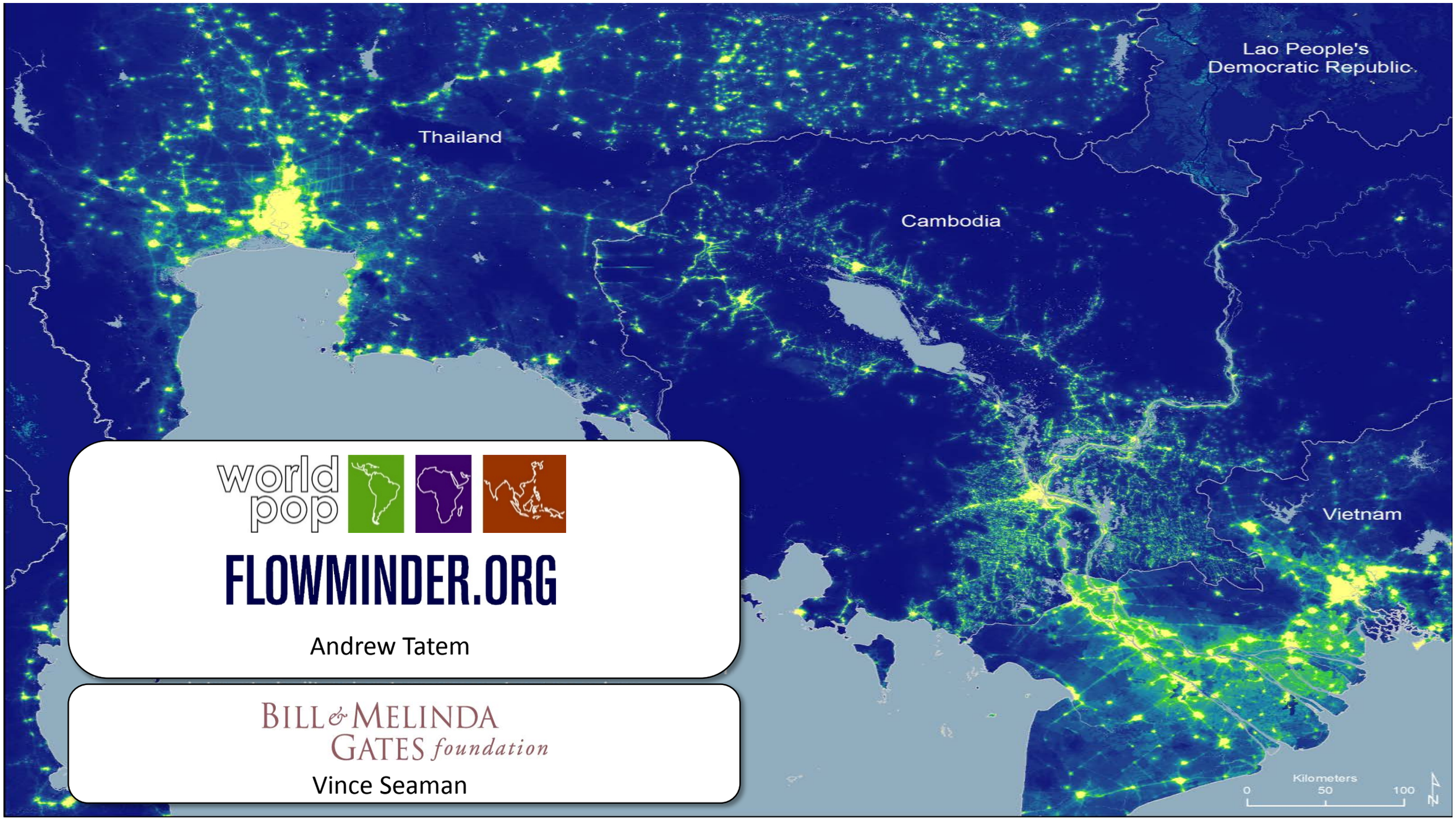



world pop

# FLOWMINDER.ORG

Andrew Tatem

BILL & MELINDA GATES foundation

Vince Seaman

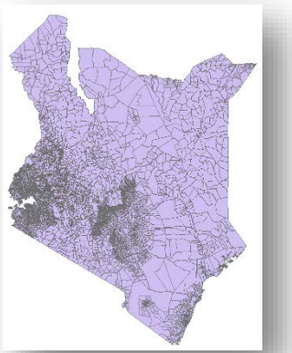
# Development goal denominators

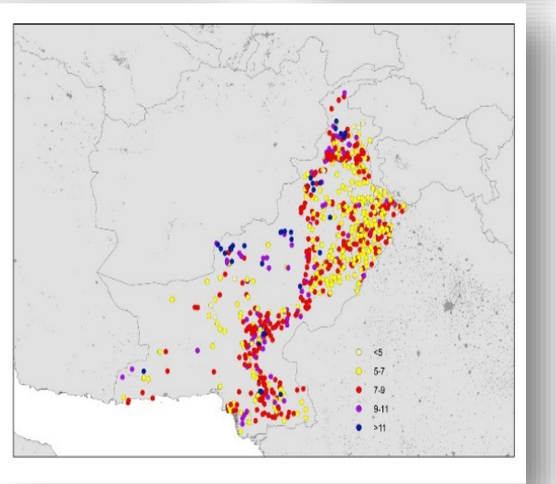
- All MDGs and SDGs are based on ensuring a certain percentage of the population has access to specific services or resources, or achieves a certain level of social, economic, or physical health.
- Improved understanding of *sub-national geographic variation and inequity* in health status, wealth, and access to resources within countries is increasingly recognized as central to meeting development goals.
- Requires a consistent, comparable and regularly updated understanding of not only how many people live in a country, but where the people are, and who they are.

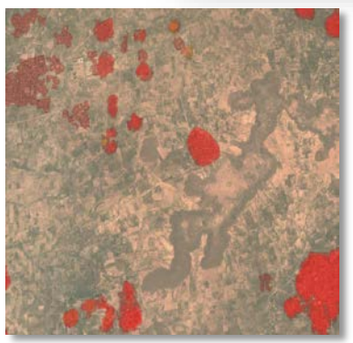
# WorldPop

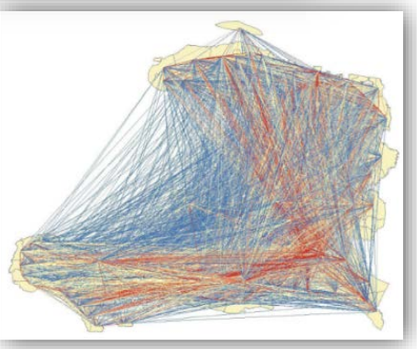
***Improve the spatial demographic evidence base for low and middle income countries***

- Work with statistical agencies, health depts to obtain finest detail, boundary-matched census data
- Develop scalable methods and models for integrating ancillary datasources to complement and fill data gaps in census
- Integrate new technologies
- Freely available high resolution data and fully documented, peer-reviewed methods





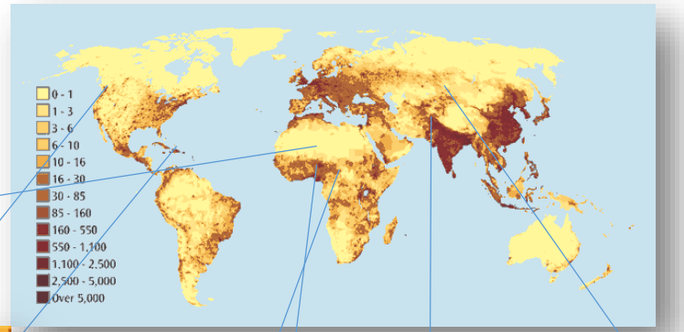



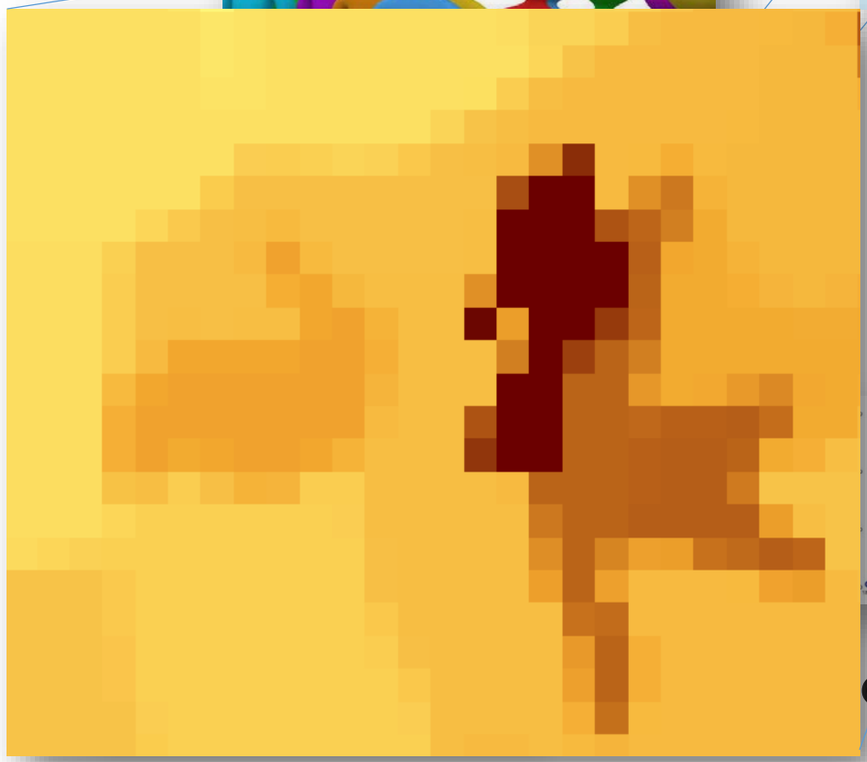


www.worldpop.org

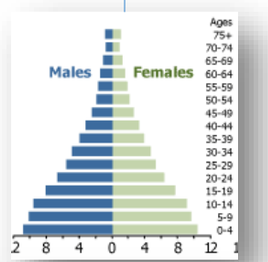
# What do we mean by spatial demographics here?

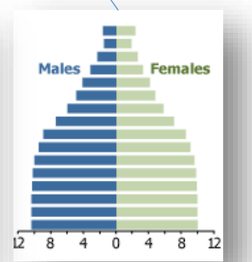
- Where is everybody?

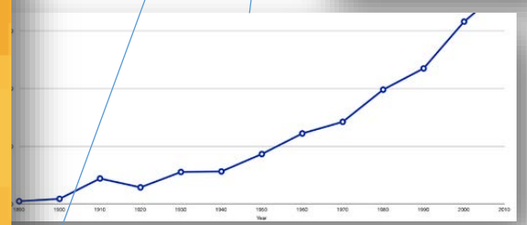


- Who is there?



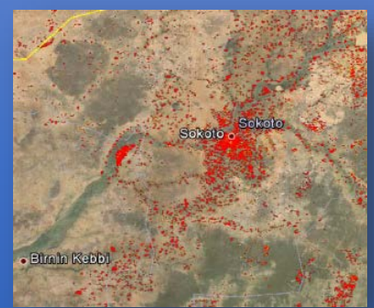



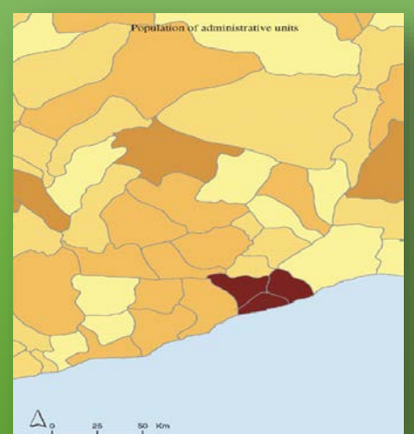
obile is the population?

# Modelling population distributions

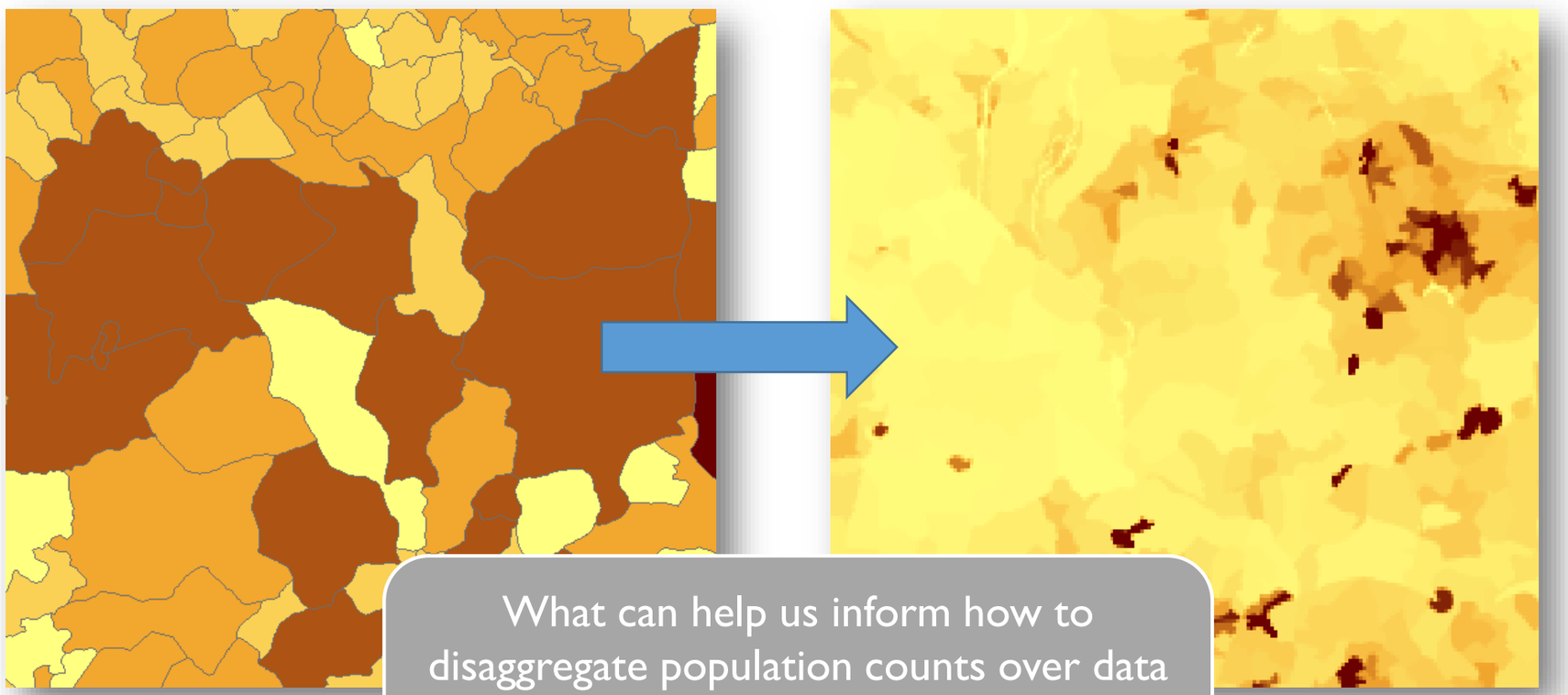
***Bottom-up:*** where census data are outdated/unreliable, integration of high resolution settlement mapping with survey data




***Top-down:*** disaggregation of admin-unit based census/official estimate counts

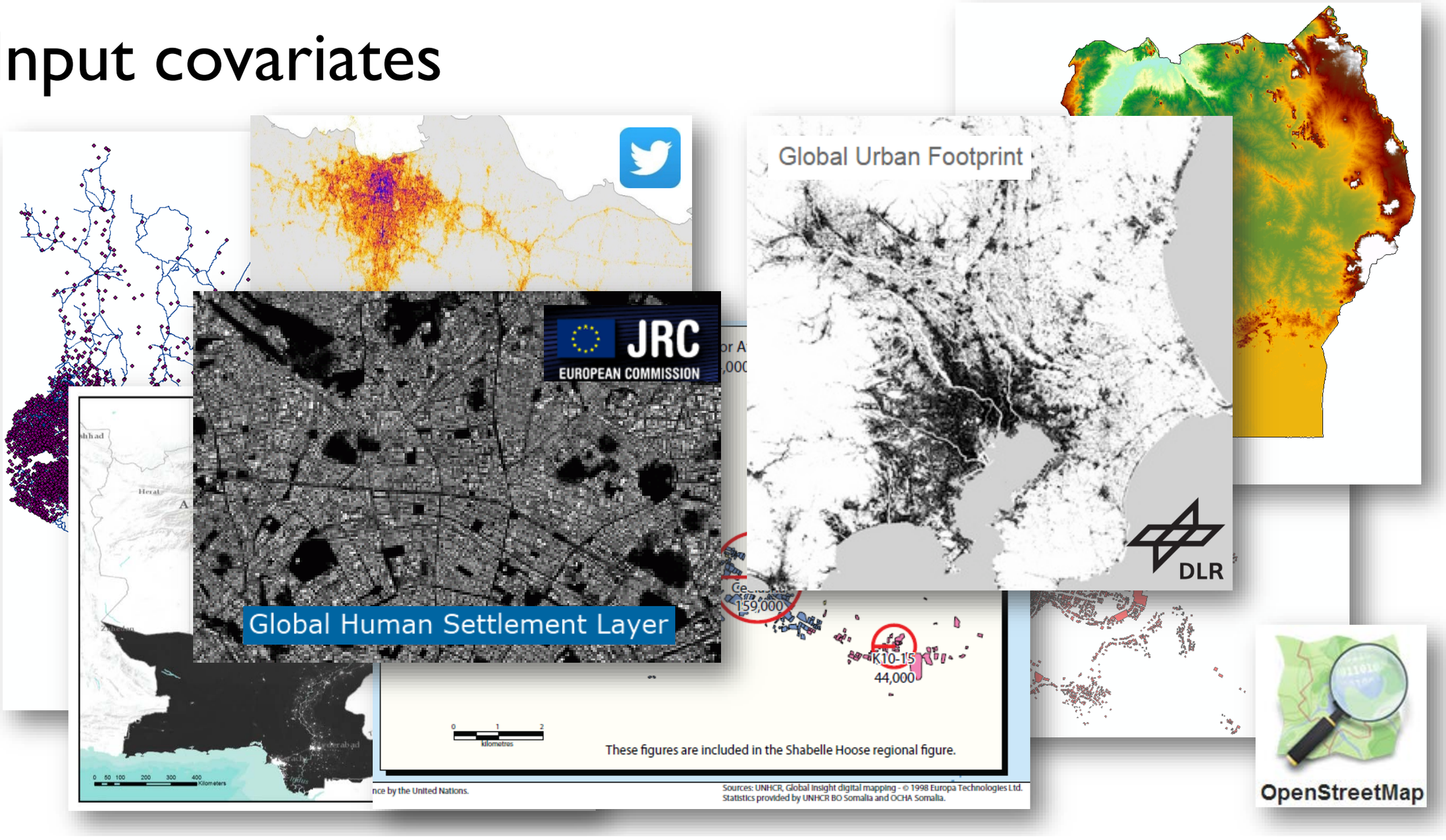


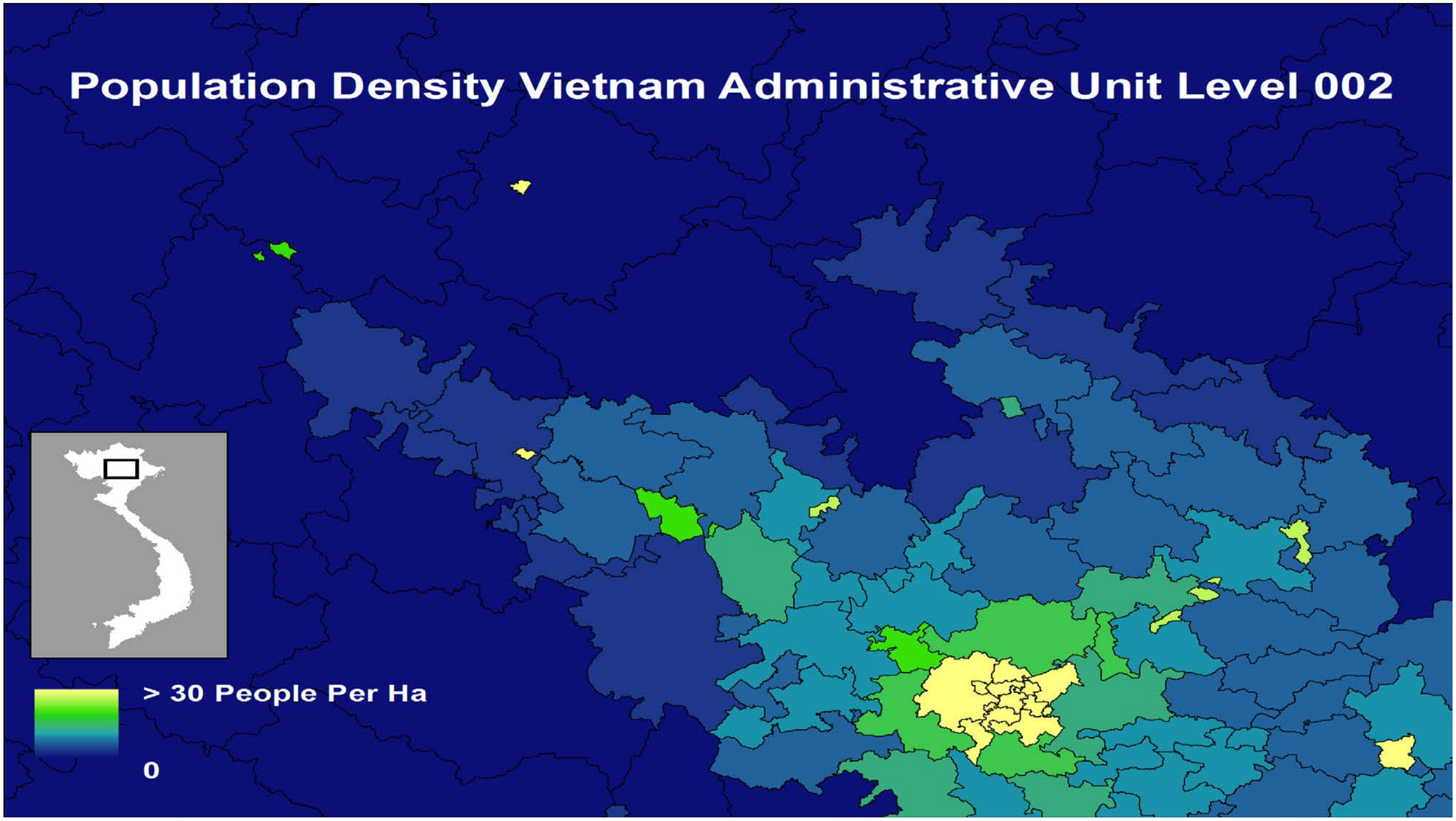
# Top-down: How can we go from aggregated counts to gridded surfaces?

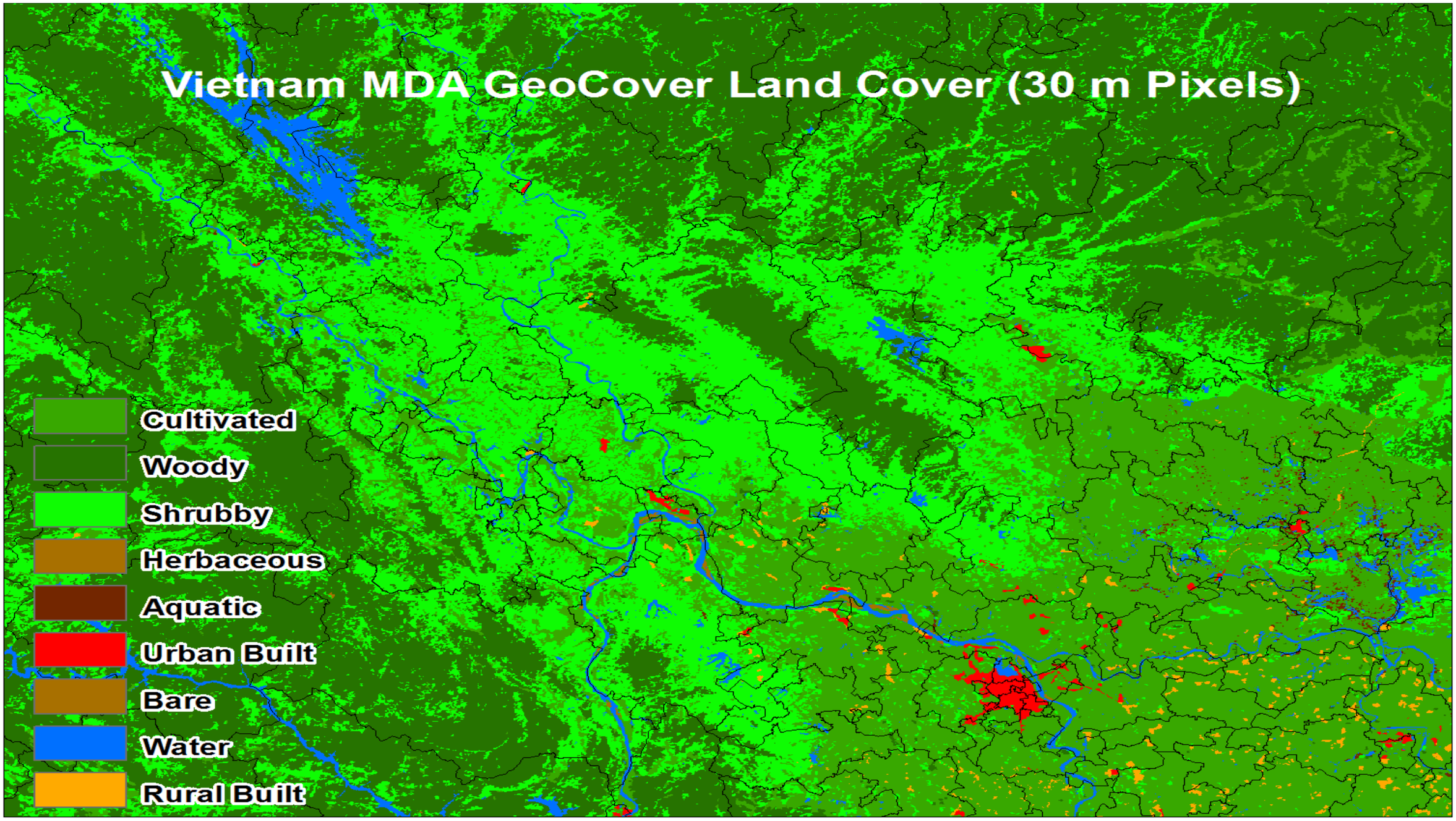


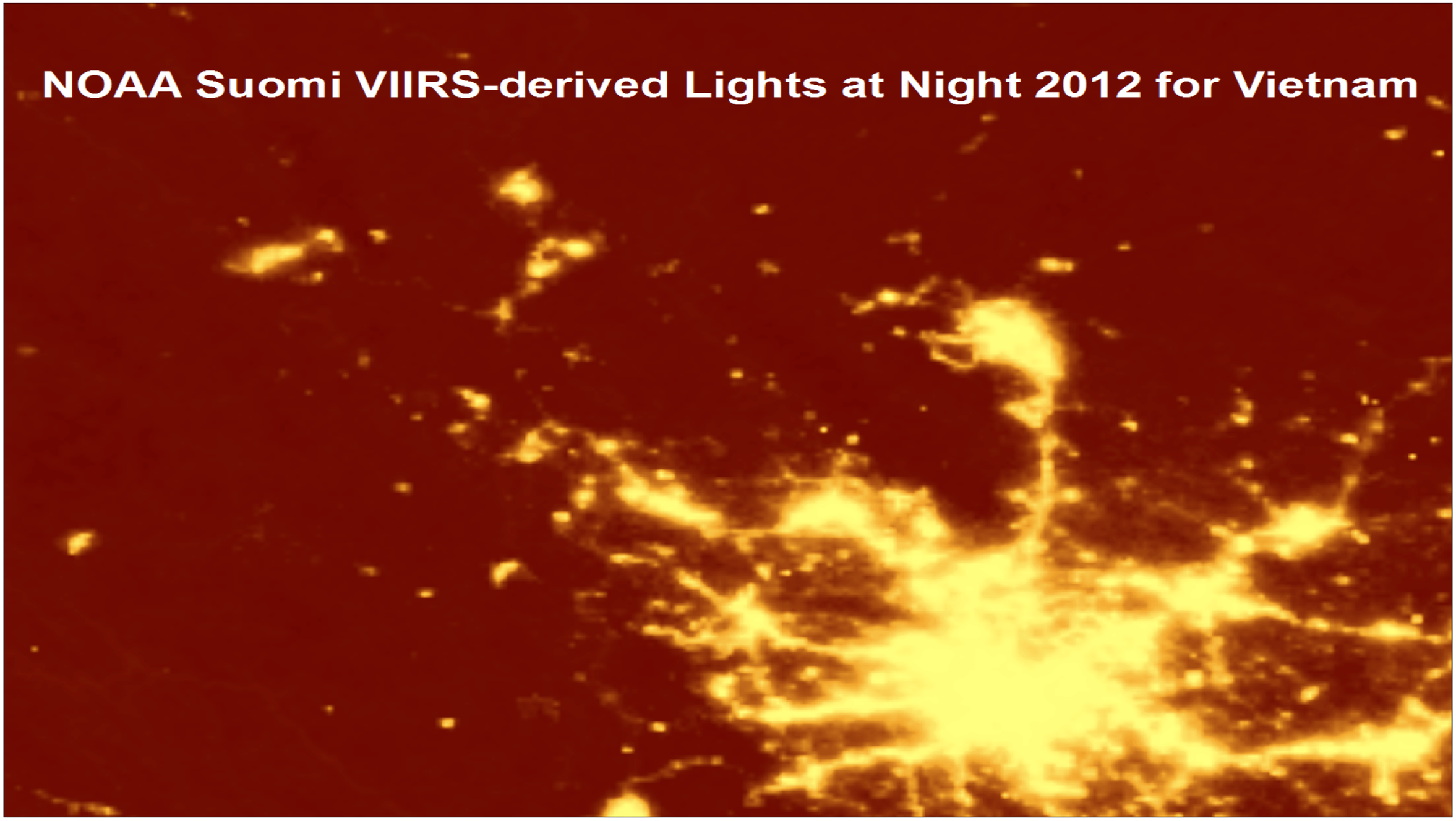
What can help us inform how to disaggregate population counts over data poor national/continental areas into small grid cells accurately?

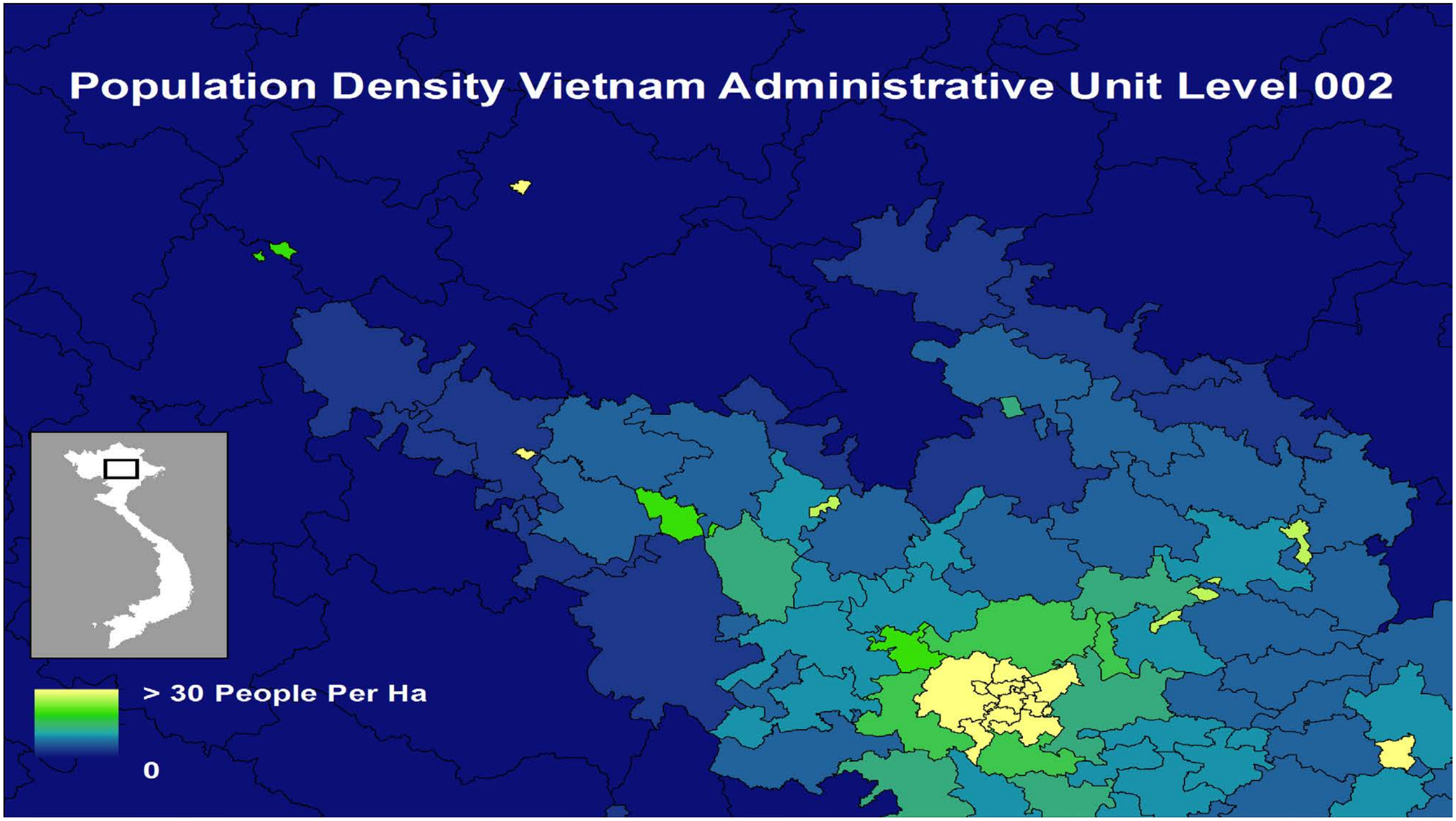
# Input covariates

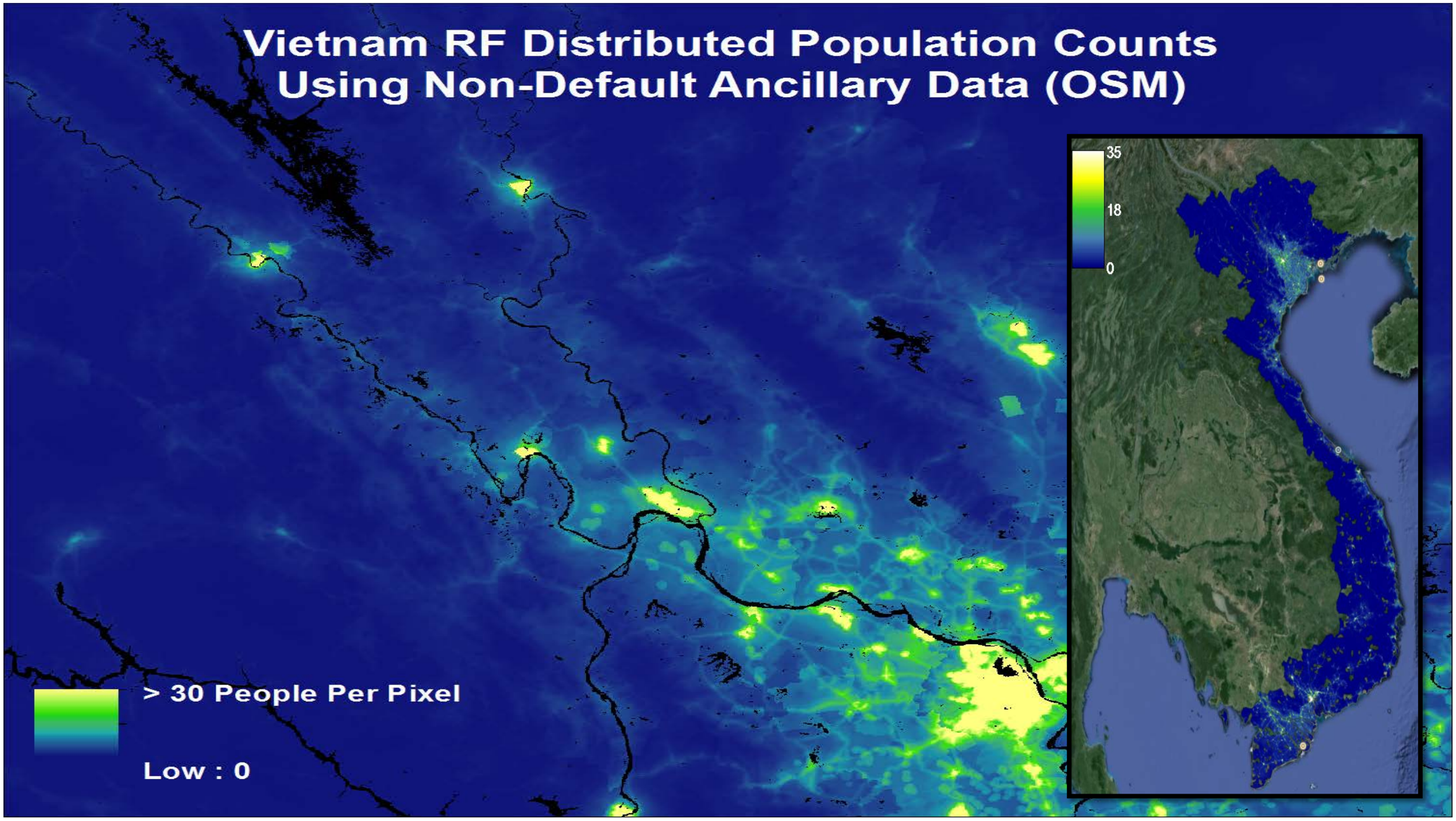



Population Density Vietnam Administrative Unit Level 002
> 30 People Per Ha
0

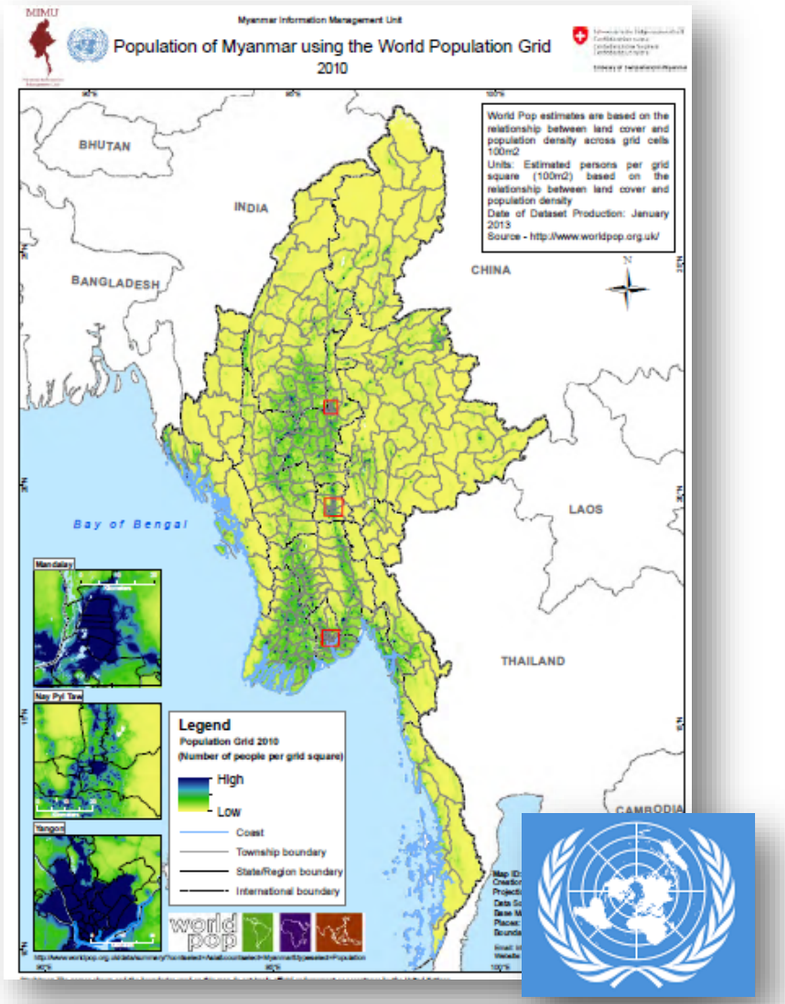

Vietnam MDA GeoCover Land Cover (30 m Pixels)
Cultivated
Woody
Shrubby
Herbaceous
Aquatic
Urban Built
Bare
Water
Rural Built

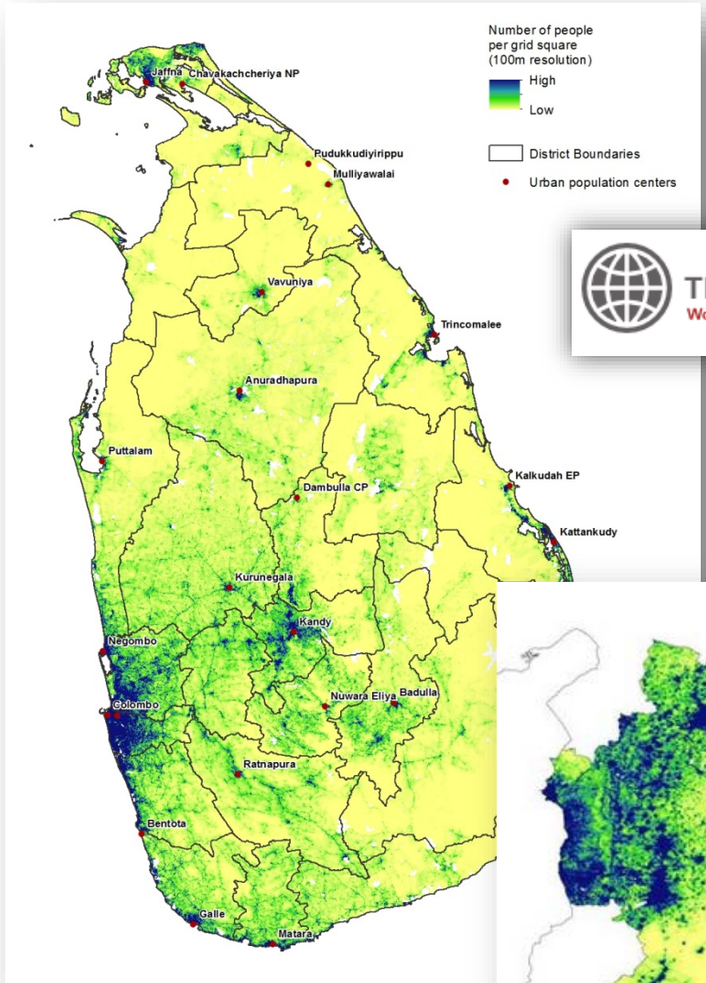

NOAA Suomi VIIRS-derived Lights at Night 2012 for Vietnam


Population Density Vietnam Administrative Unit Level 002
> 30 People Per Ha
0

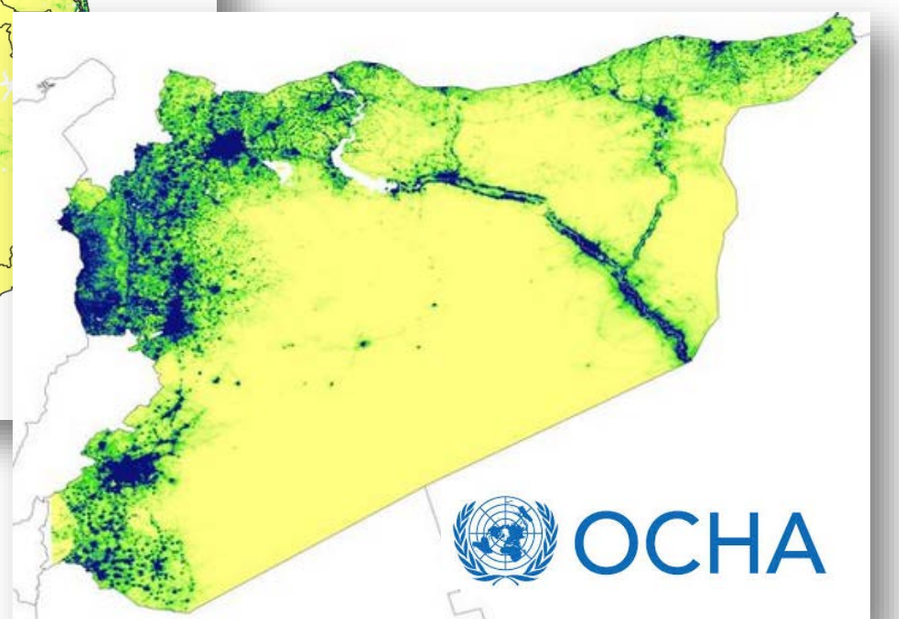

Vietnam RF Distributed Population Counts
Using Non-Default Ancillary Data (OSM)
35
18
0
> 30 People Per Pixel
Low : 0

www.worldpop.org



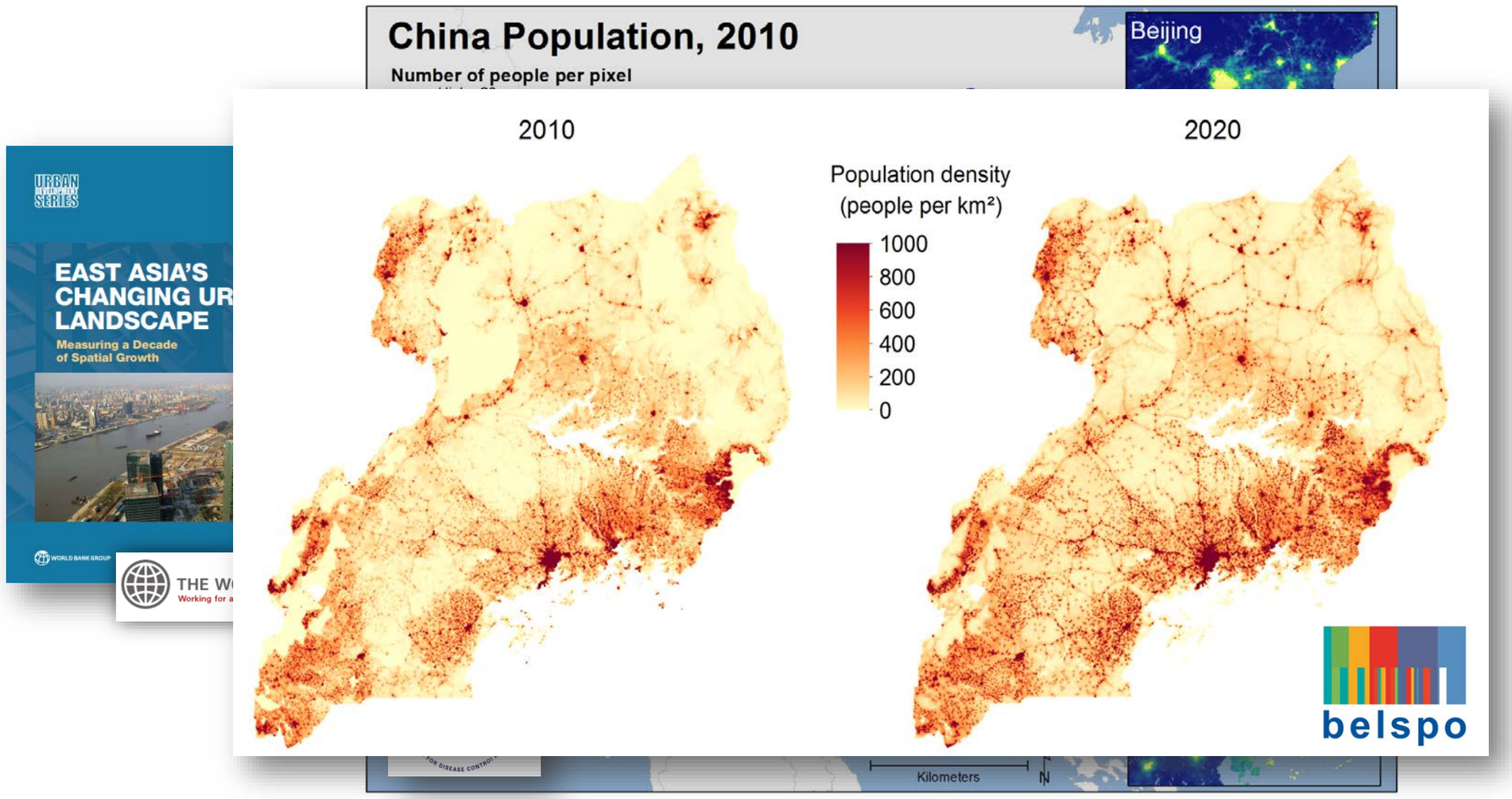




THE WORLD BANK
Working for a World Free of Poverty



OCHA

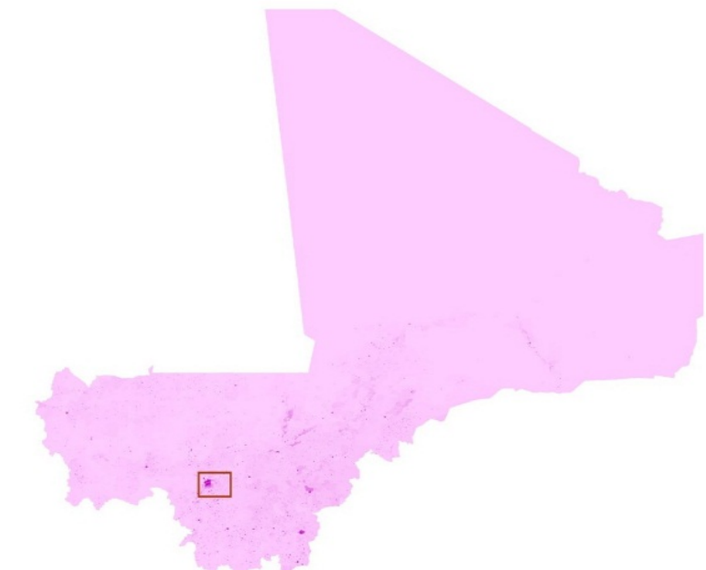
# Temporal change



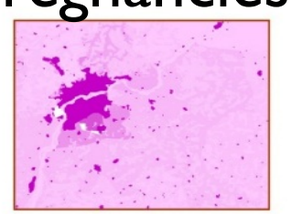

*Gaughan et al (2015) under review; Linard et al (2013) Applied Geography; Schneider et al (2015) Env Res Letters*

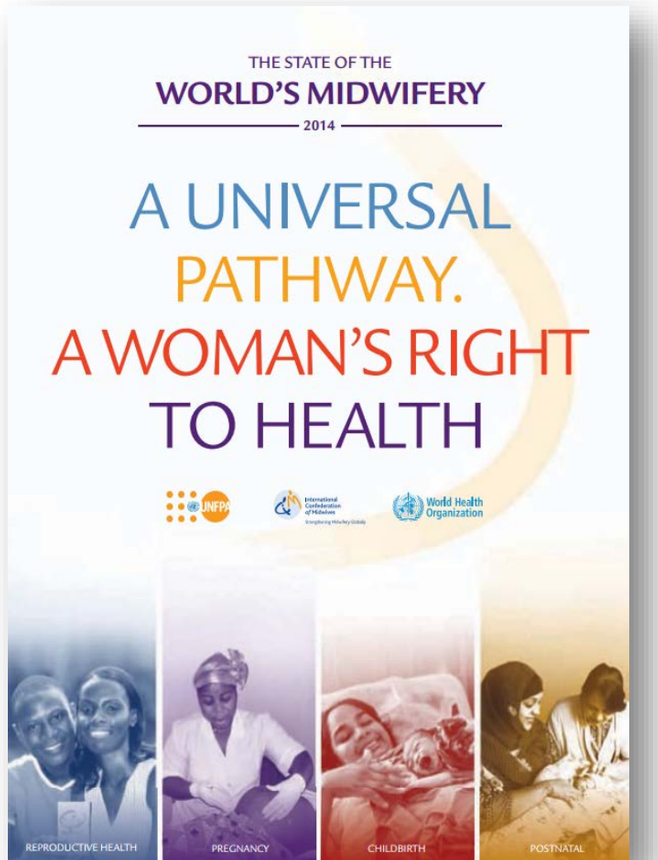
# Data integration: Maternal and newborn health

Mali



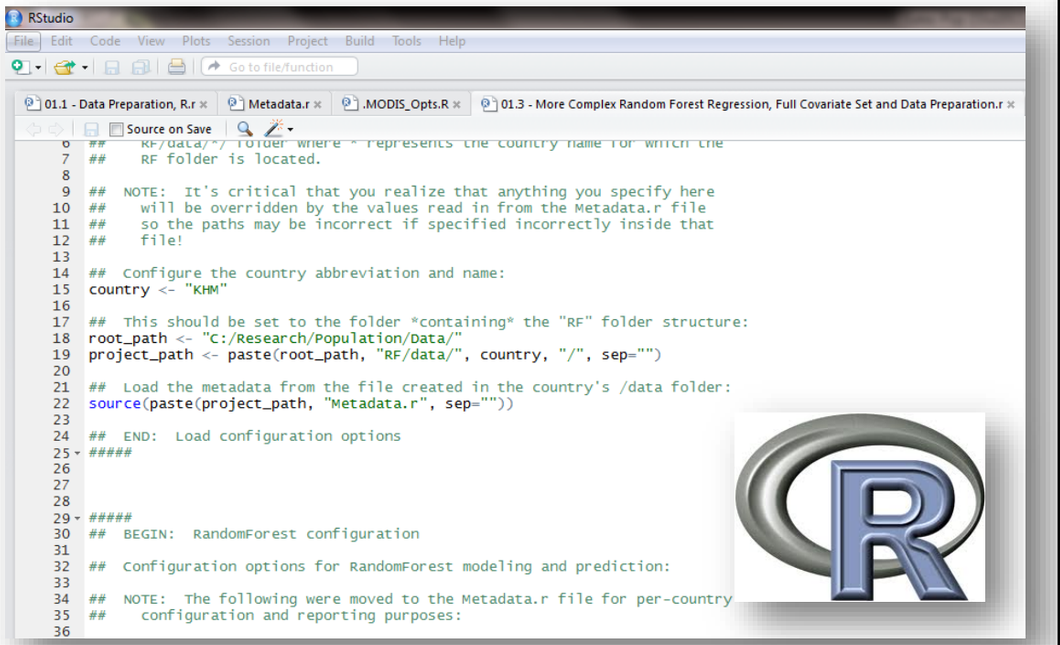

Pregnancies

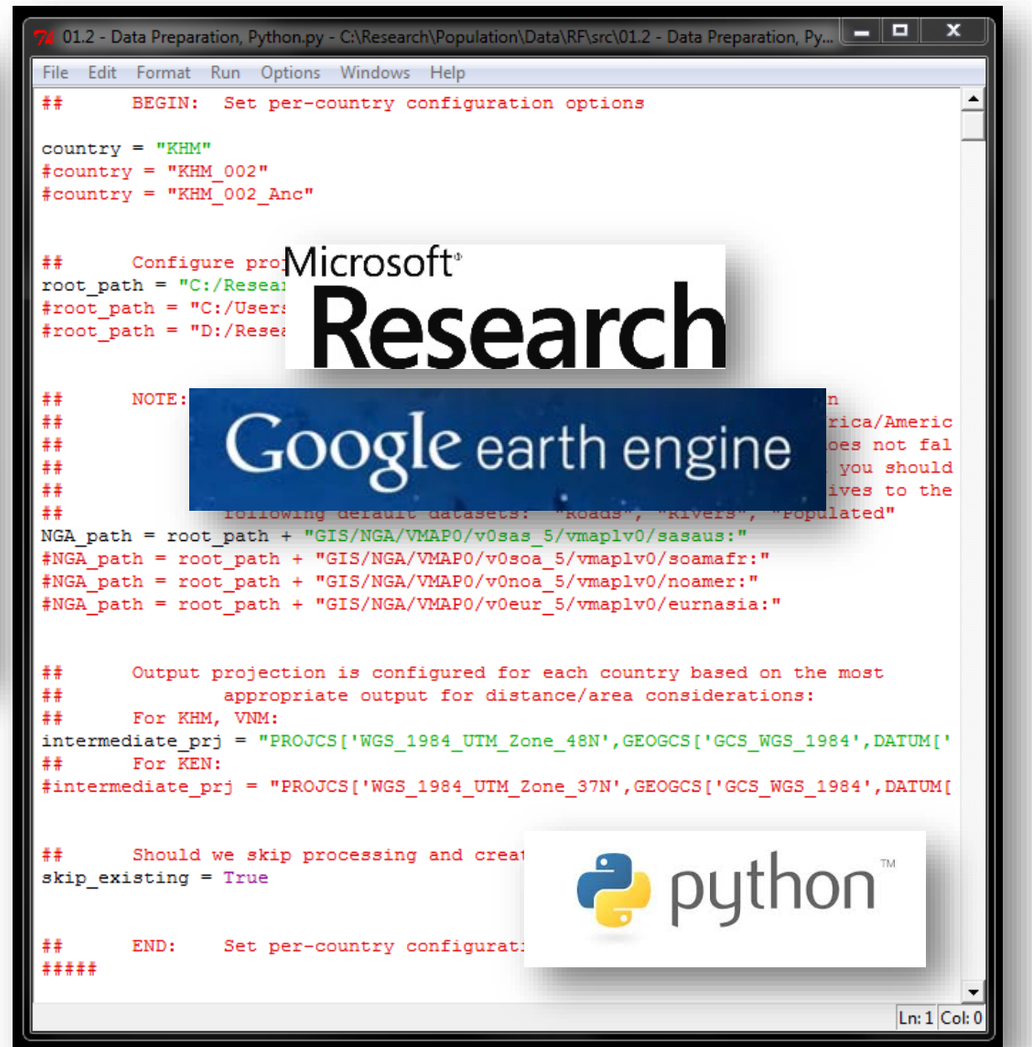





*Tatem et al (2014) IJHG, Ebener et al (2015) IJHG*

# Open code

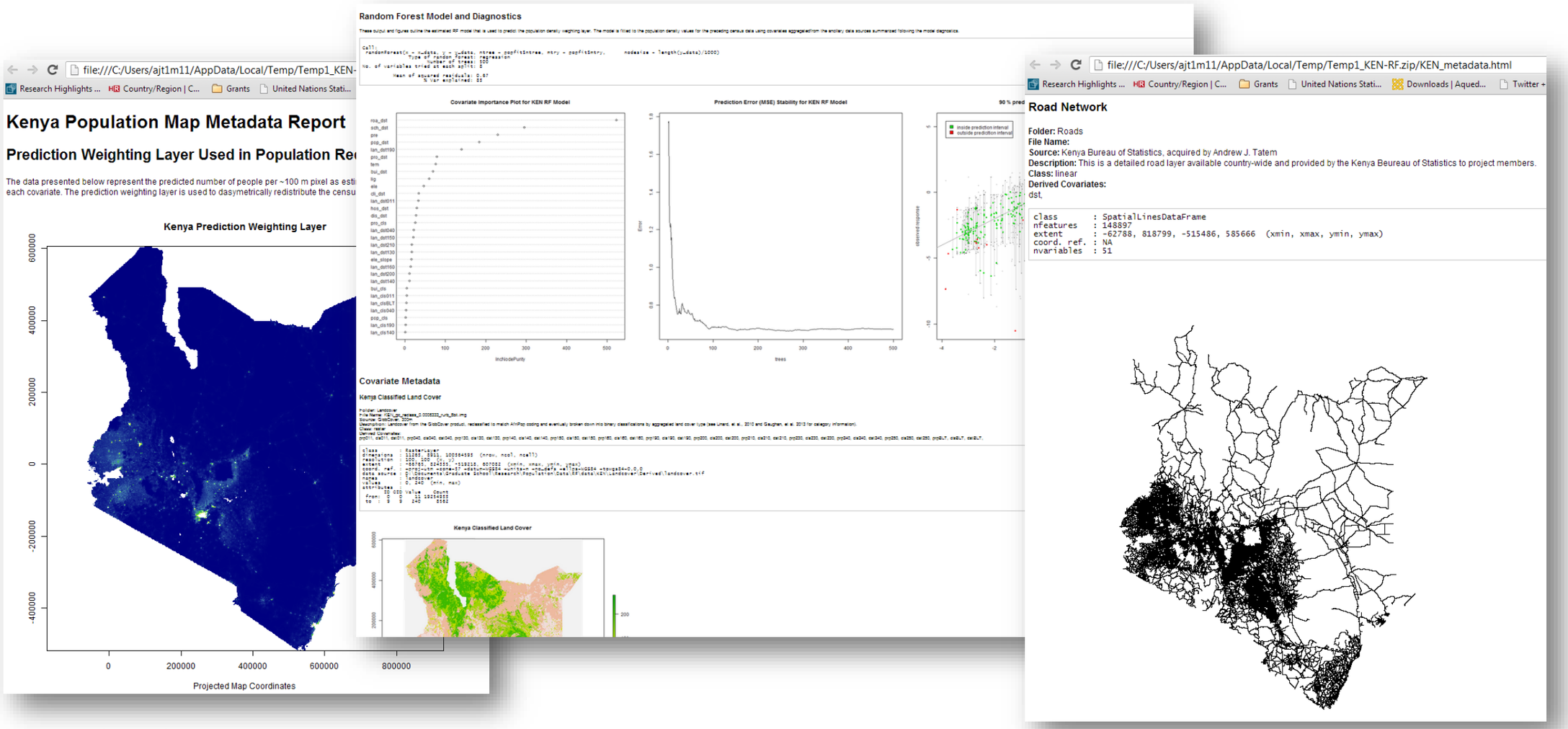



- Feedback & improvements
- Methodological clarity
- User-specific datasets
- Platform independent

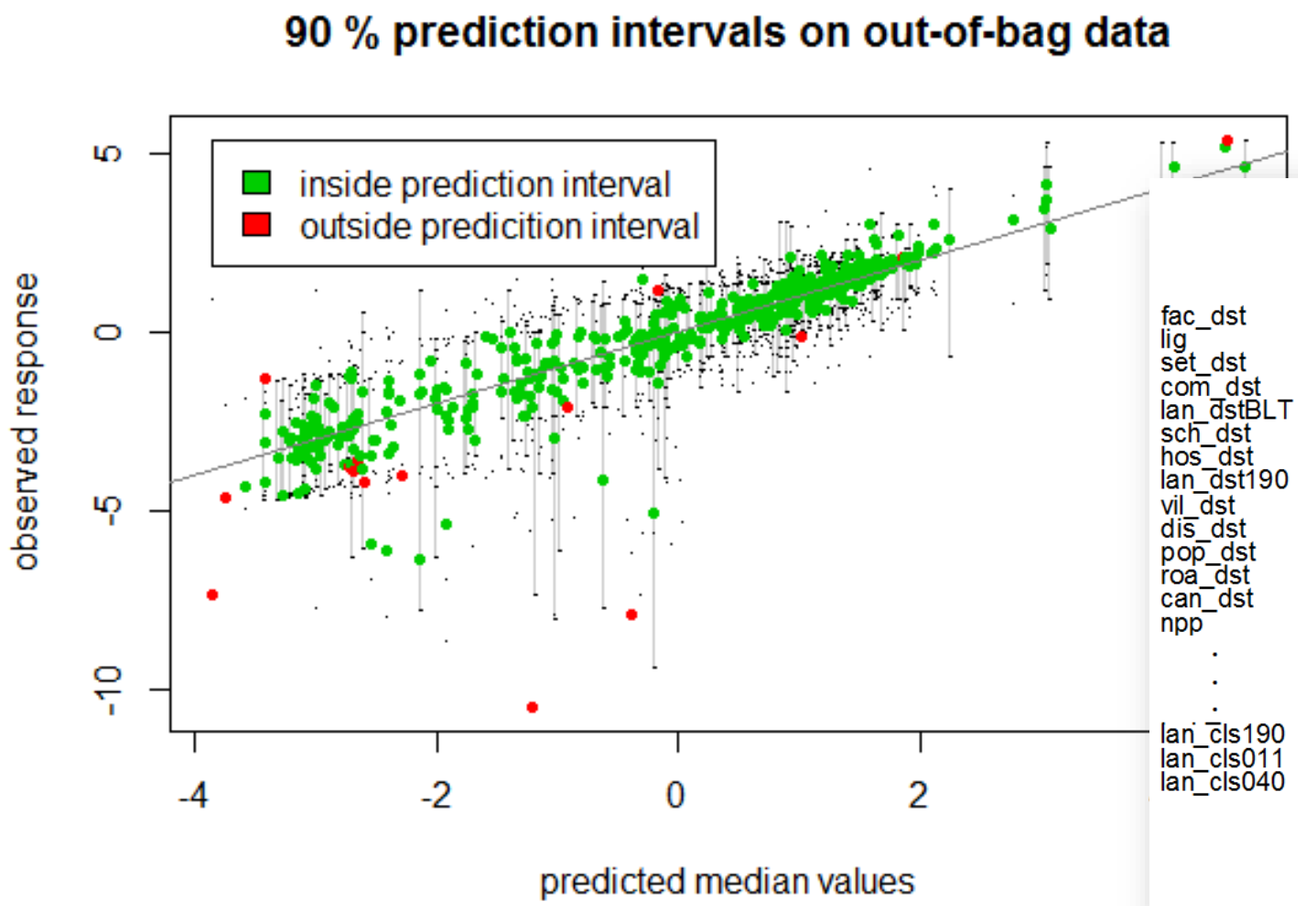
*Stevens et al (2015) PLoS ONE*

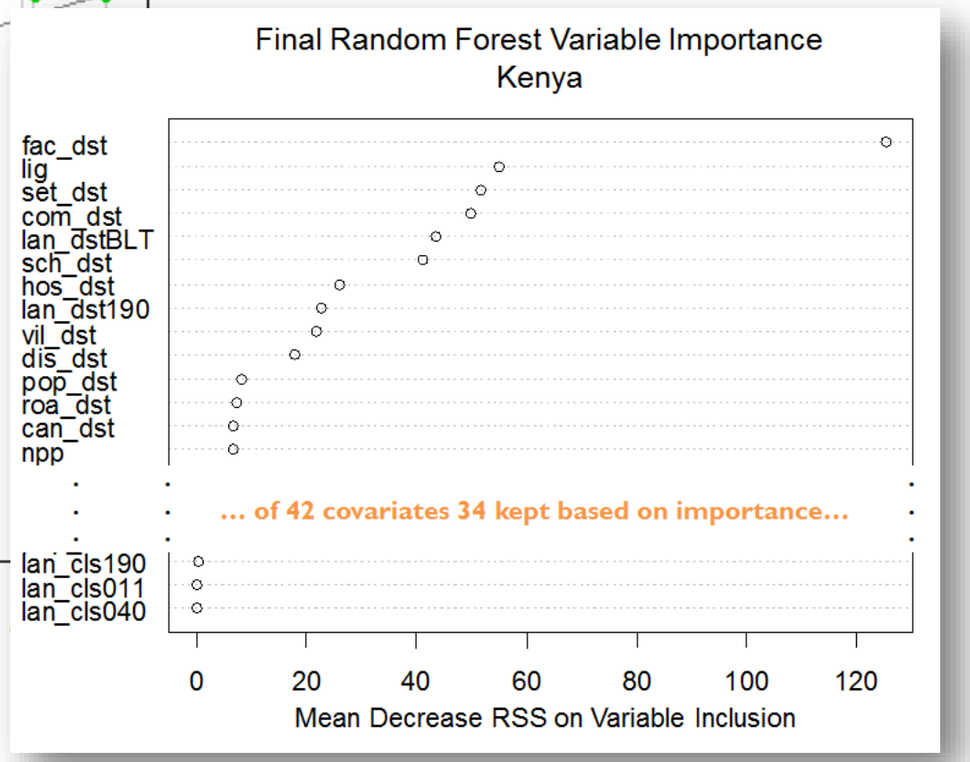
# Automated metadata




*Stevens et al (2015) PLoS ONE*

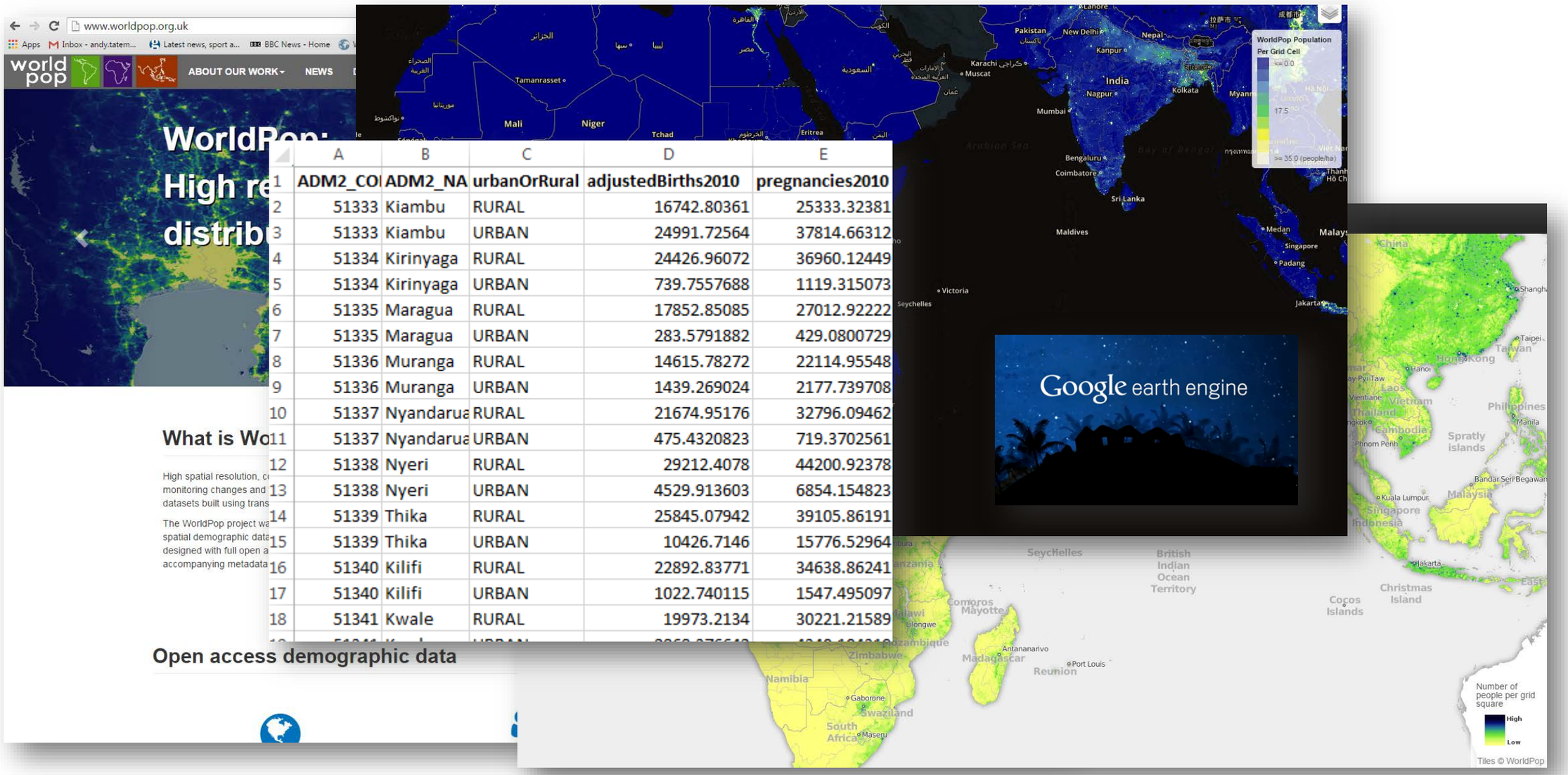
# Internal and external accuracy assessments




*Stevens et al (2015) PLoS ONE*

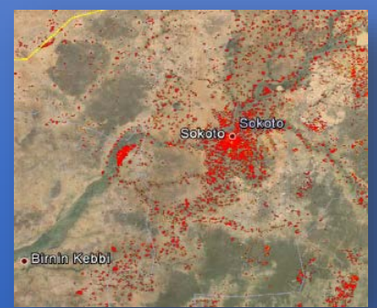
# www.worldpop.org



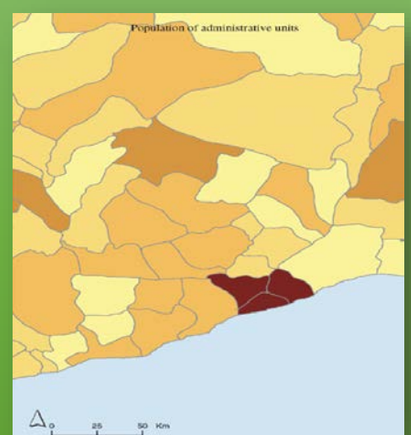

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | ADM2_CO | ADM2_NA | urbanOrRural | adjustedBirths2010 | pregnancies2010 |
| 2 | 51333 | Kiambu | RURAL | 16742.80361 | 25333.32381 |
| 3 | 51333 | Kiambu | URBAN | 24991.72564 | 37814.66312 |
| 4 | 51334 | Kirinyaga | RURAL | 24426.96072 | 36960.12449 |
| 5 | 51334 | Kirinyaga | URBAN | 739.7557688 | 1119.315073 |
| 6 | 51335 | Maragua | RURAL | 17852.85085 | 27012.92222 |
| 7 | 51335 | Maragua | URBAN | 283.5791882 | 429.0800729 |
| 8 | 51336 | Muranga | RURAL | 14615.78272 | 22114.95548 |
| 9 | 51336 | Muranga | URBAN | 1439.269024 | 2177.739708 |
| 10 | 51337 | Nyandarua | RURAL | 21674.95176 | 32796.09462 |
| 11 | 51337 | Nyandarua | URBAN | 475.4320823 | 719.3702561 |
| 12 | 51338 | Nyeri | RURAL | 29212.4078 | 44200.92378 |
| 13 | 51338 | Nyeri | URBAN | 4529.913603 | 6854.154823 |
| 14 | 51339 | Thika | RURAL | 25845.07942 | 39105.86191 |
| 15 | 51339 | Thika | URBAN | 10426.7146 | 15776.52964 |
| 16 | 51340 | Kilifi | RURAL | 22892.83771 | 34638.86241 |
| 17 | 51340 | Kilifi | URBAN | 1022.740115 | 1547.495097 |
| 18 | 51341 | Kwale | RURAL | 19973.2134 | 30221.21589 |

# Modelling population distributions

***Bottom-up:*** where census data are outdated/unreliable, integration of high resolution settlement mapping with survey data




***Top-down:*** disaggregation of admin-unit based census/official estimate counts



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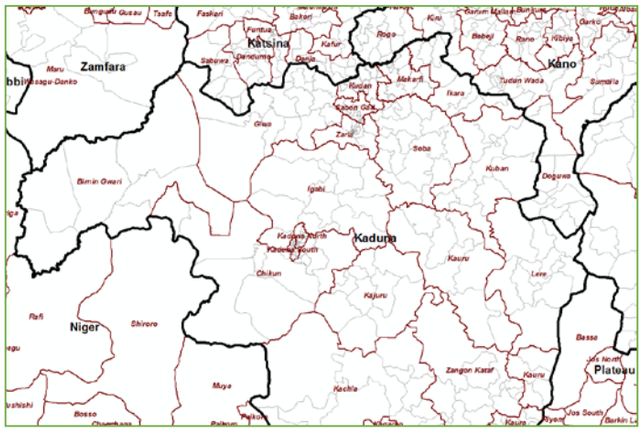
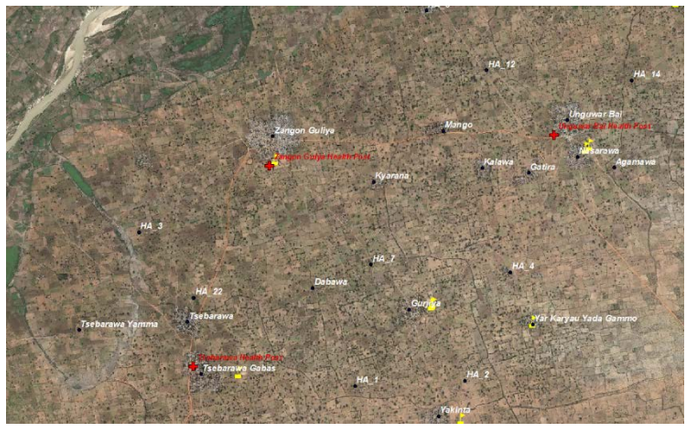
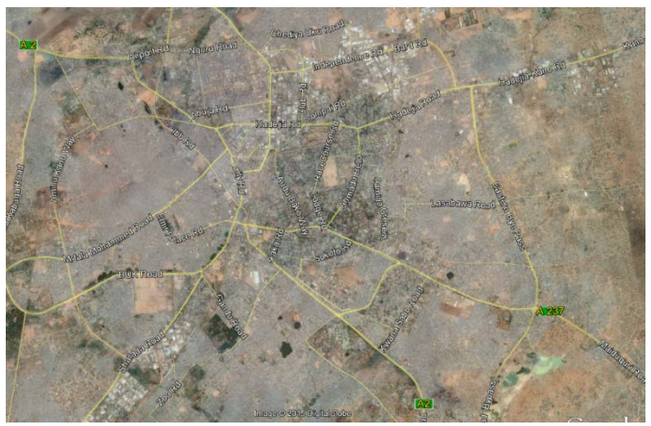
# Core Data Layers



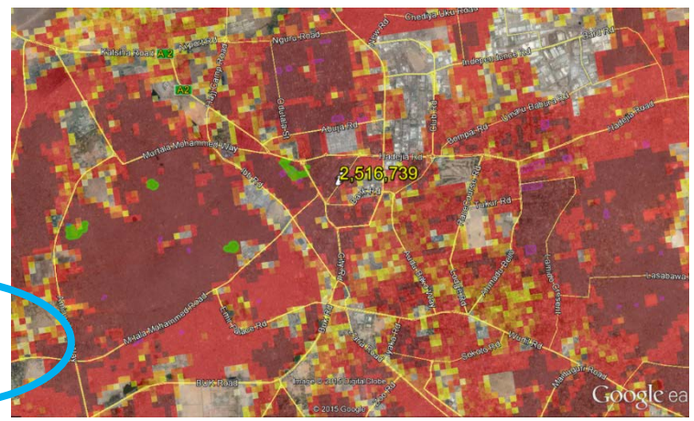

***Administrative Boundaries***




***Settlements and Points of Interest***



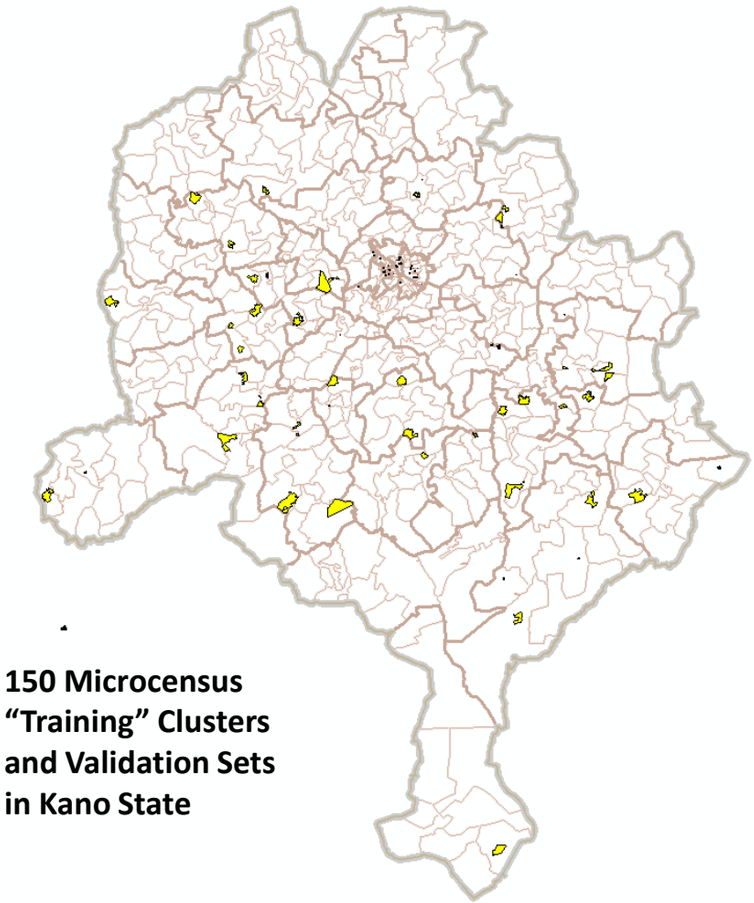
***Transportation Network***



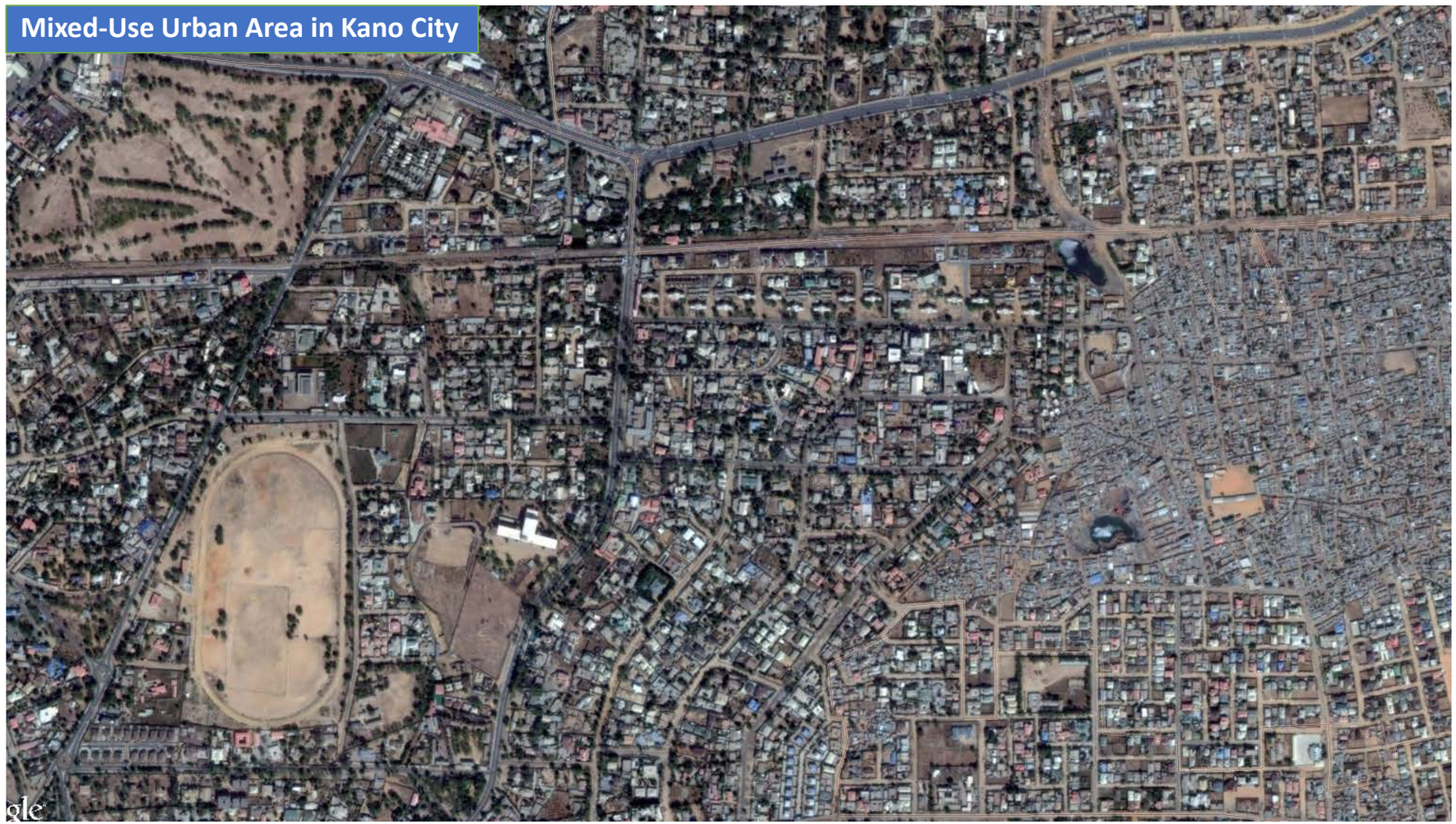

***Population / Demographics***

# Basis for Population Modeling with Satellite Imagery

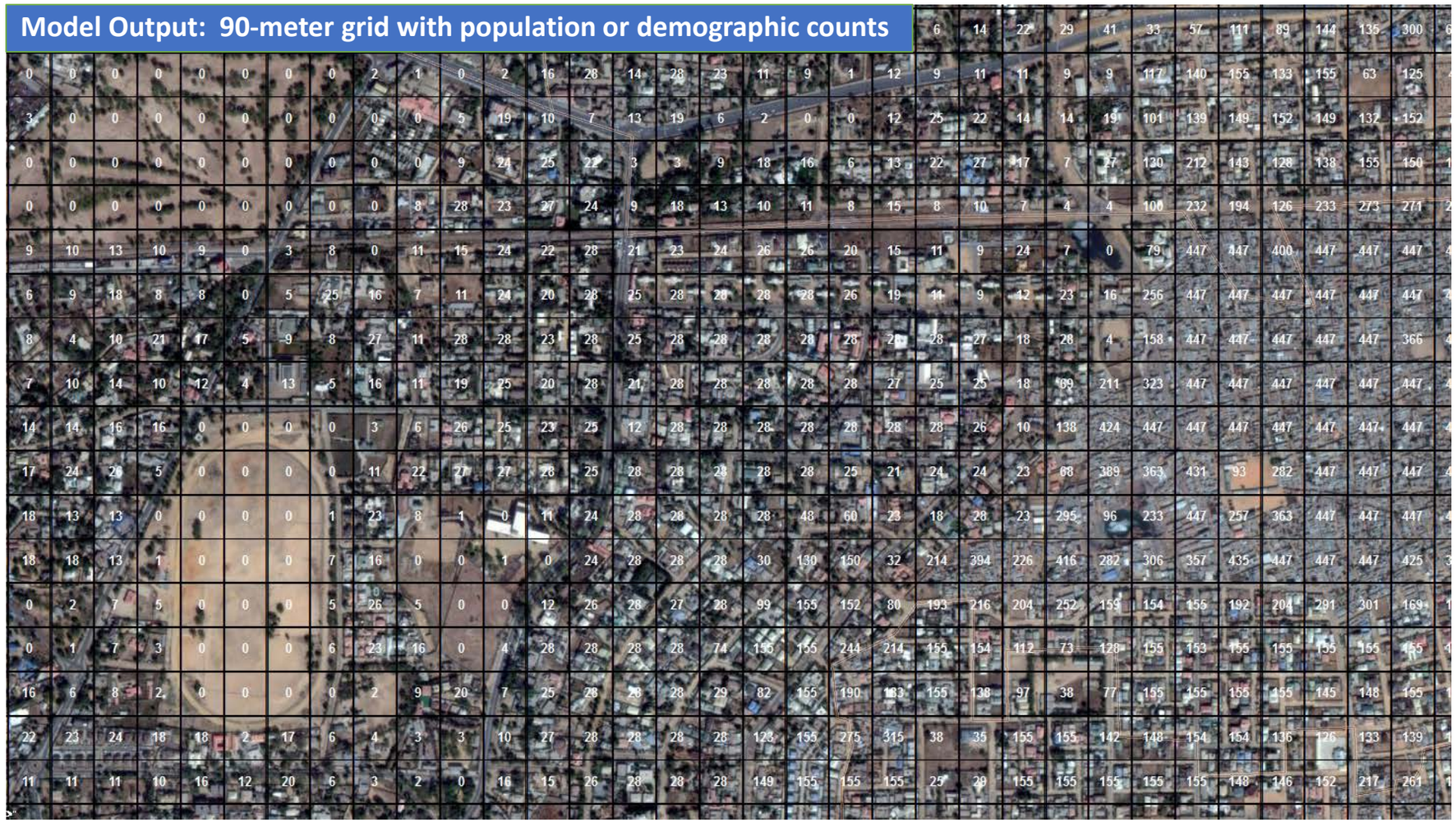
- **Obtain High-Resolution Satellite Imagery**
- **Extract Settlement & Building Features**
- **Identify Neighborhood categories, covariates**
- **Collect Microcensus/Validation Data**
- **Generate & Validate Initial Output**
- **If Needed, Collect & Validate Additional Microcensus Data.**
- **Repeat until Accuracy Requirements are met.**



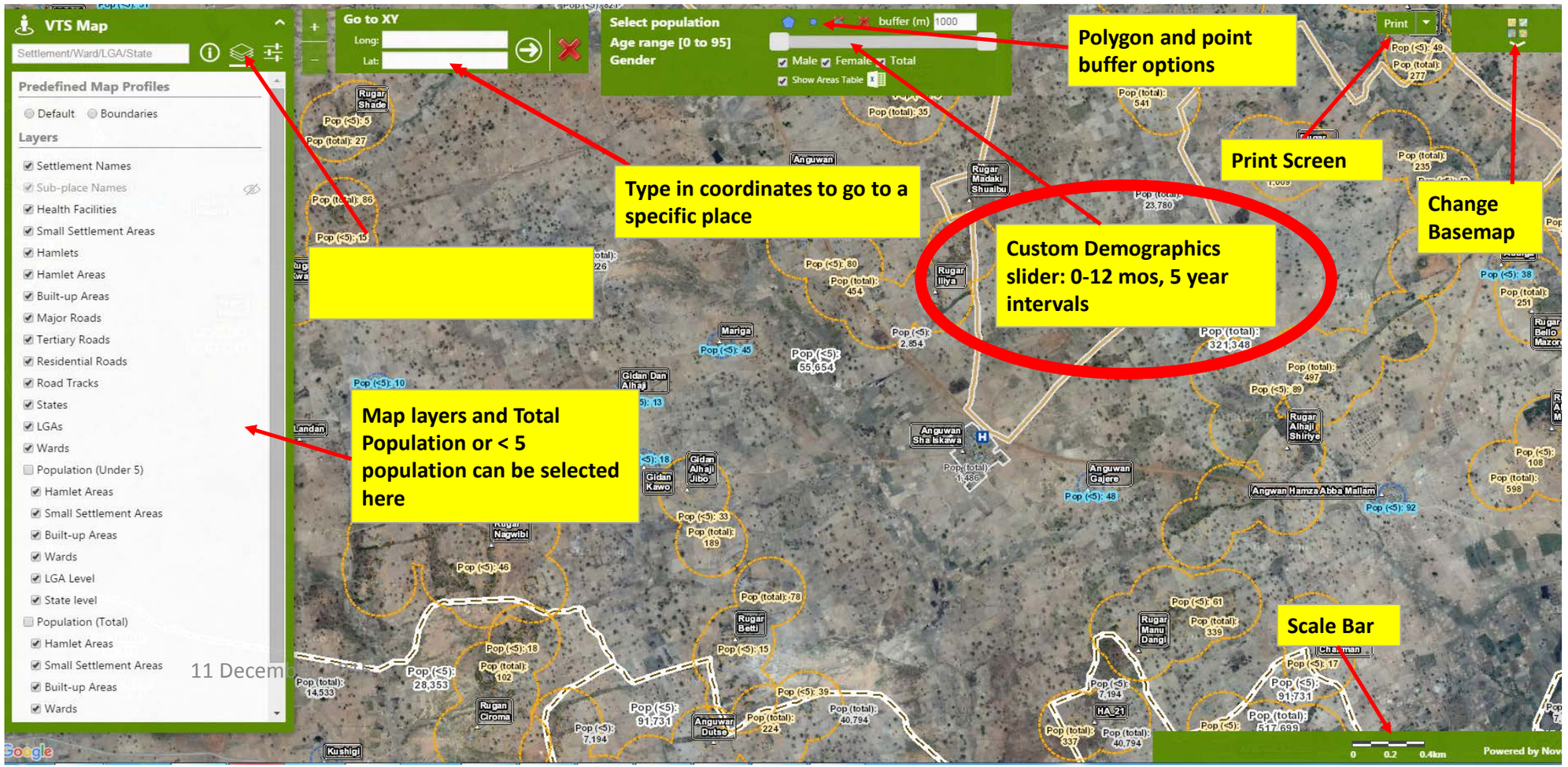
**150 Microcensus "Training" Clusters and Validation Sets in Kano State**


Mixed-Use Urban Area in Kano City

## Model Output: 90-meter grid with population or demographic counts

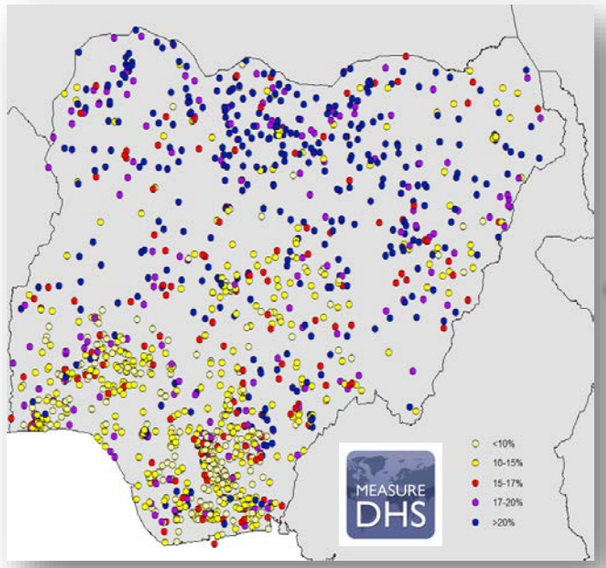


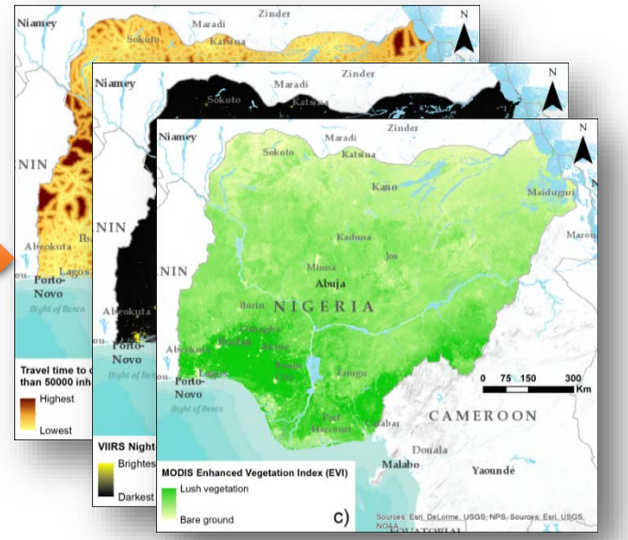
# POPULATION MODEL – USER INTERFACE OPTIONS

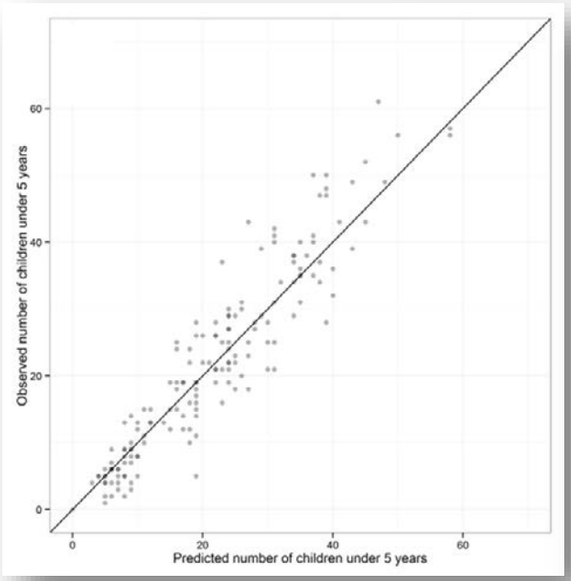


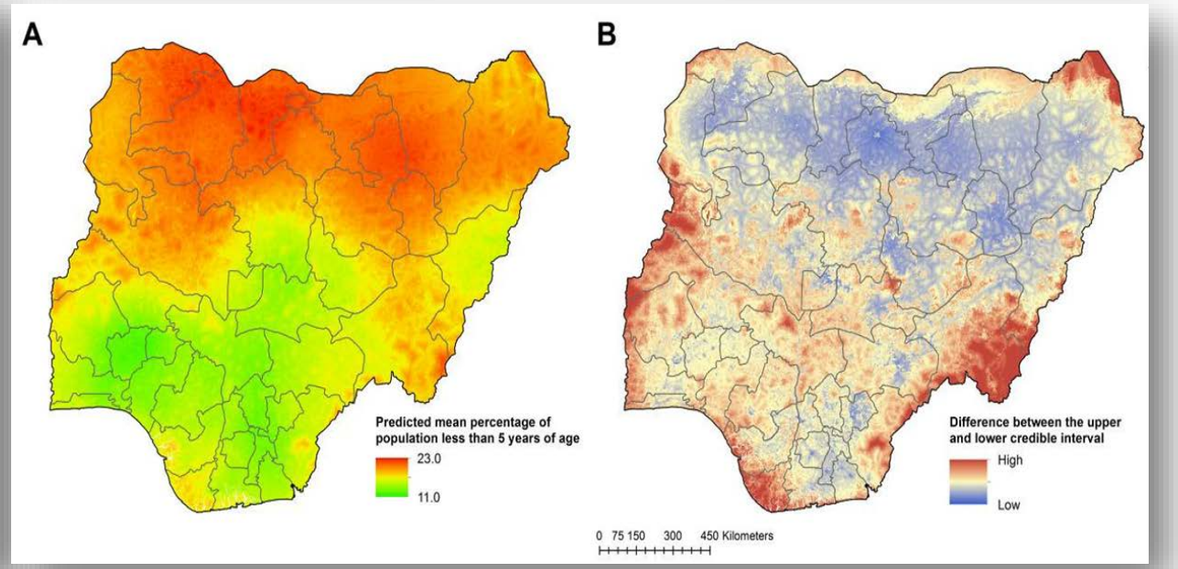

http://vts.eocng.org/

# Nigeria age structures: Bayesian model-based geostatistics

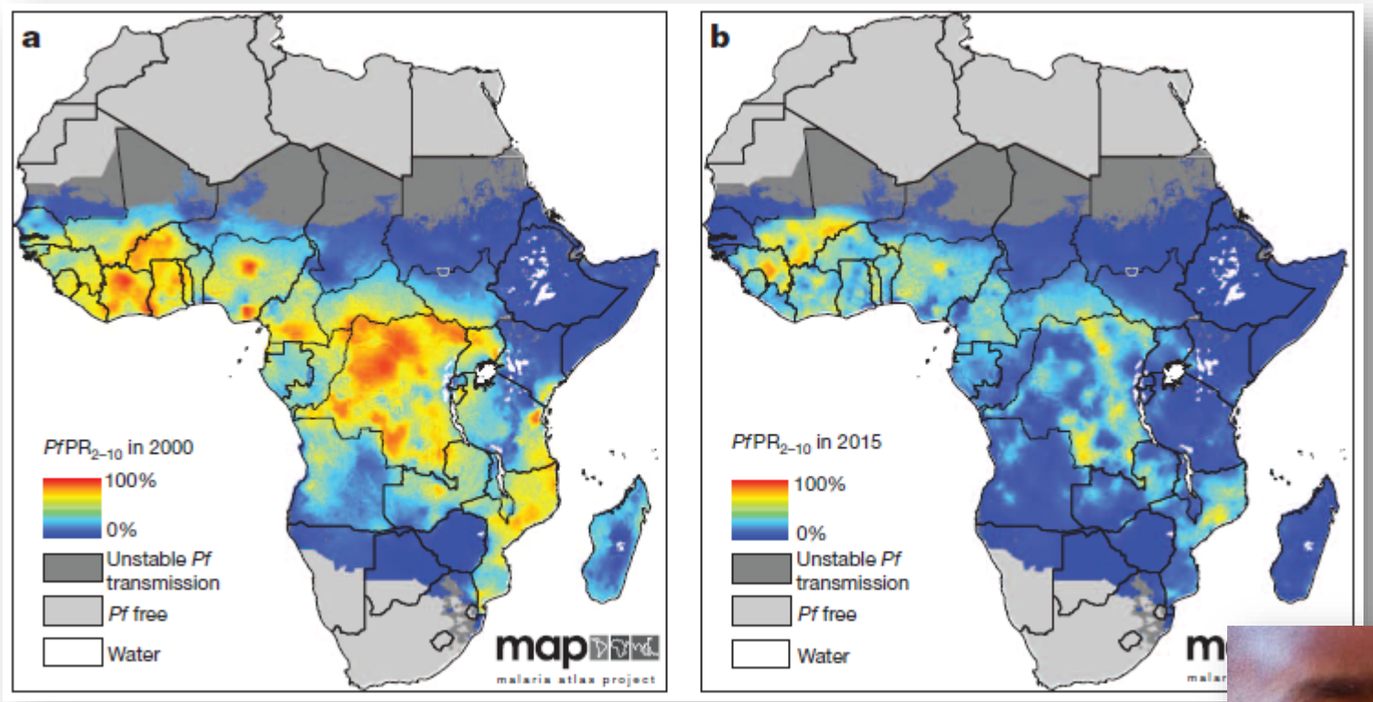


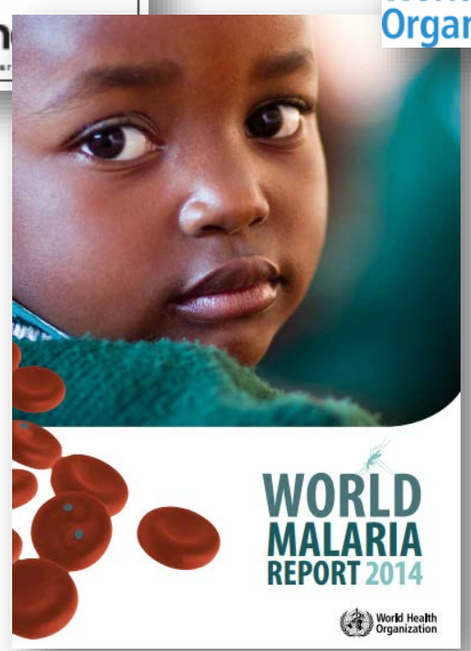

*Alegana et al (2015) Royal Society Interface*

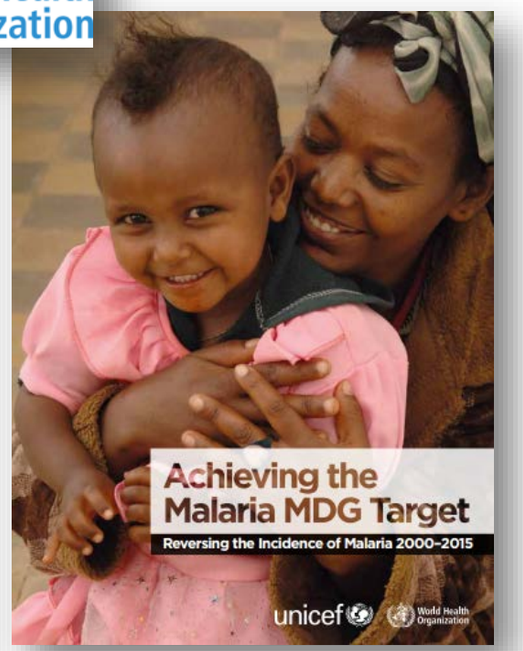



world pop

map

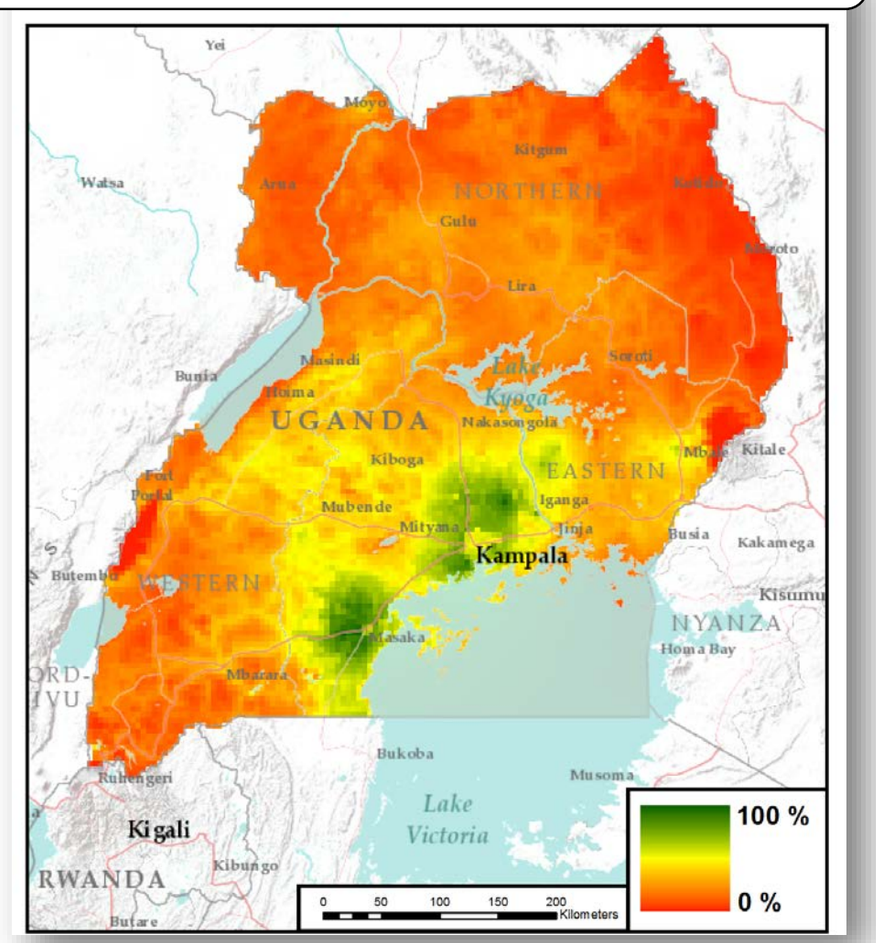
World Health Organization

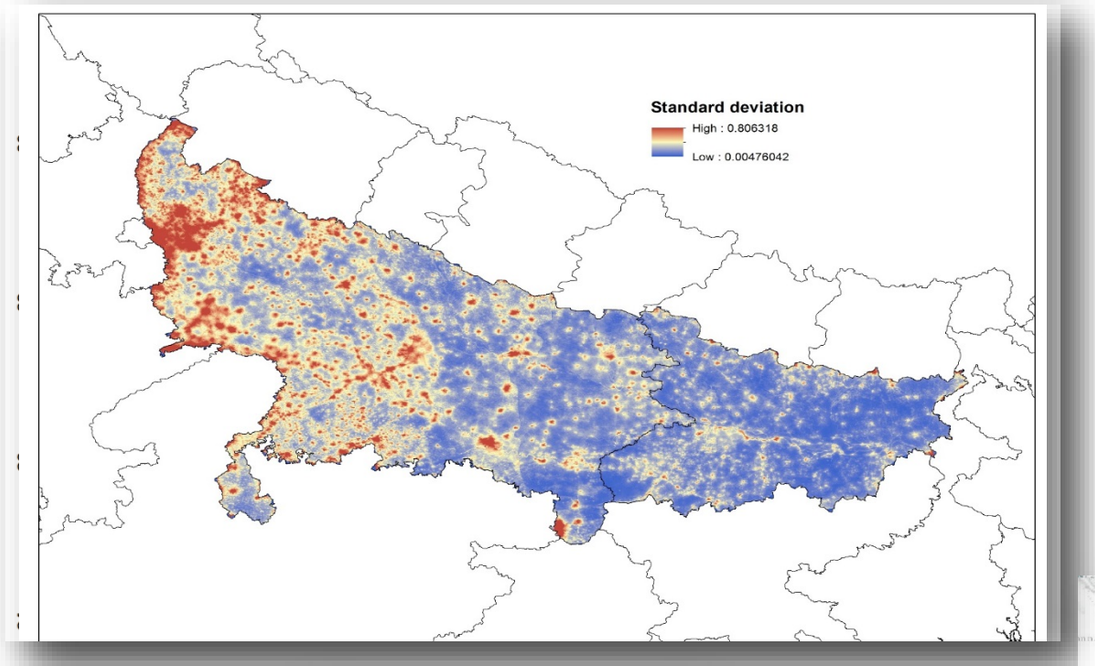


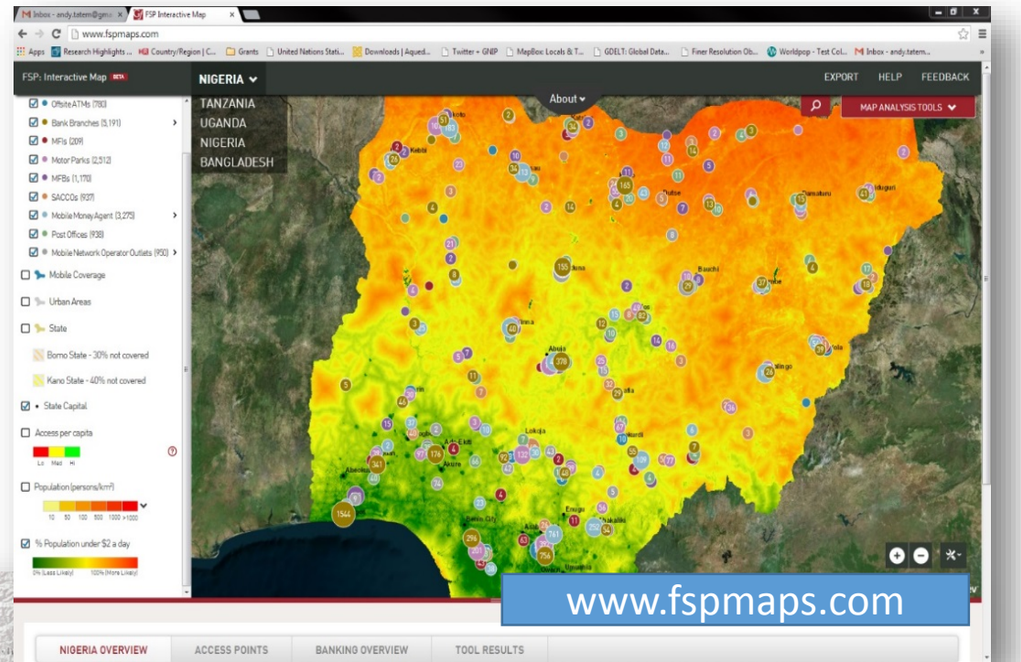



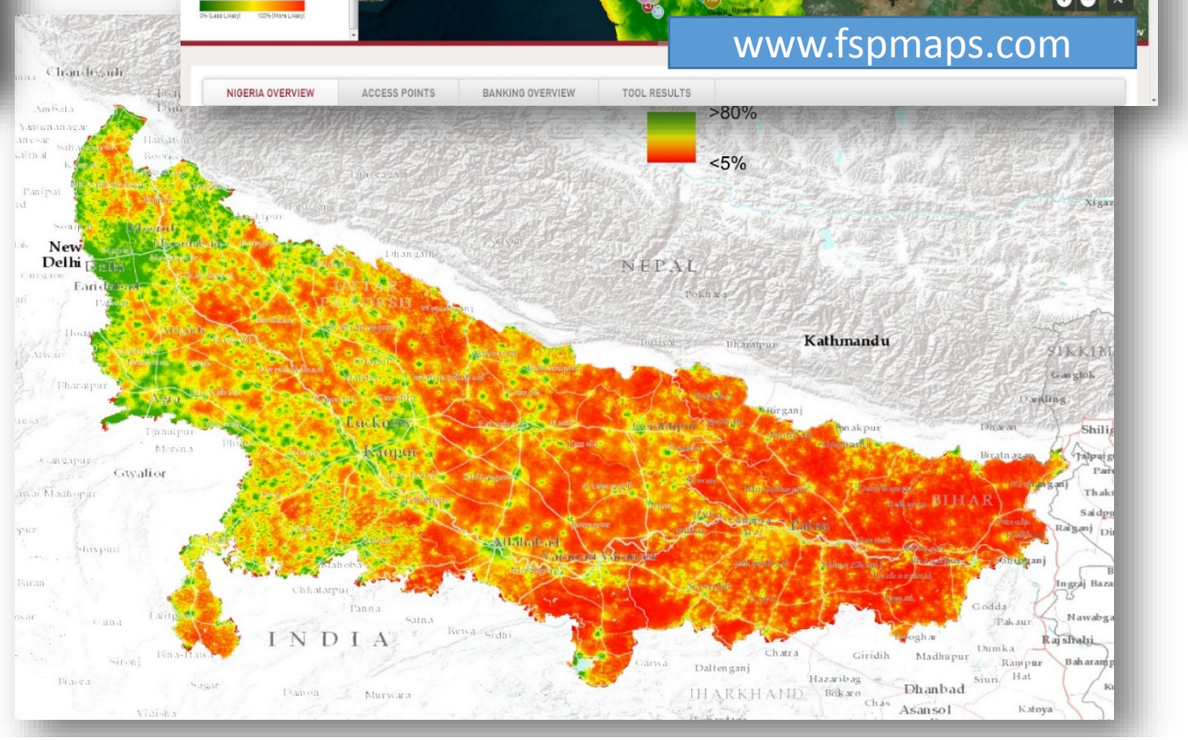

*Bhatt et al (2015) Nature*


Percentage of households with access to improved sanitation

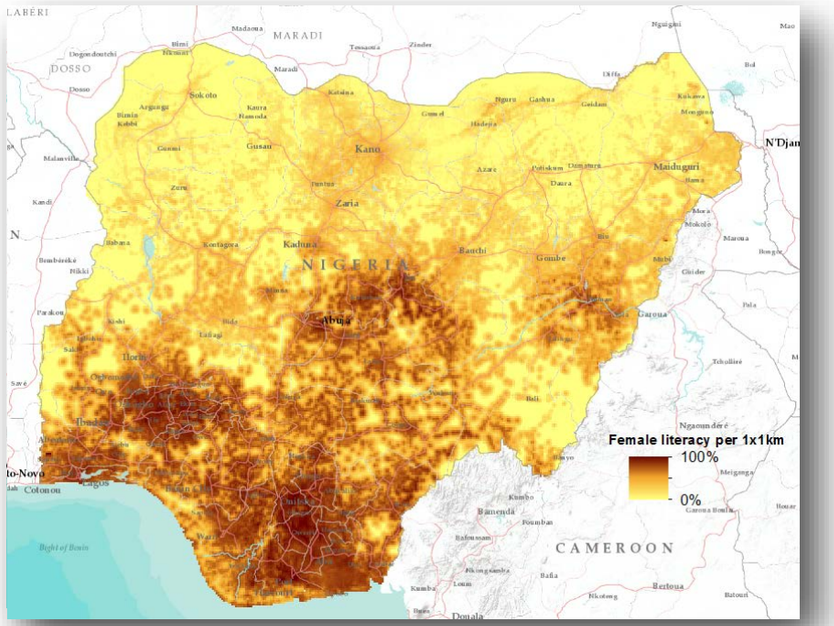


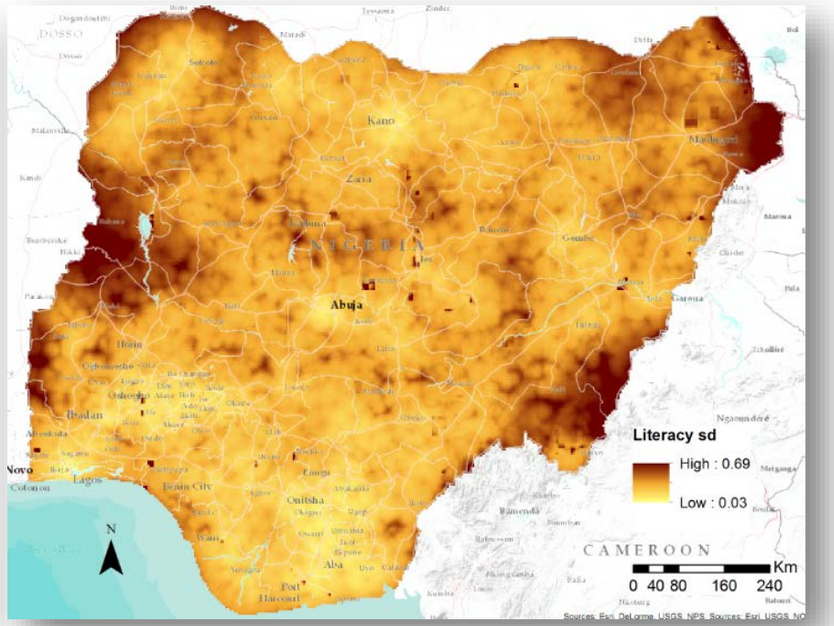


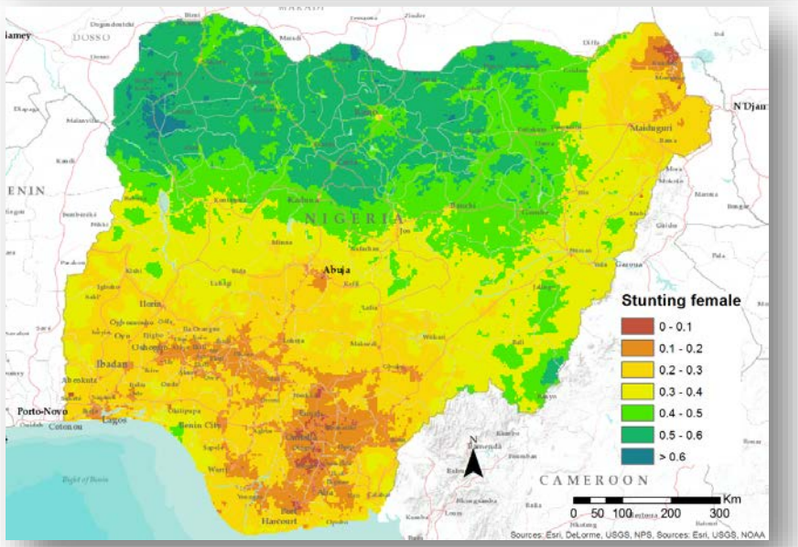



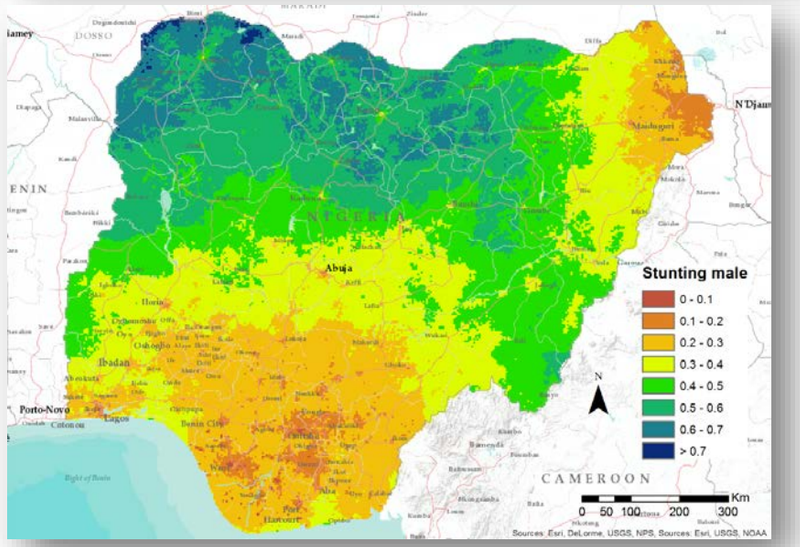




*Bird et al (2015) under review,*
*Tatem et al (2014) BMGF report*




data2x
partnering for a gender data revolution

UNITED NATIONS FOUNDATION

world pop

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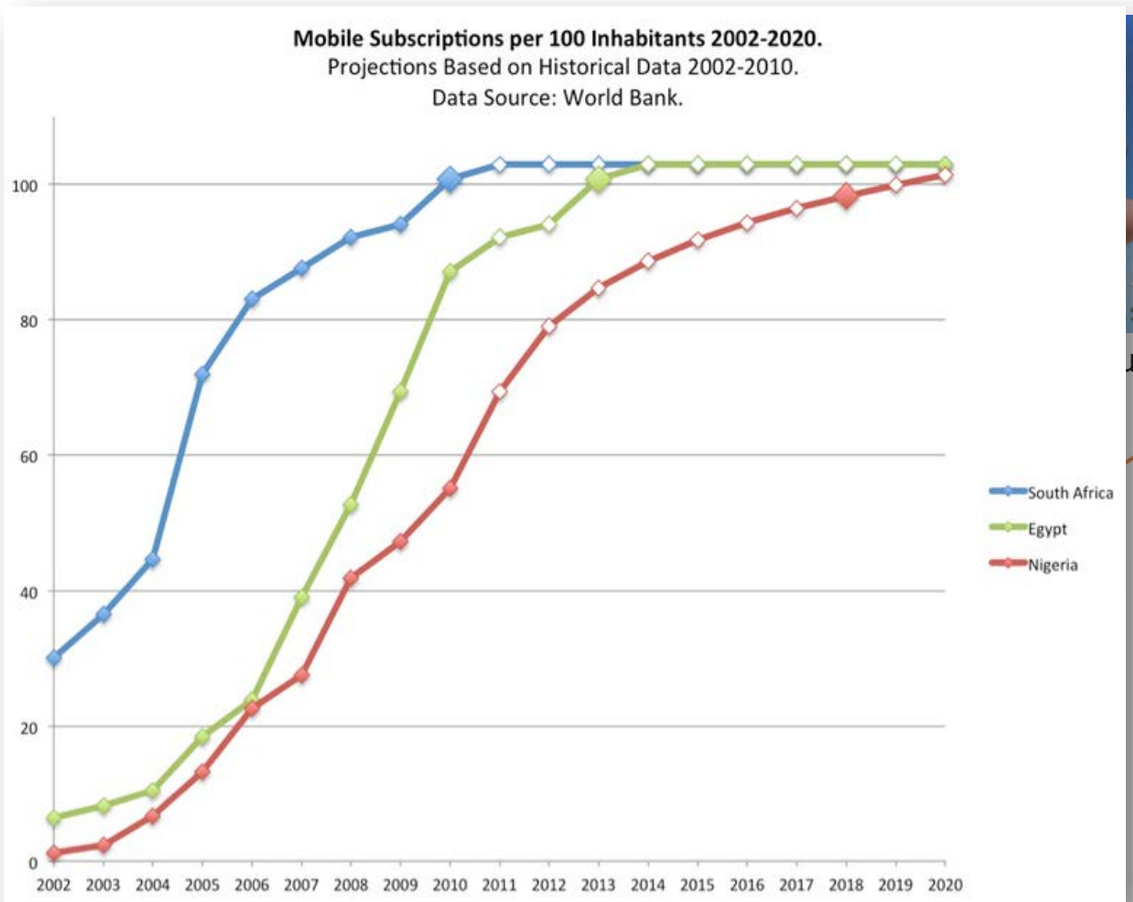
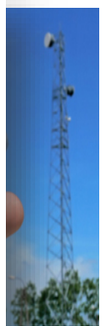
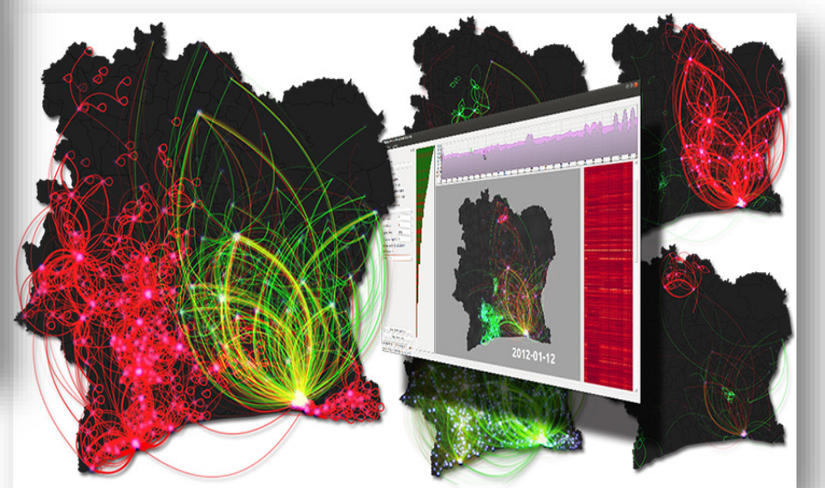
# Cellphone call data records (CDRs)



Network operator records time and tower of call for billing



## Cellphone demographics work

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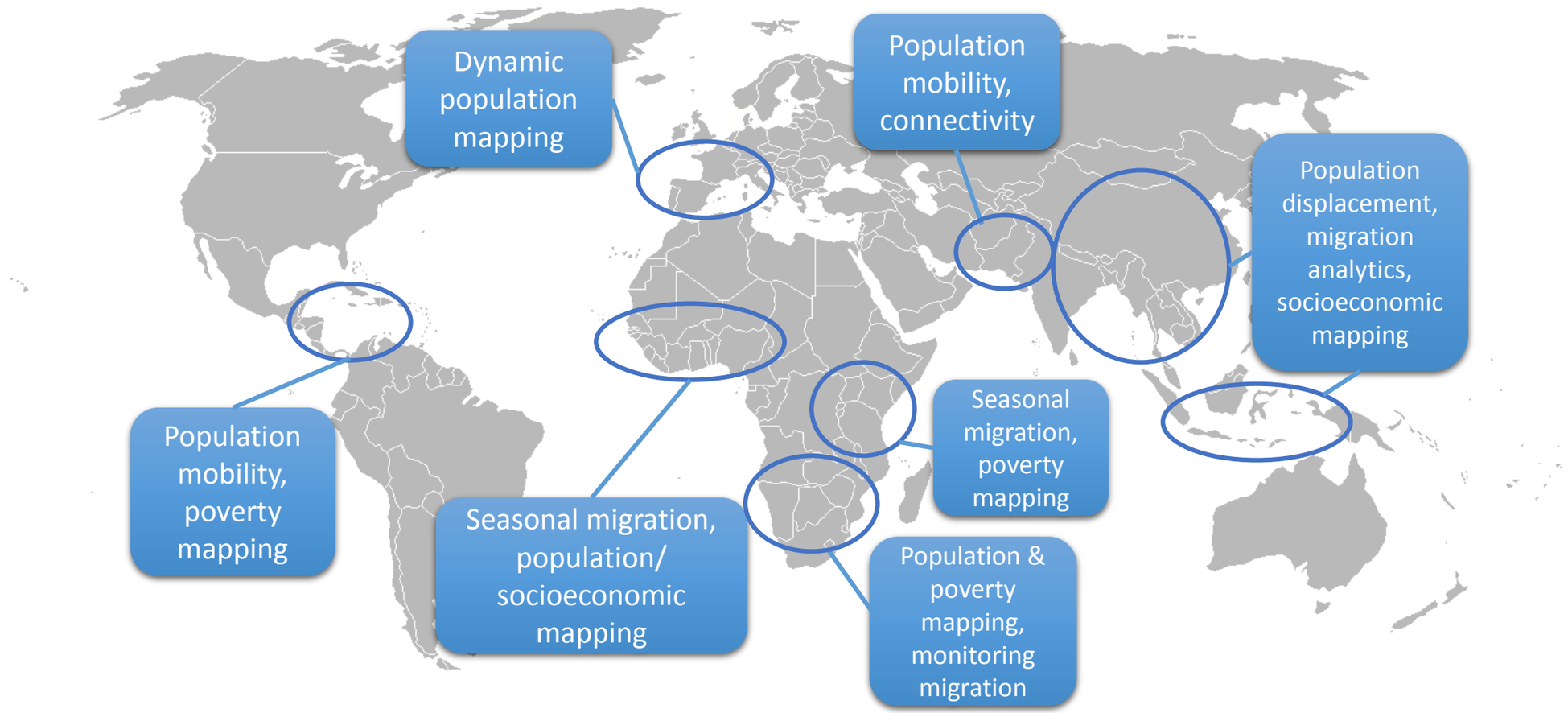
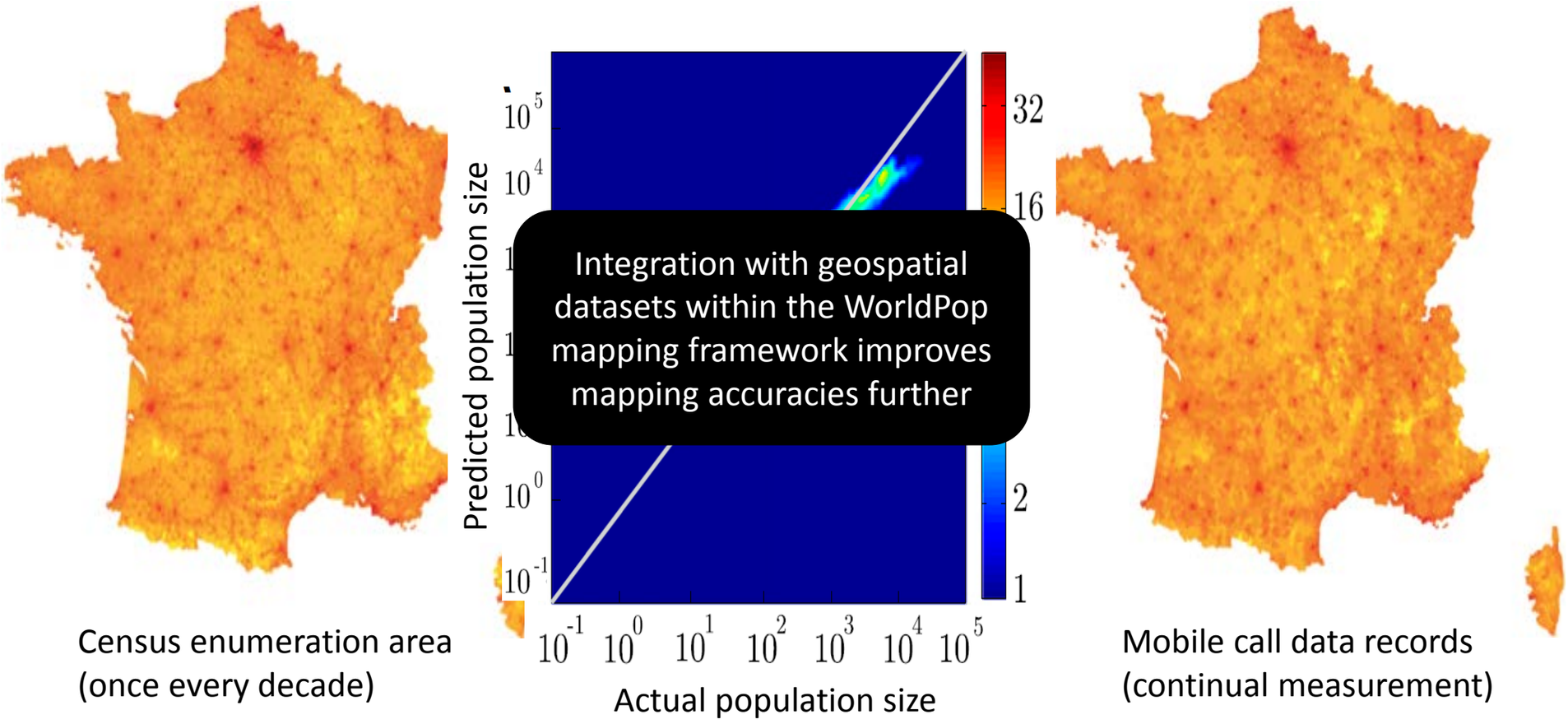
worldpop



# Dynamic population mapping

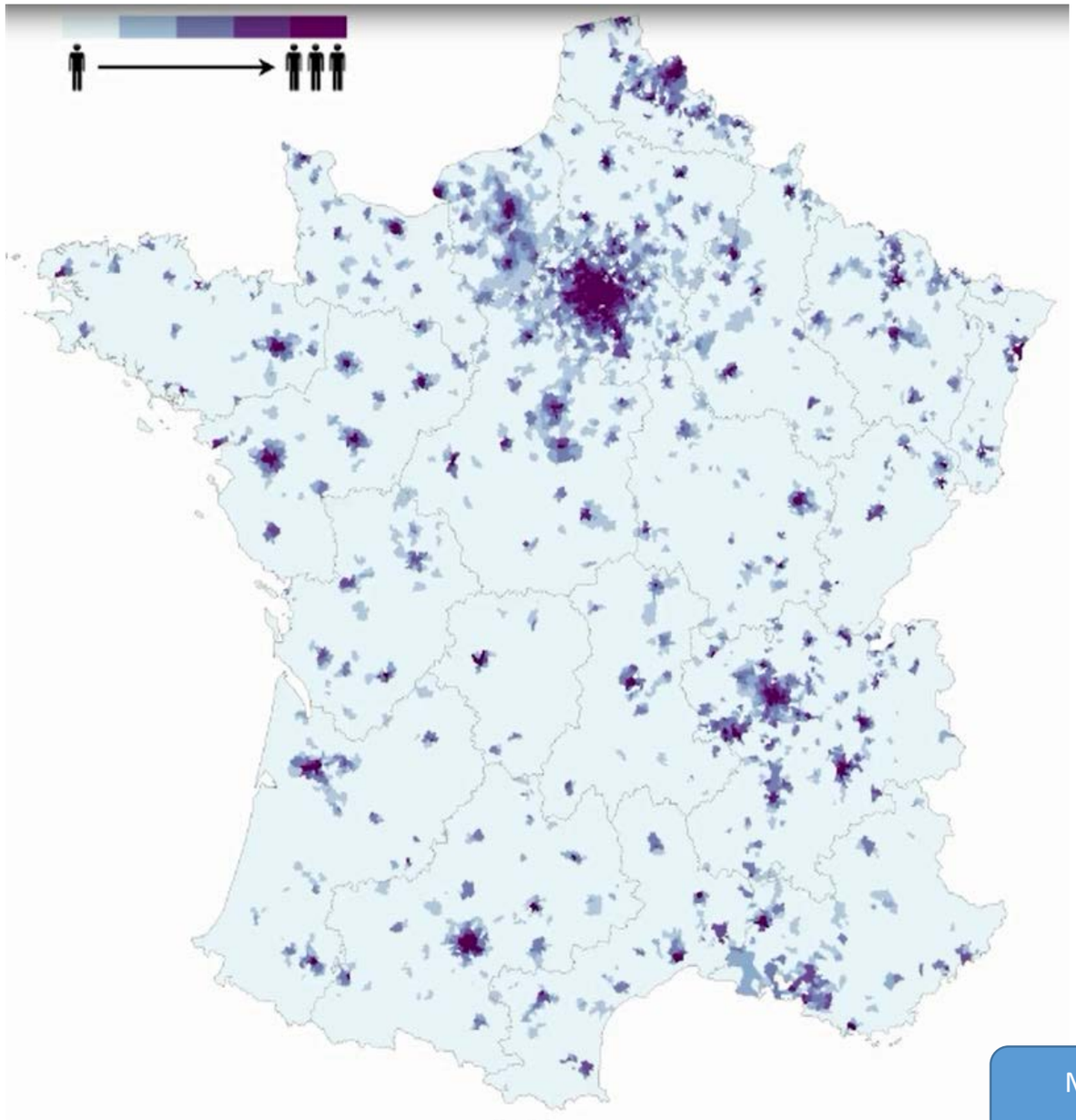



Census enumeration area (once every decade)

Mobile call data records (continual measurement)

*Deville et al (2014) PNAS*

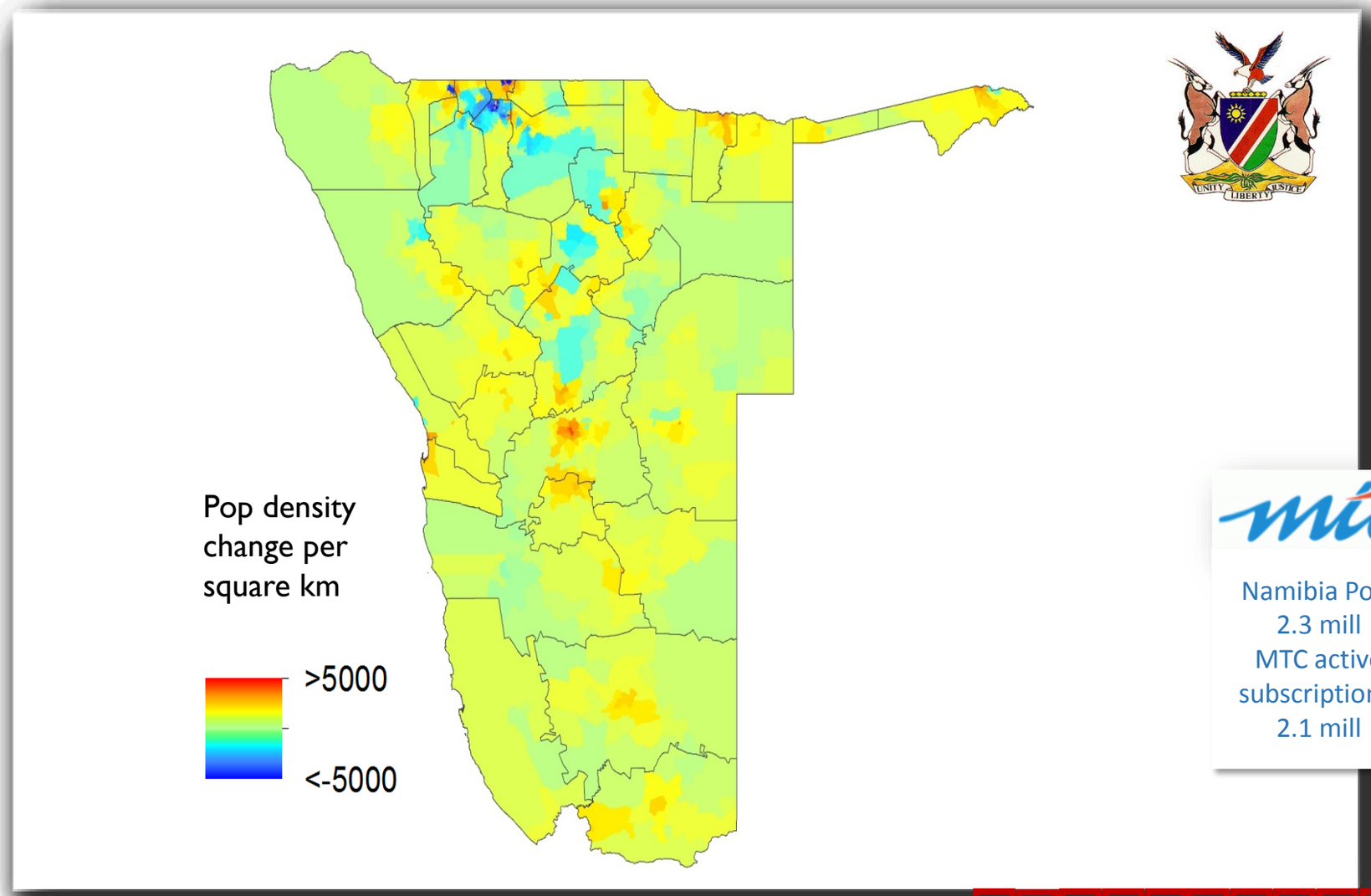
Wednesday
Thursday
Friday
Saturday
Sunday
Monday



*Deville et al (2014) PNAS*

Watch the video at:
http://youtu.be/qsUDH5dUnvY

Monthly data available:
www.worldpop.org


Pop density
change per
square km
>5000
<-5000
UNITY
LIBERTY
JUSTICE
mic
Namibia Pop:
2.3 mill
MTC active
subscriptions:
2.1 mill
NOV_12
DEC_12
JAN_13
FEB_13
MAR_13
APR_13
MAY_13
JUN_13
JUL_13
AUG_13
SEP_13
world pop
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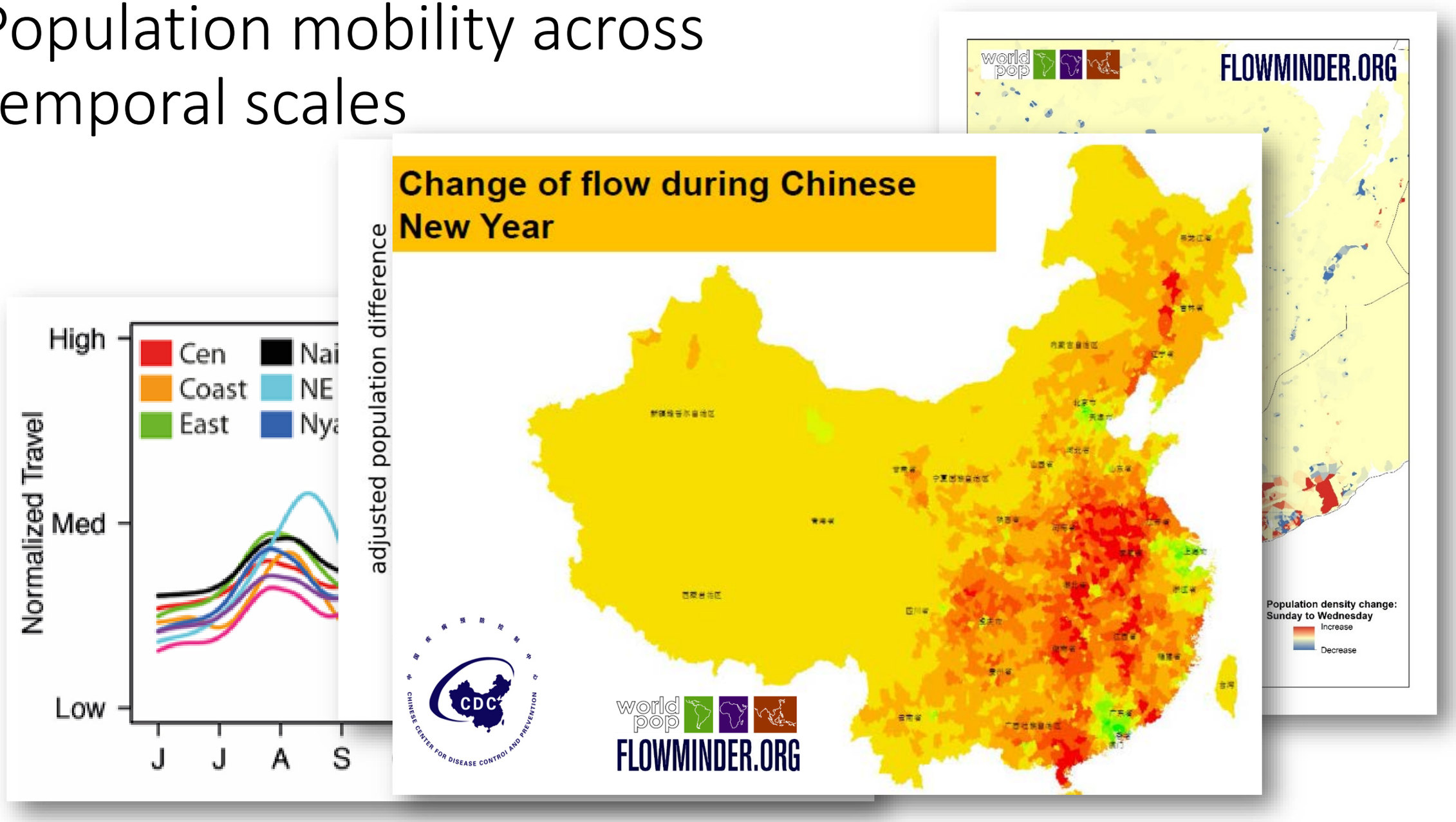
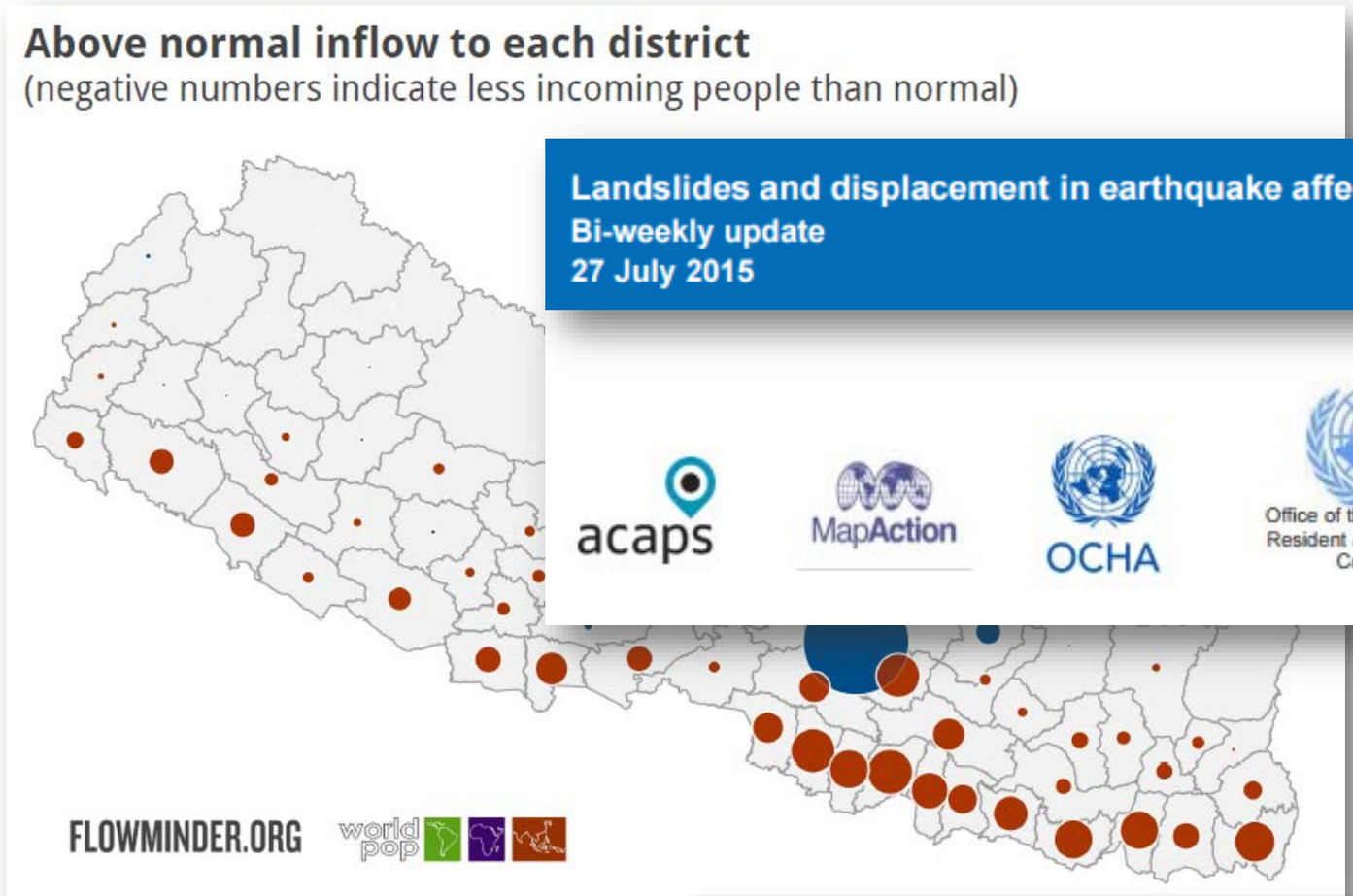
# Population mobility across temporal scales



# Population displacements




**Landslides and displacement in earthquake affected areas**
**Bi-weekly update**
**27 July 2015**

Nepal Earthquake Assessment Unit

acaps

MapAction

OCHA

Office of the United Nations Resident and Humanitarian Coordinator

UKaid

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world pop

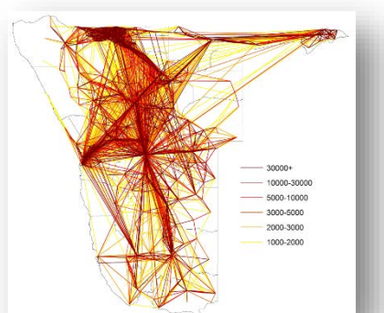
www.worldpop.org.uk/nepal

# Modelling connectivity for disease elimination


*Wesolowski et al (2014) PLoS Currents Outbreaks; Garcia et al (2014) Migration Studies; Sorichetta et al (2015) in review; Tatem et al (2009) Malaria Journal*

# Data integration: Targeting interventions

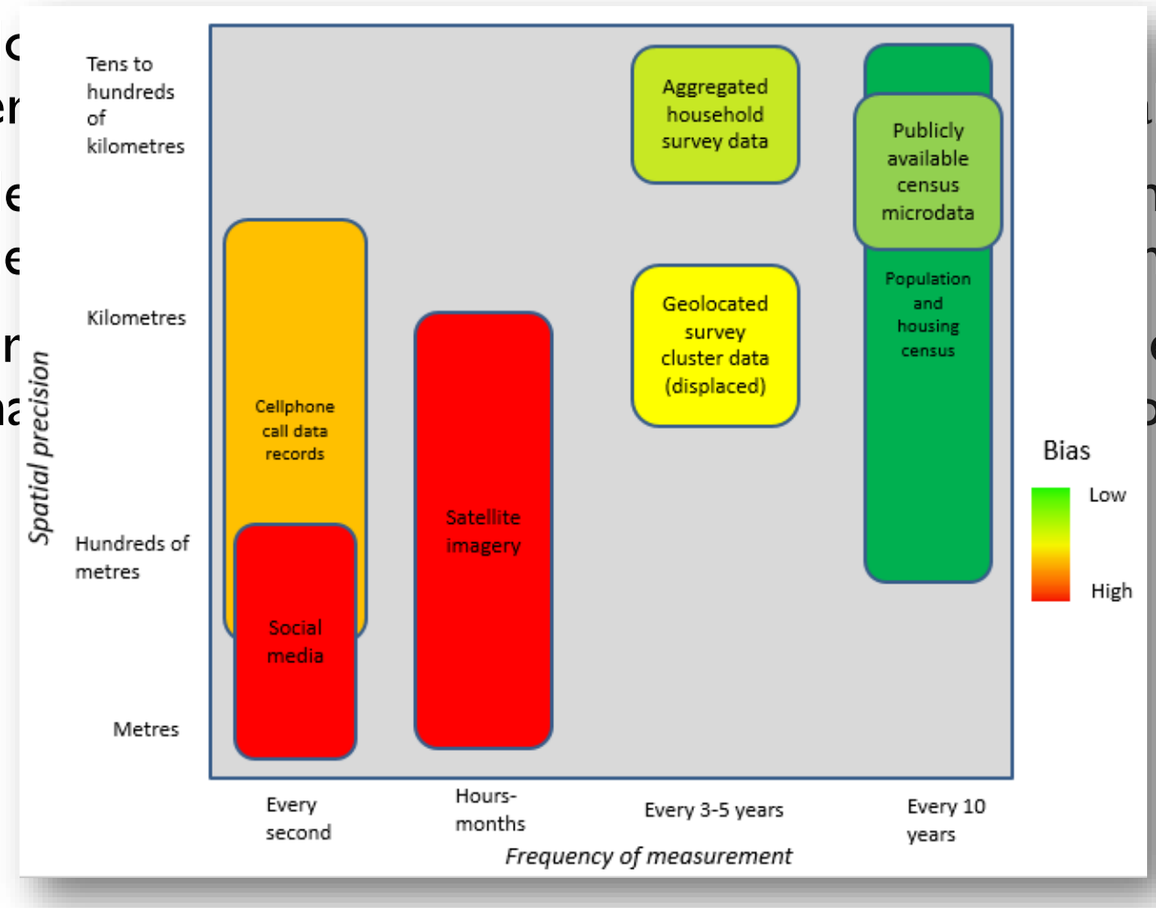
| Malaria risk zone | Zone map | Population residing in zone in 2011 |
|---|---|---|
| Pre-2013 intervention deployment |  | 1.29 million |




*Tatem et al (2014) Malaria Journal*

# Summary

- In producing estimates for different geographical scales and time periods, the integration of multiple types of data to compliment traditional sources is required
- Nc each has advantages over census data in ter l precision
- Me nties and providing clear me portant
- Gr es to build strong demographic databases tha proaches



# Acknowledgements

# Further information


www.worldpop.org

@WorldPopProject

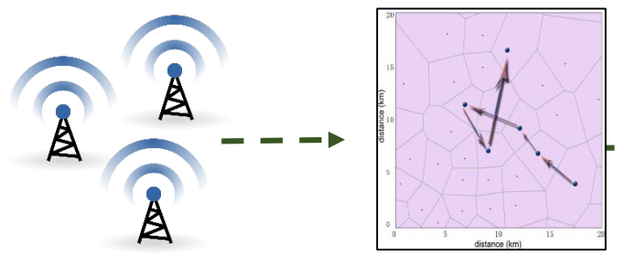
FLOWMINDER.ORG

www.flowminder.org

@Flowminder

# Extra slides

# Preserving confidentiality






Operators Call Detail Records' (CDRs) including low-resolution location data (nearest tower location) anonymized on separate server hosted by operator.

We conduct analyses under operator supervision, anonymous raw data always behind operator firewall

Mobile operator firewall

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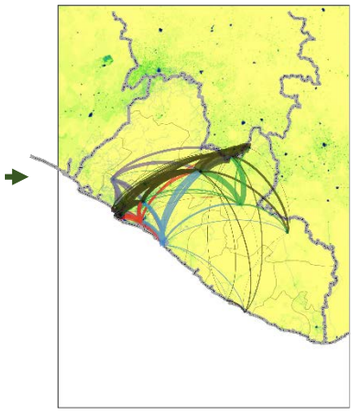


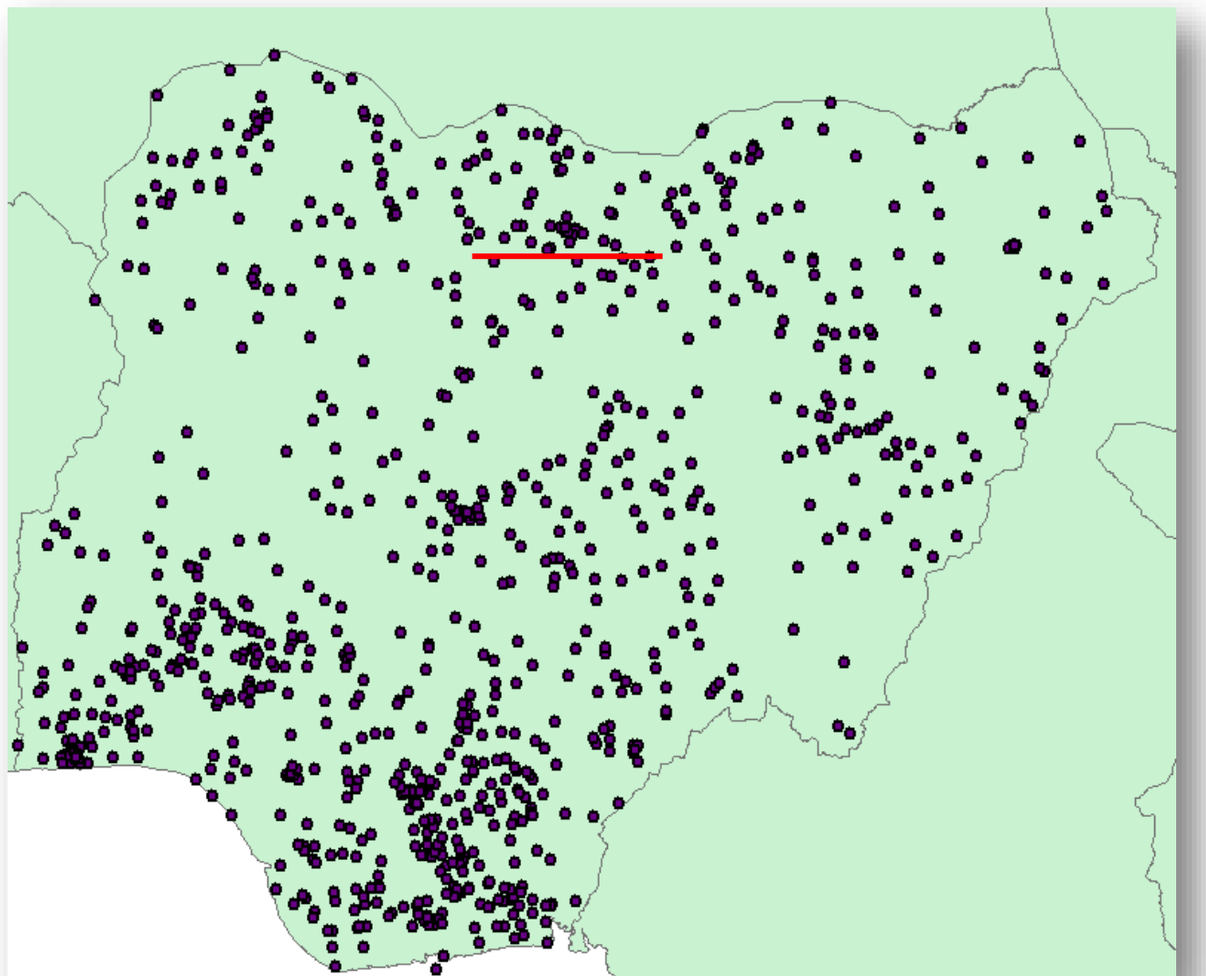
Aggregated mobility estimates are exported and made open access - can be used with other mobility estimates, epidemiological data

**<u>Compliance with GSMA data integrity guidelines</u>: Data never leaves mobile operator's system to avoid any privacy, commercial concerns.**

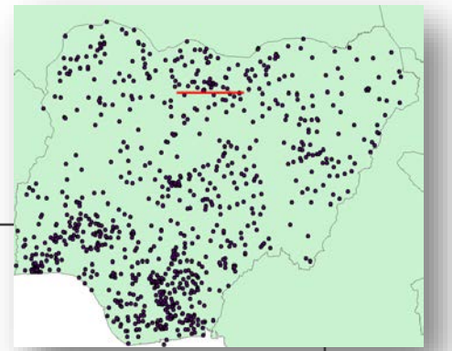
# Problem statement

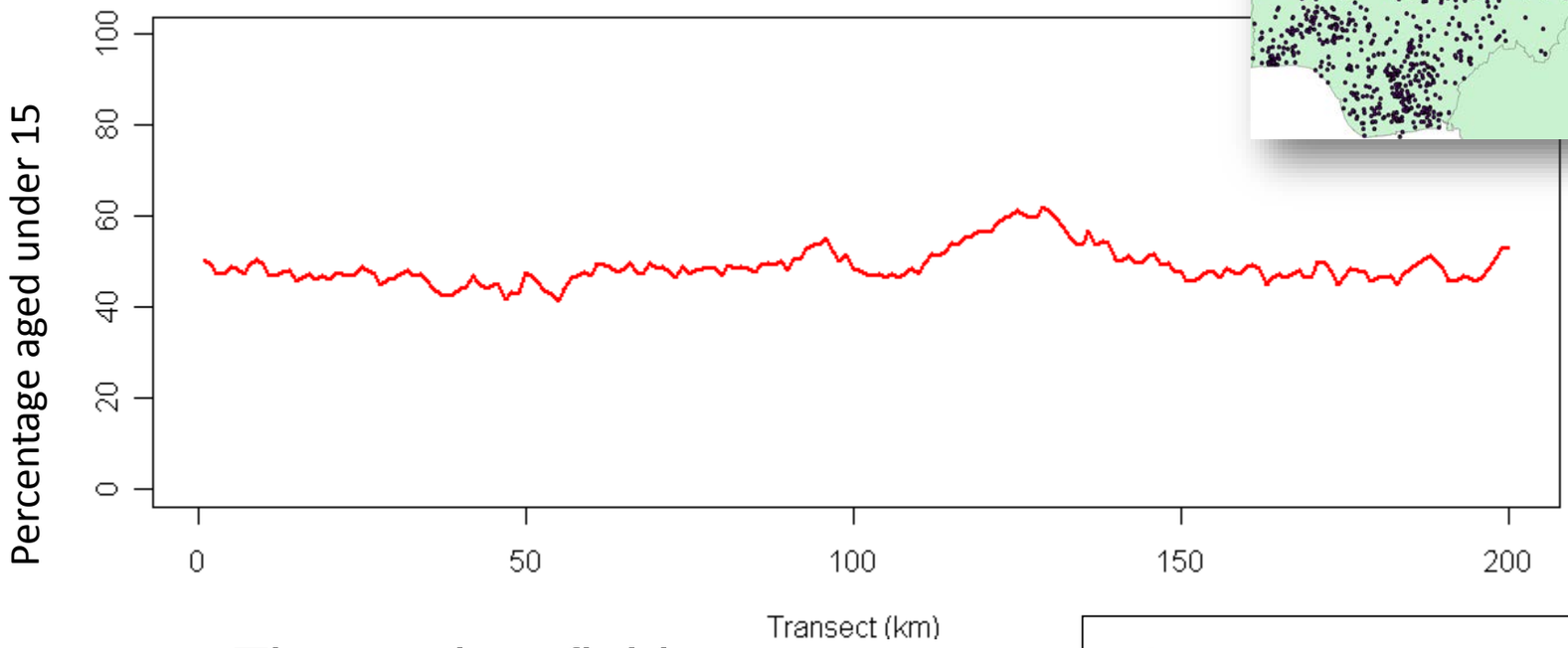
- We have
  - Hundreds of geolocated community surveys
  - Spread (unevenly) across areas of interest
  - Spread (unevenly) through time
- We want
  - Per-grid square estimates of age structure/household size etc
  - Must estimate these variables at locations with no data
  - Want to model uncertainty in our estimates
- Approach
  - Space-time model based geostatistics within a Bayesian framework

# Geostatistics: the random field



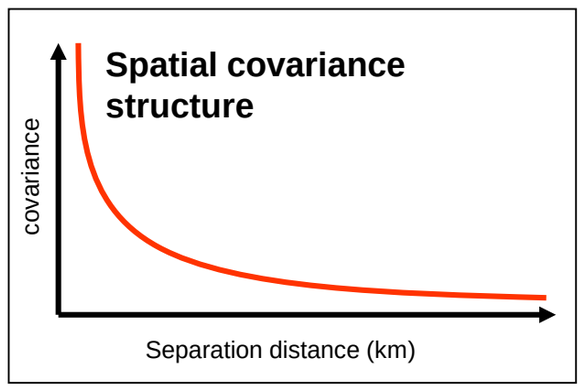
# Geostatistics: the random field



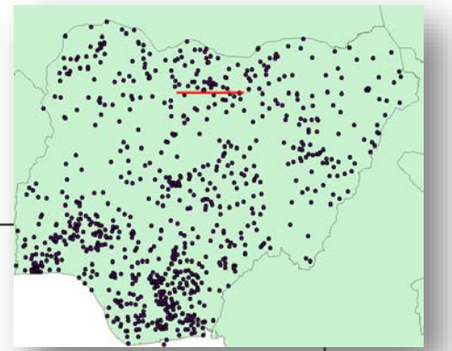


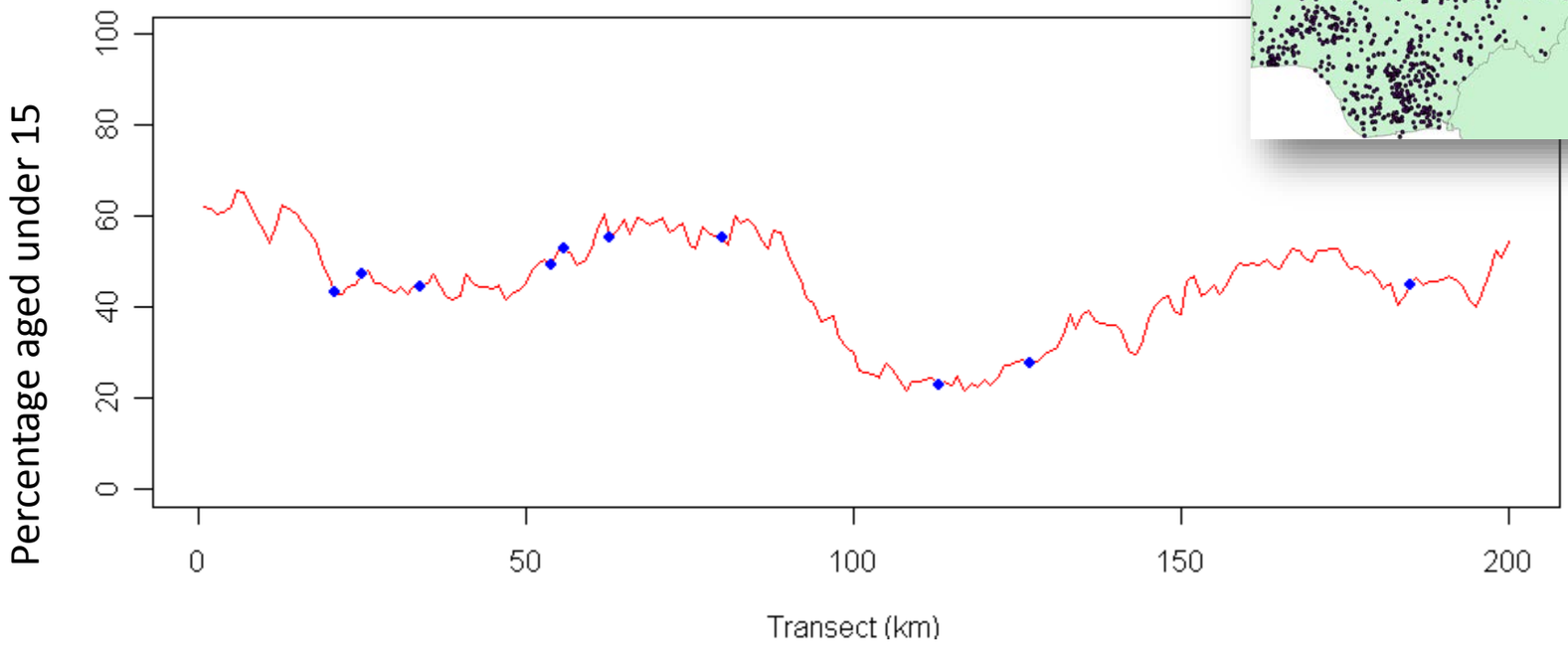

The random field:

- Mean
- Covariance structure
  1. Amplitude of variation
  2. Spatial range of correlation



# Geostatistics: the random field

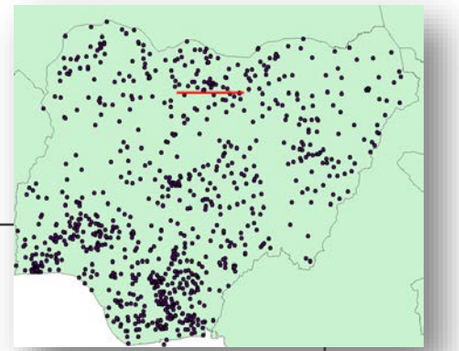


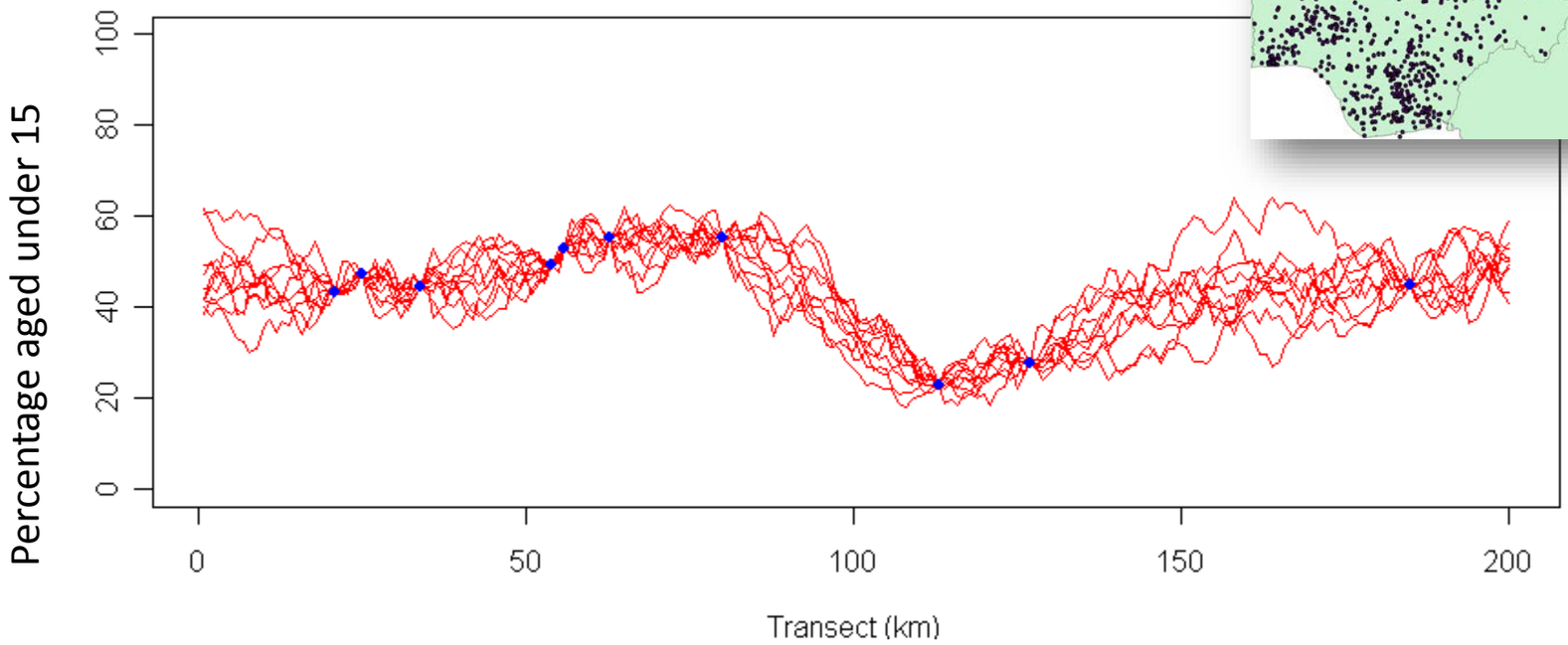



How do we use the data?

1. Parameterise mean and covariance function
2. ‘Condition’ on data values to predict everywhere

# Geostatistics: the random field

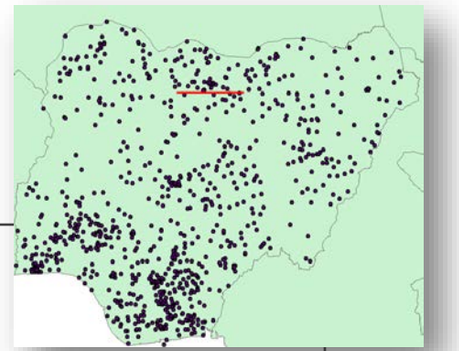


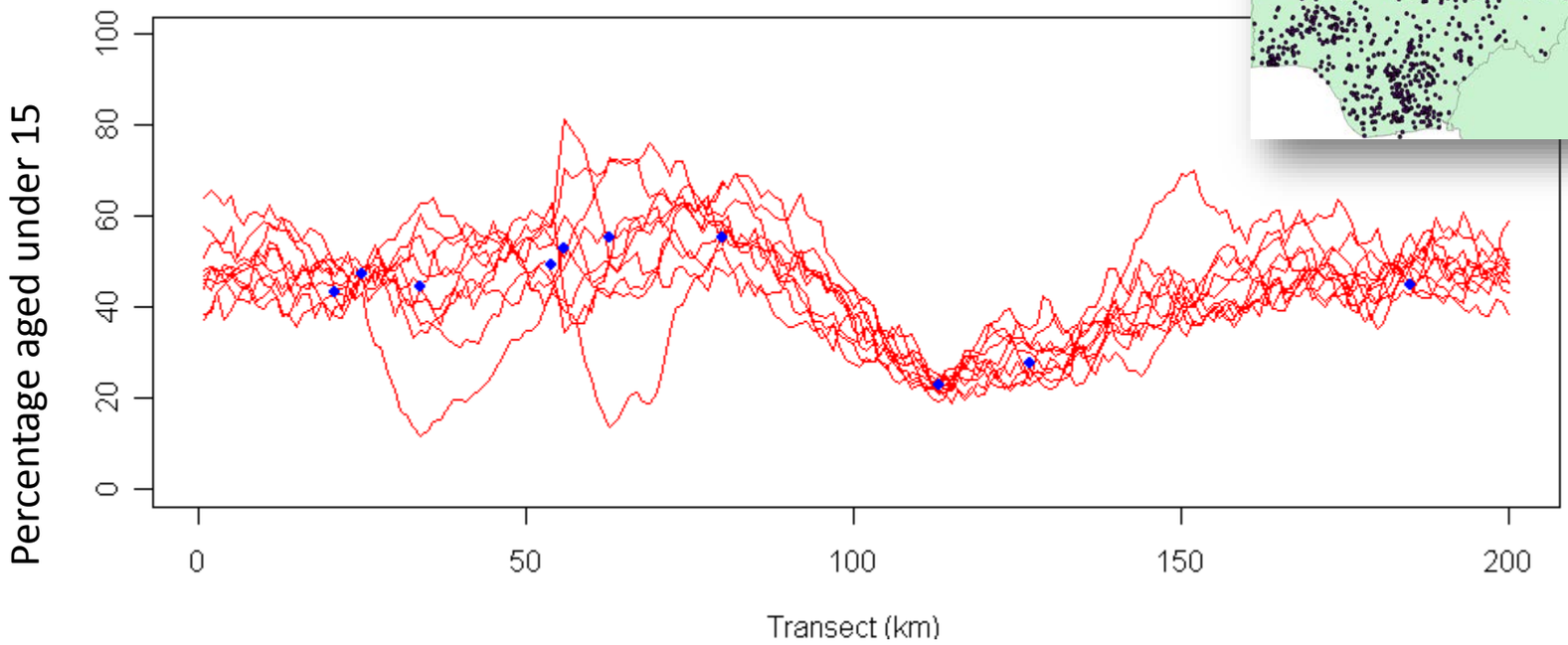



## Incorporating prediction uncertainty

- Represent using multiple realisations
- Uncertainty increases away from data
- Determined by amplitude / range

# Geostatistics: the random field



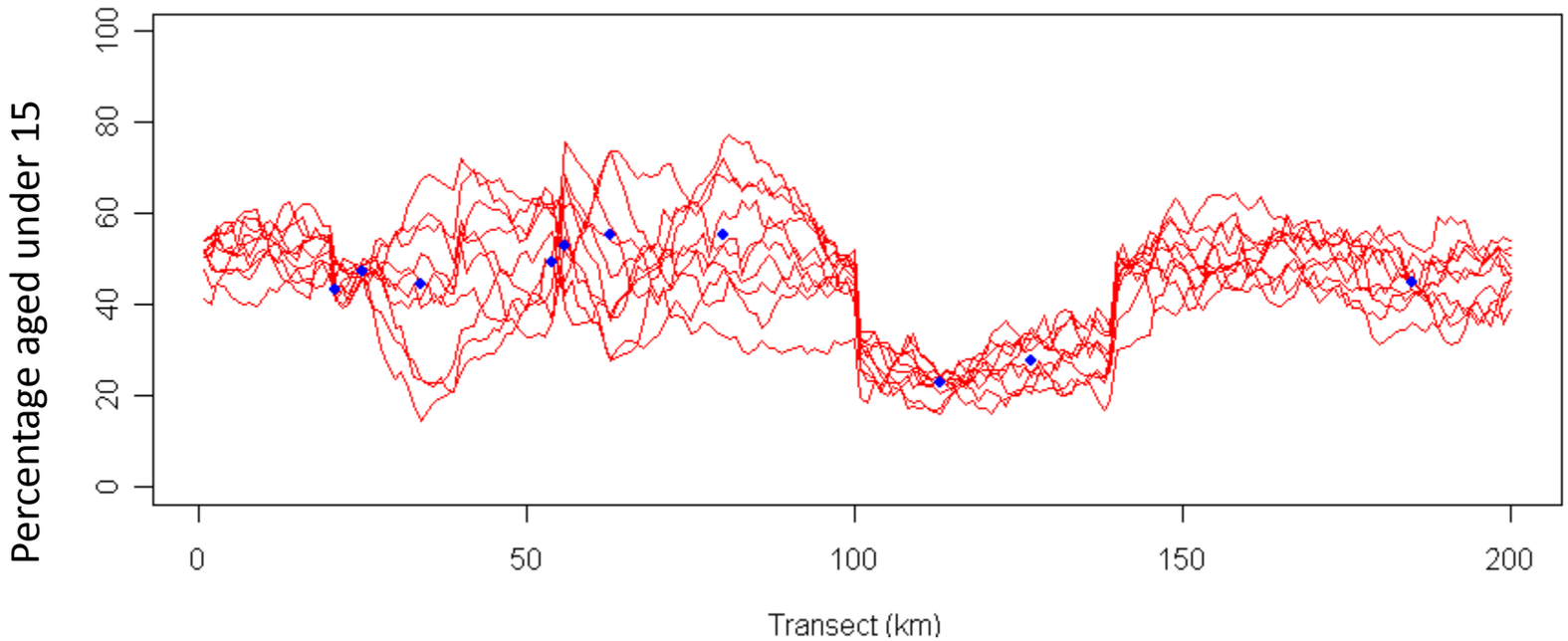



## Incorporating sampling variation

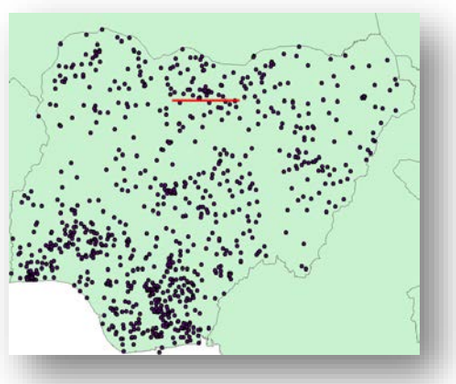
- Data are sampled with error (e.g. function of sample size)
- Adopt sampling model (e.g. binomial)
- Field is better defined where data are more certain

# Elaborations for demographic mapping

2. Incorporating environmental/infrastructure/socioeconomic covariates

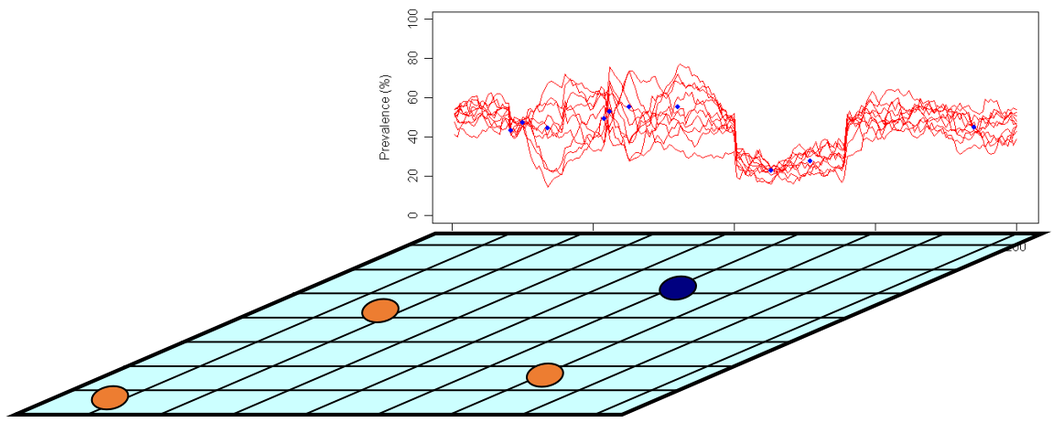


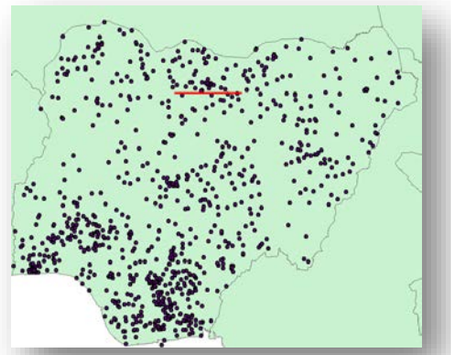

- E.g. Effect of urban vs rural areas
- R/U/Other status of data and predictions assigned from satellite data analyses
- Allowed underlying mean to vary between classes
- Multiple covariates selected in multivariate model



# Elaborations for demographic mapping

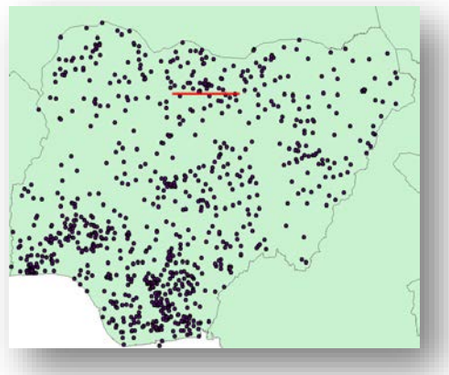
3. Incorporating spatial anisotropy

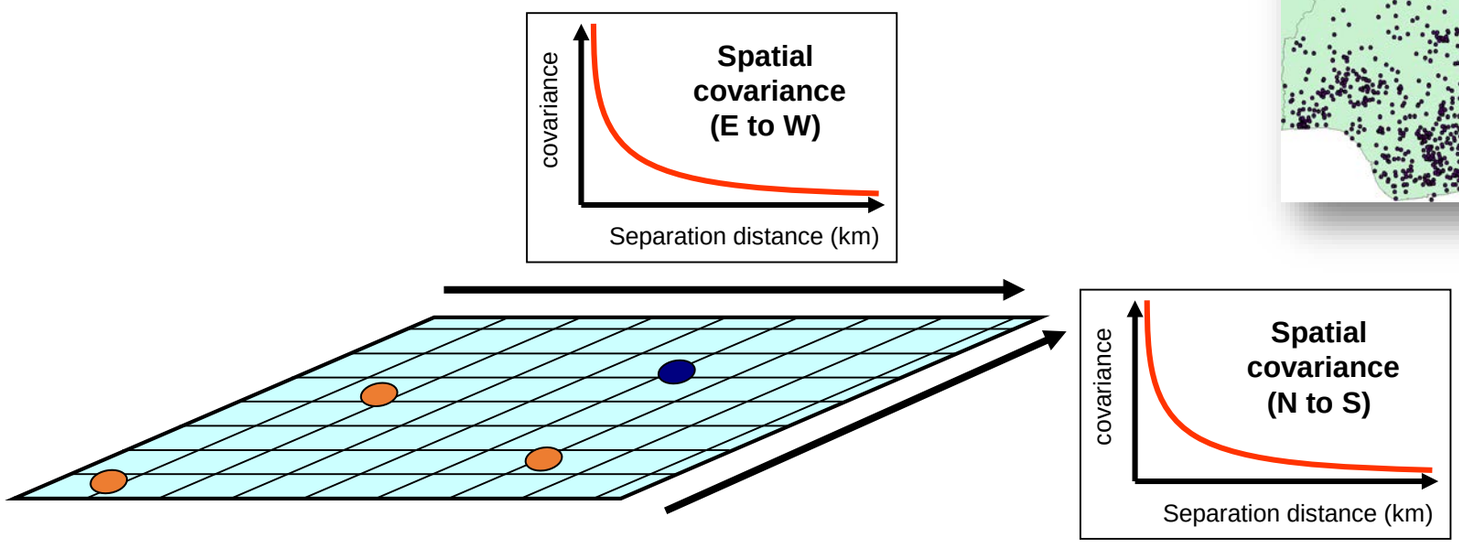


# Elaborations for demographic mapping

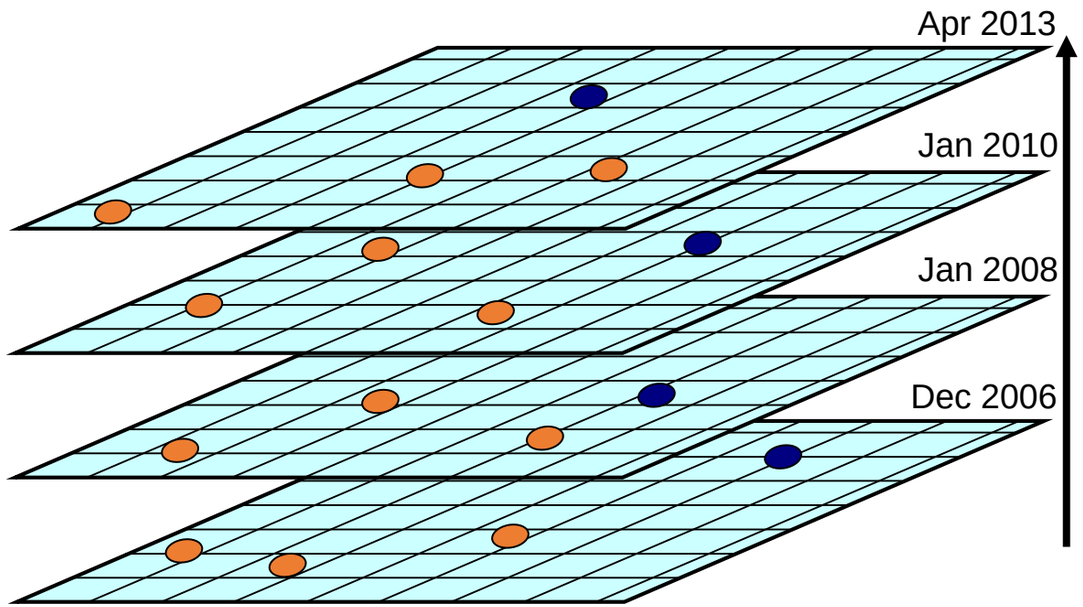
3. Incorporating spatial anisotropy

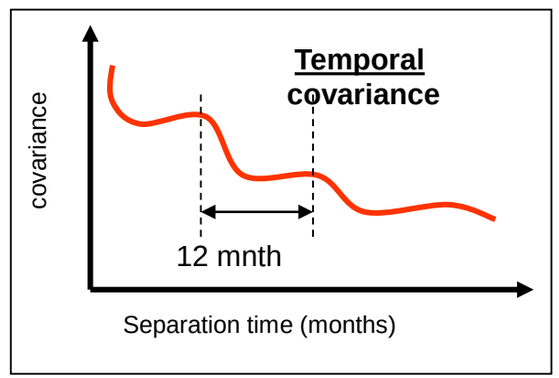




# Elaborations for demographic mapping

4. Full space-time dimensionality

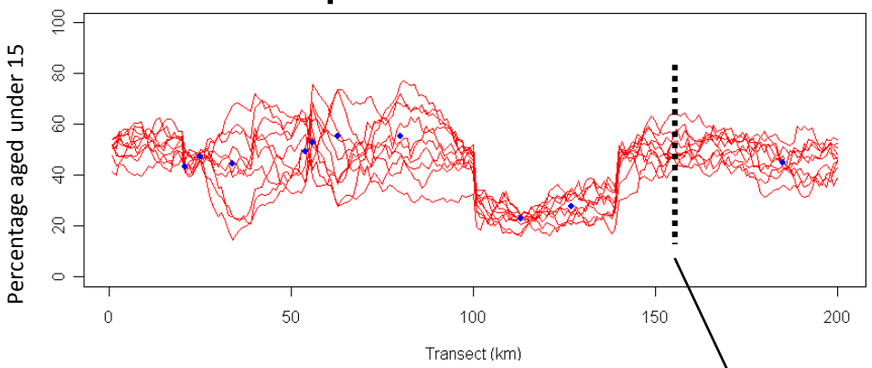


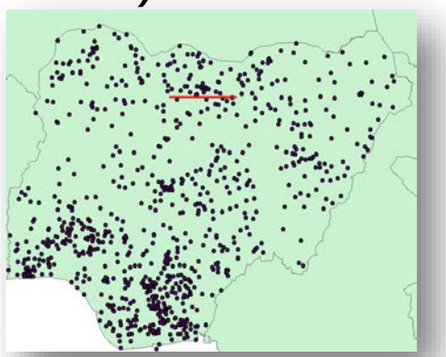




- 2d spatiotemporal covariance function: temporal axis
- Sinusoidal seasonal component…? (see mobility mapping later)

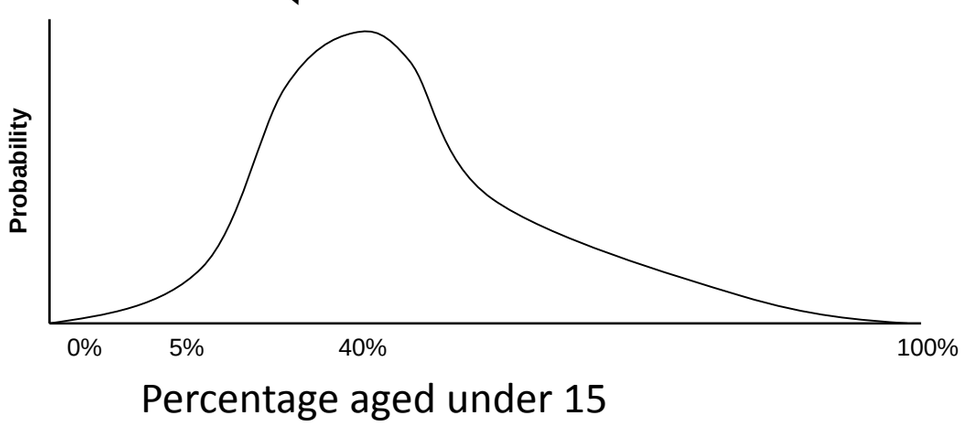
# Geostatistics: making maps

- Model output is set of realisations (e.g. $n$ = 10000)



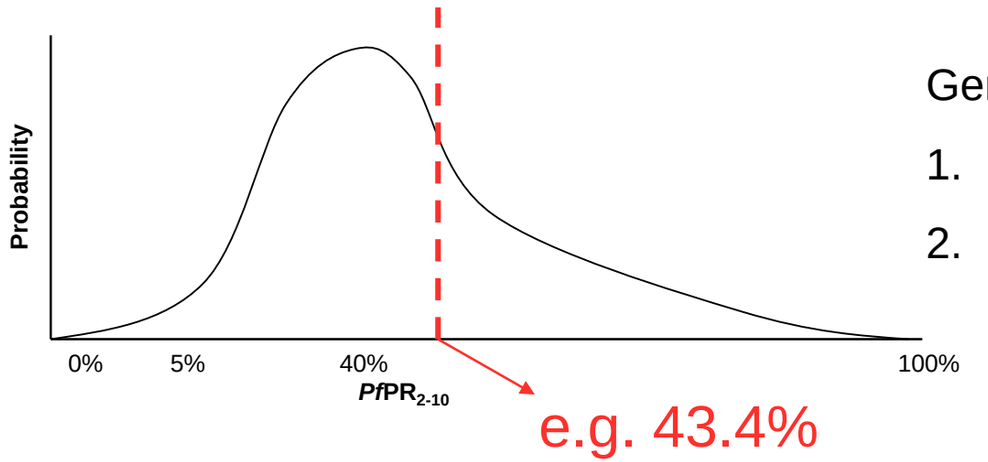



- Realisations provide posterior distribution for each location



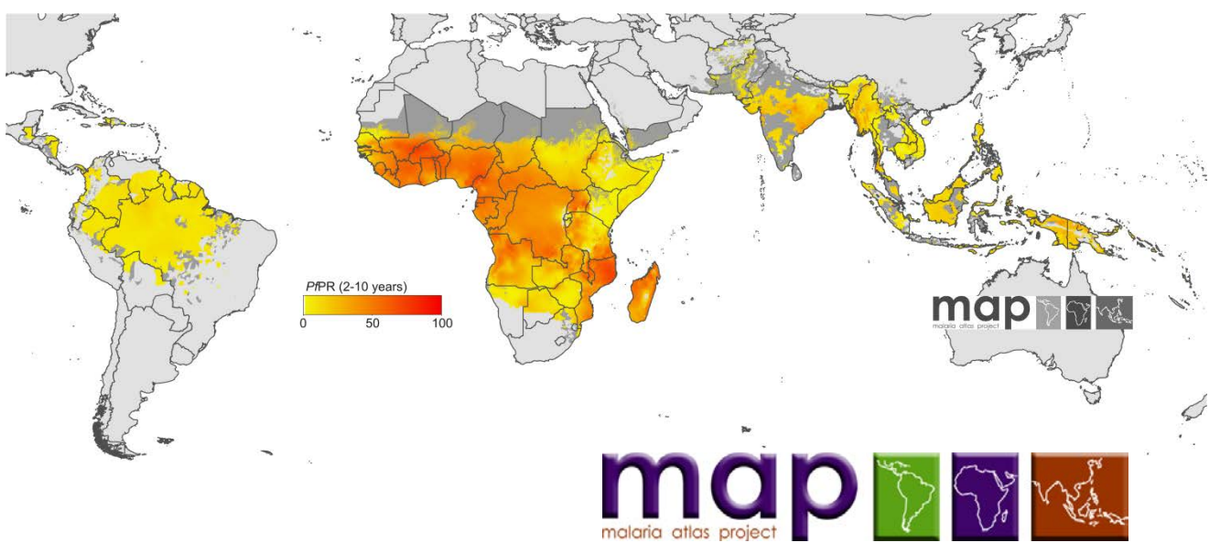
# Geostatistics: making maps

## Generating maps from posterior distributions of *Pf*PR$_{2\text{-}10}$




Generated various summaries:

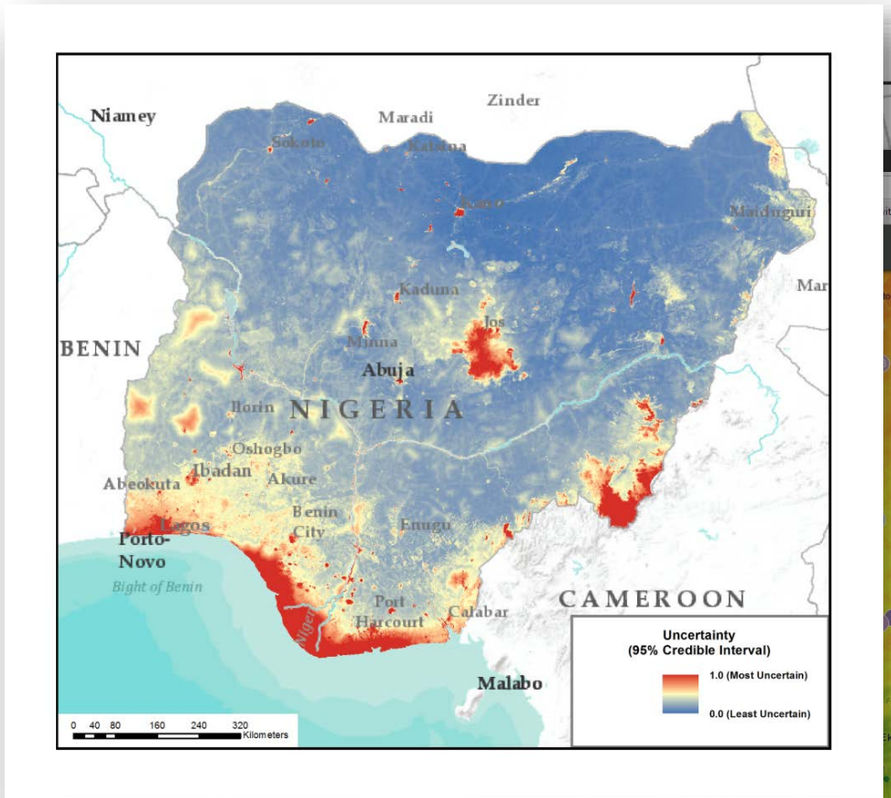
1. A ‘point estimate’ (mean)
2. A summary of uncertainty (e.g. St.deviation)

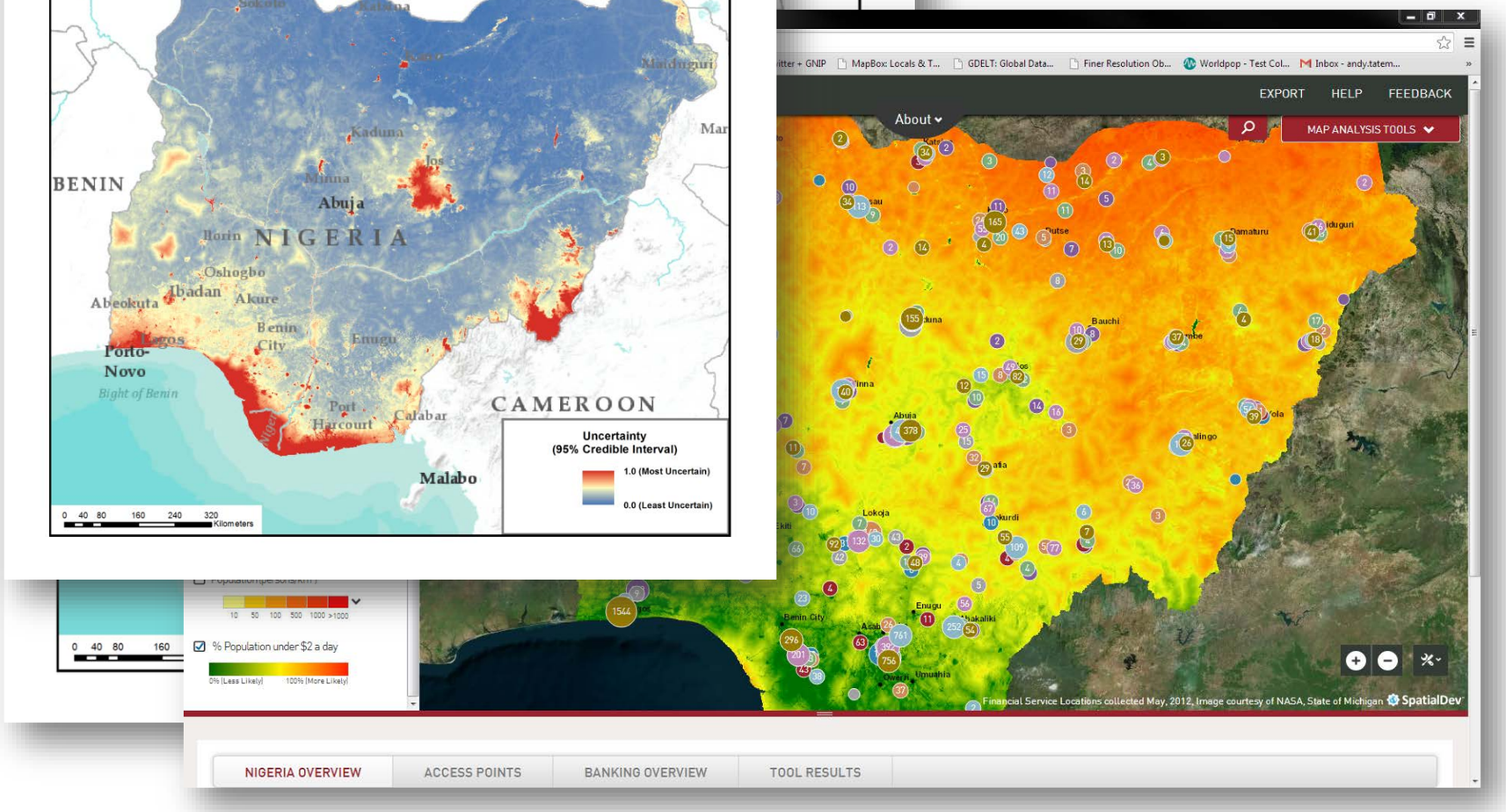


# Poverty mapping

THE WORLD BANK
Working for a World Free of Poverty

world pop



# Modeling Approach Overview