Dasymetric Modeling and Uncertainty, Ann. Assoc. Am. Geogr., 104, 80–95, https://doi.org/10.1080/00045608.2013.843439, 2014.

Nelson, A., Weiss, D.J., van Etten, J. *et al.* A suite of global accessibility indicators. *Sci Data* **6,** 266 (2019). https://doi.org/10.1038/s41597-019-0265-5

Pesaresi, M., Ehrlich, D., Florczyk, A. J., Freire, S., Julea, A., Kemper, T., and Syrris, V.: The global human settlement layer from landsat imagery, in: 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Beijing, China, 10–15 July 2016, IEEE, 7276–7279, https://doi.org/10.1109/IGARSS.2016.7730897, 2016b.

Ruther, M., Leyk, S., & Buttenfield, B. P. Comparing the effects of an NLCD-derived dasymetric refinement on estimation accuracies for multiple areal interpolation methods. GIScience & Remote Sensing, 52(2), 158-178, 2015.

Sorichetta, A., Hornby, G., Stevens, F. *et al.* High-resolution gridded population datasets for Latin America and the Caribbean in 2010, 2015, and 2020. *Sci Data* **2,** 150045 (2015). https://doi.org/10.1038/sdata.2015.45

Stevens, F. R., Gaughan, A. E., Linard, C., and Tatem, A. J.: Disaggregating Census Data for Population Mapping Using Random Forests with Remotely-Sensed and Ancillary Data, PLOS ONE, 10, e0107042, https://doi.org/10.1371/journal.pone.0107042, 2015.

Tatem, A. J.: WorldPop, open data for spatial demography, Scientific Data, 4, 170004, https://doi.org/10.1038/sdata.2017.4, 2017.

Tayi, G. K. and Ballou, D. P.: Examining data quality, Commun. ACM, 41, 54–57, https://doi.org/10.1145/269012.269021, 1998.

Tuholske, C., Caylor, K., Evans, T., & Avery, R.: Variability in urban population distributions across Africa. Environmental Research Letters, 14(8), 085009, 2019.

WorldPop (School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Département de Géographie, Université de Namur) and CIESIN (Center for International Earth Science Information Network), Columbia University: Global High Resolution Population Denominators Project – Funded by The Bill and Melinda Gates Foundation (OPP1134076), https://www.worldpop.org/doi/10.5258/SOTON/WP00645, 2018.


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!