Modeling global, urban, and rural exposure to climate-related hazards

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Article

Climate-Related Hazards: A Method for Global Assessment of Urban and Rural Population Exposure to Cyclones, Droughts, and Floods

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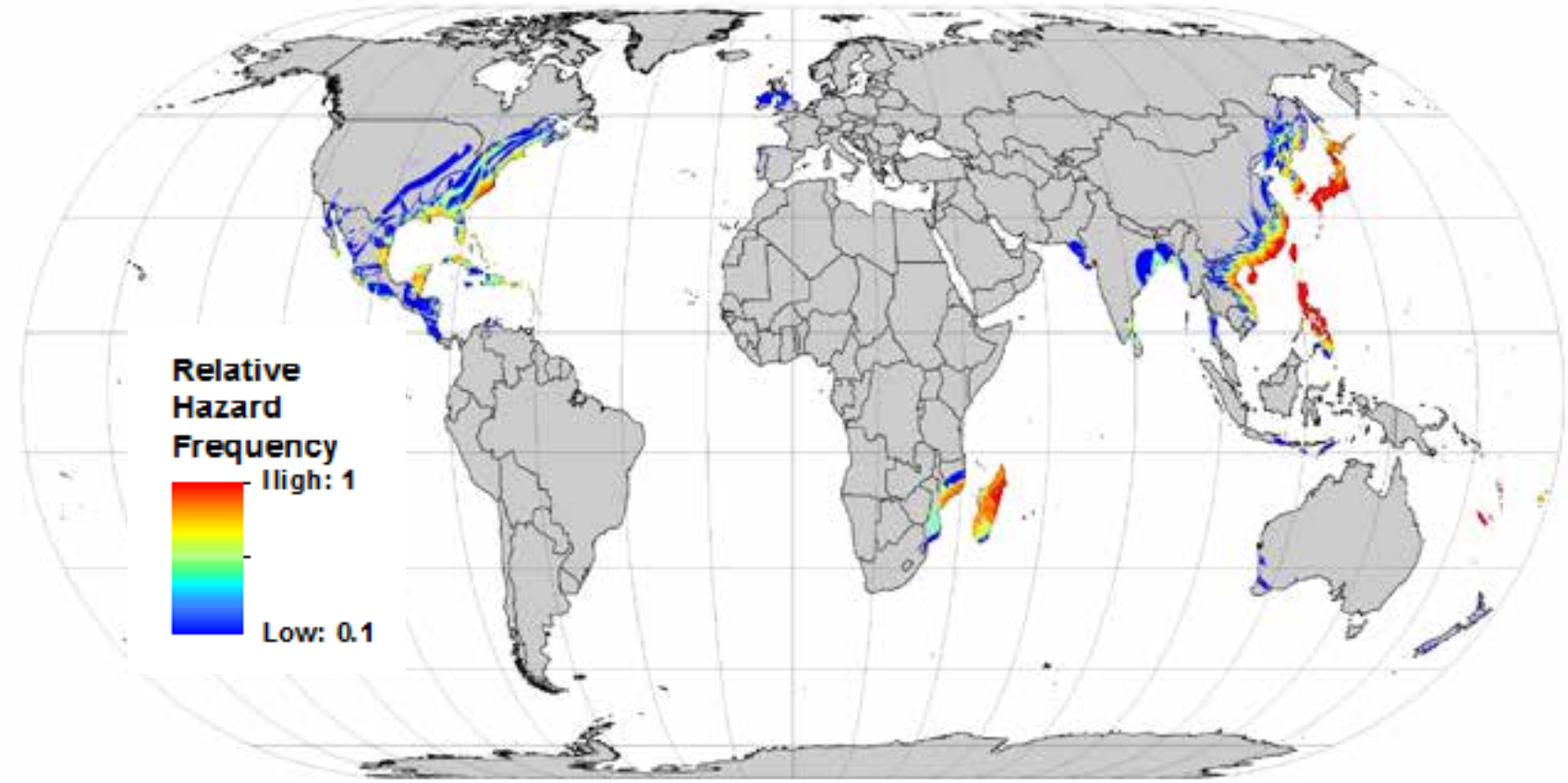
Objectives

1. Estimate and rank relative population exposure of countries to the climate-related hazard events of cyclone, drought, and flood

   Relative Population Exposure: the likelihood that a person in a location would be exposed to a given hazard event in a given period of time

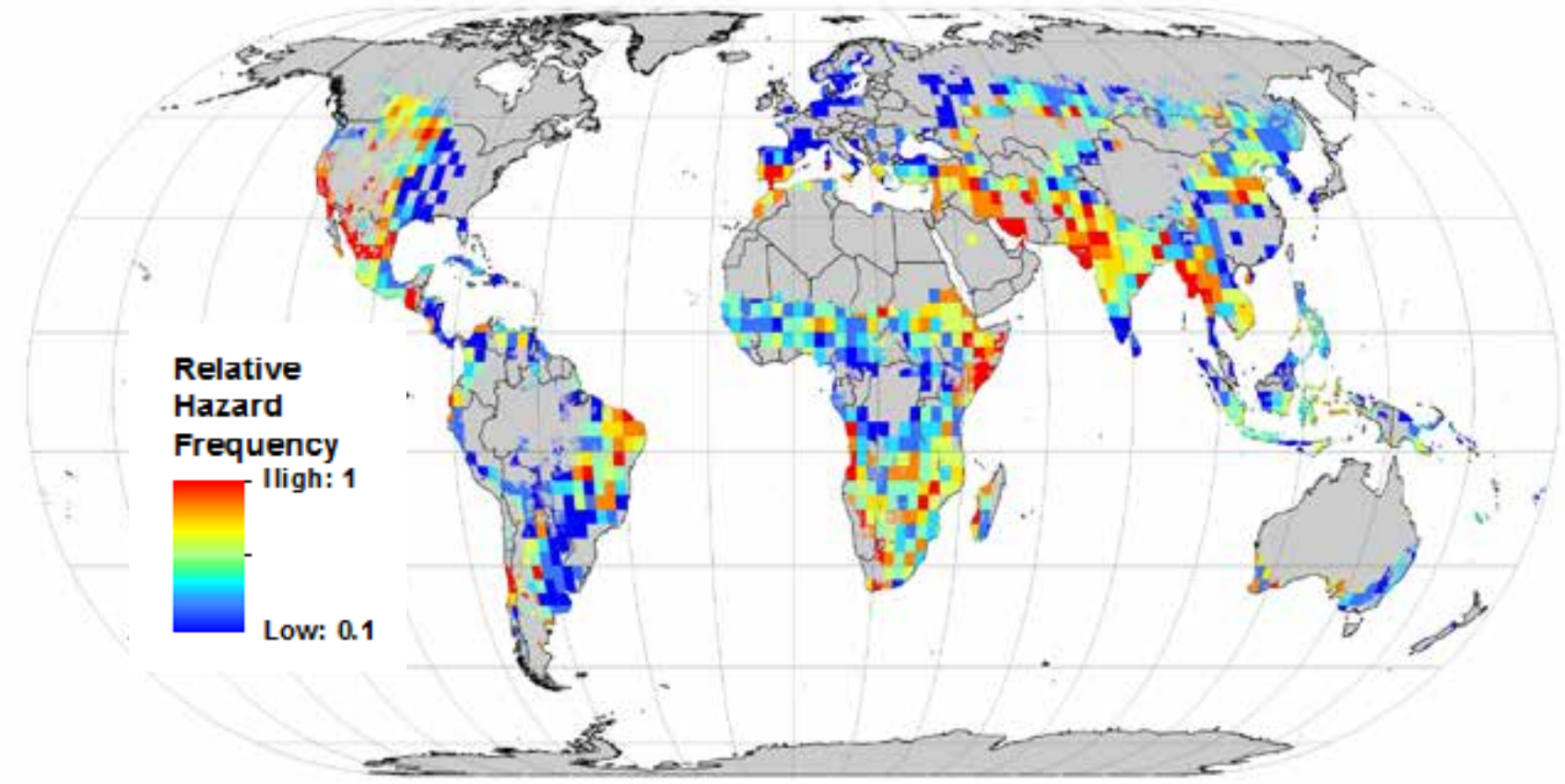
2. Differentiate urban and rural areas
3. Automate global, urban, and rural exposure estimates using ArcGIS Model Builder

CHRR Global Cyclone Frequency and Distribution



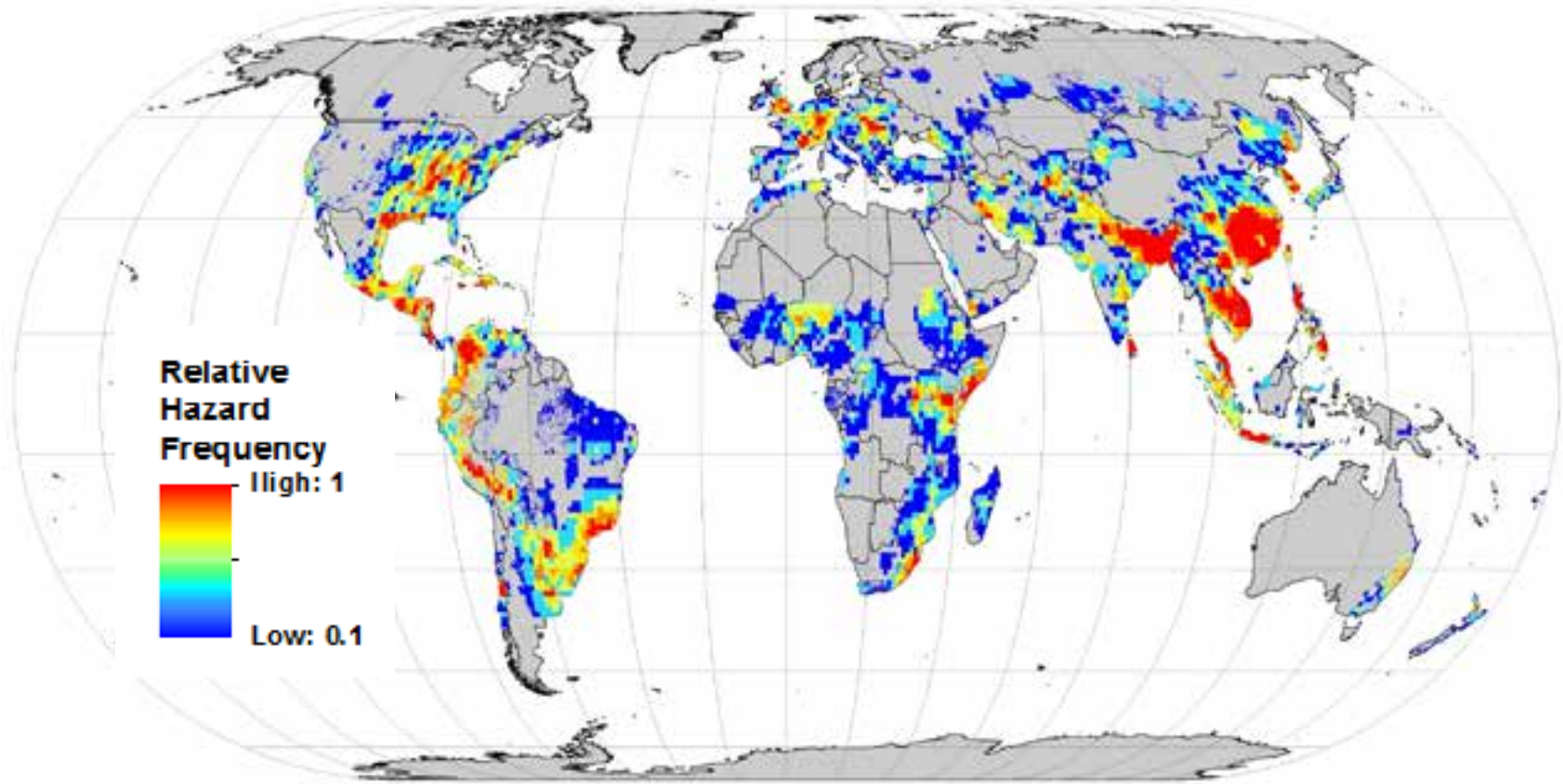
Source: Center for Hazards and Risk Research (CHRR)
www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html

CHRR Global Drought Frequency and Distribution



Source: Center for Hazards and Risk Research (CHRR)
www.ldeo.columbia.edu/chrr/research/hotspots/coredata.html

CHRR Global Flood Frequency and Distribution



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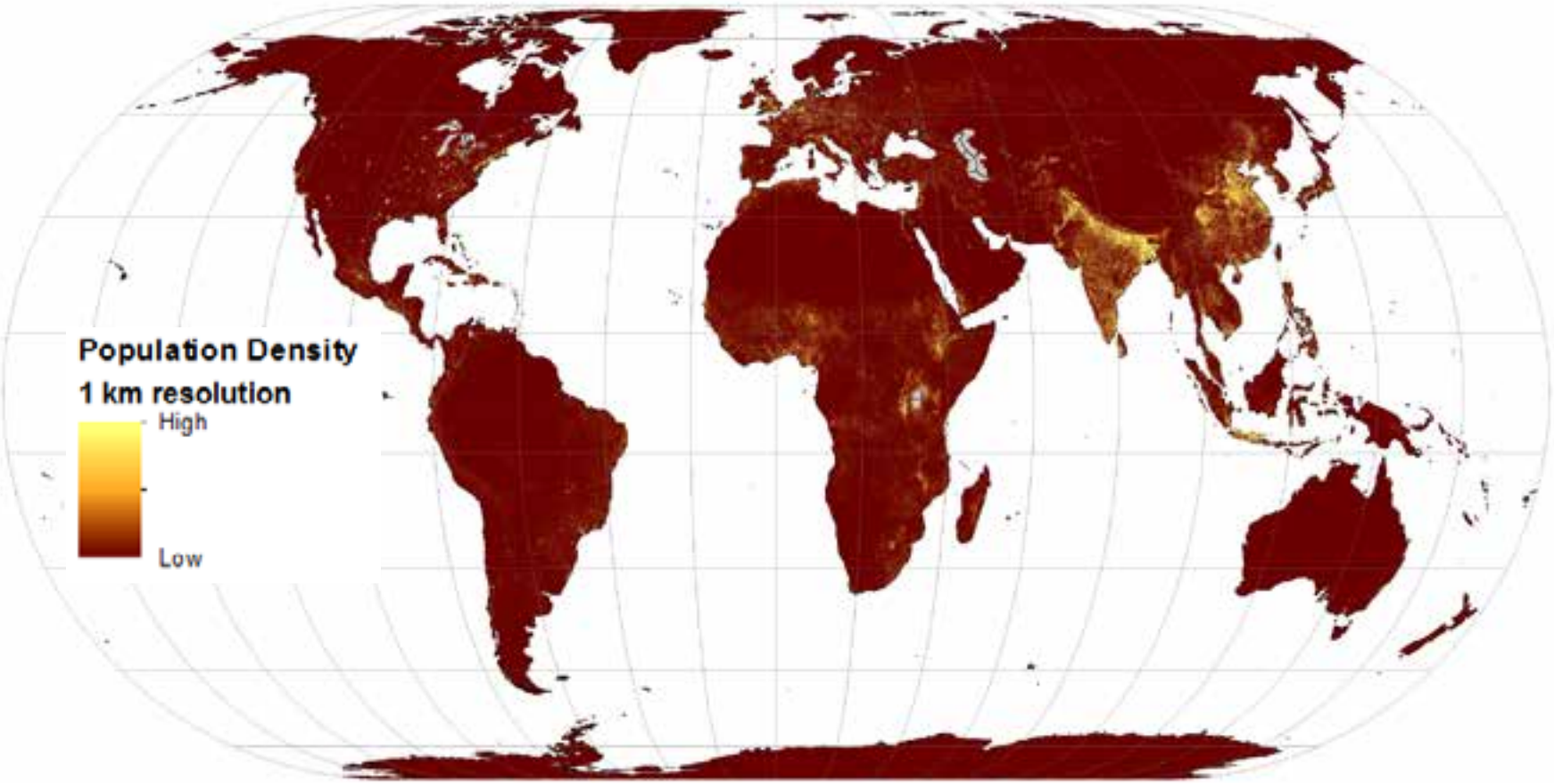
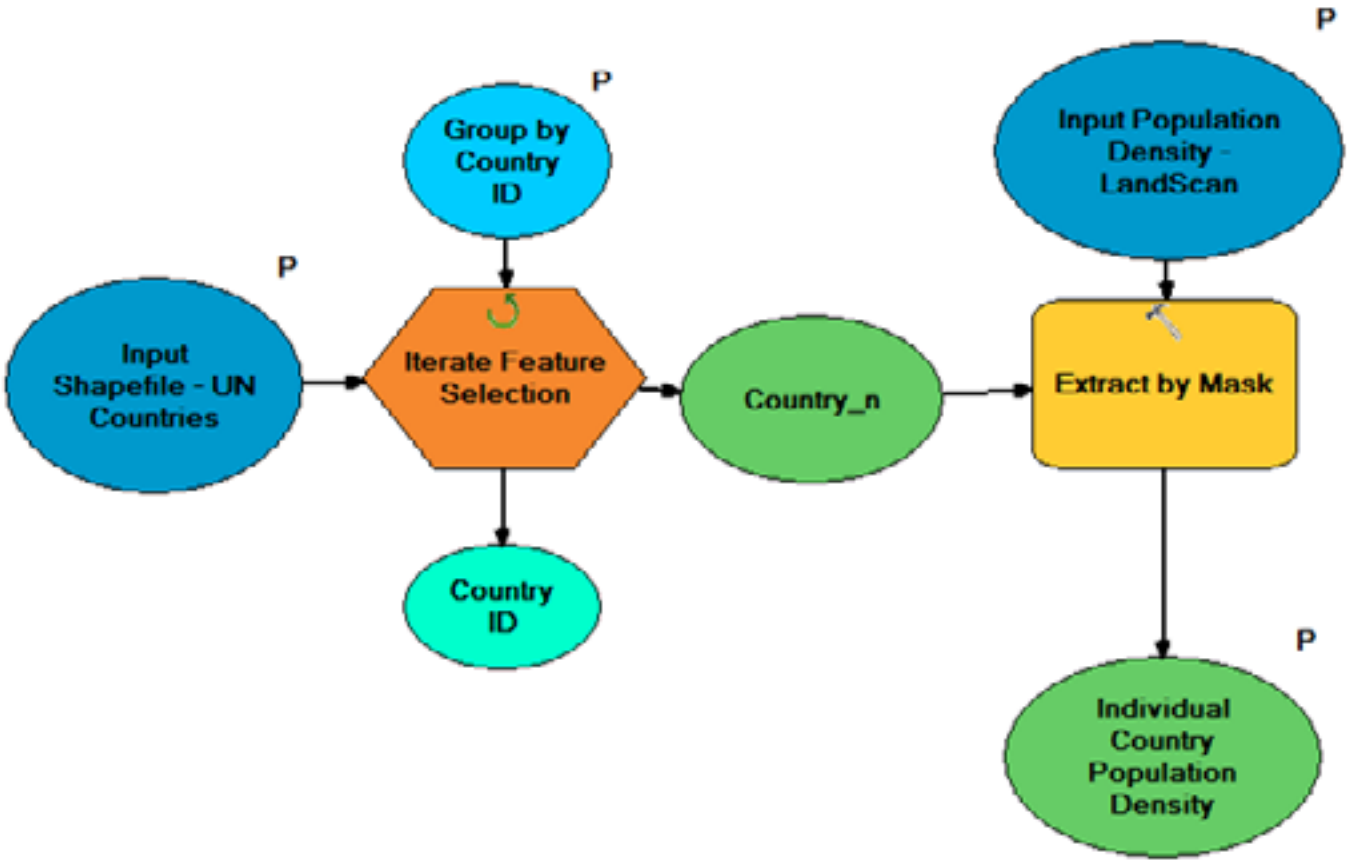
LandScan 2008 Global Population Density



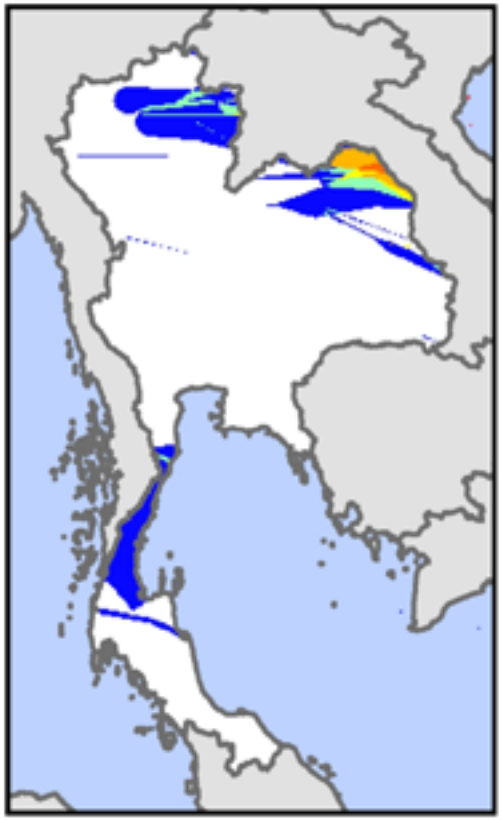
Source: www.web.ornl.gov/sci/landscan

Model Builder: Country-level data



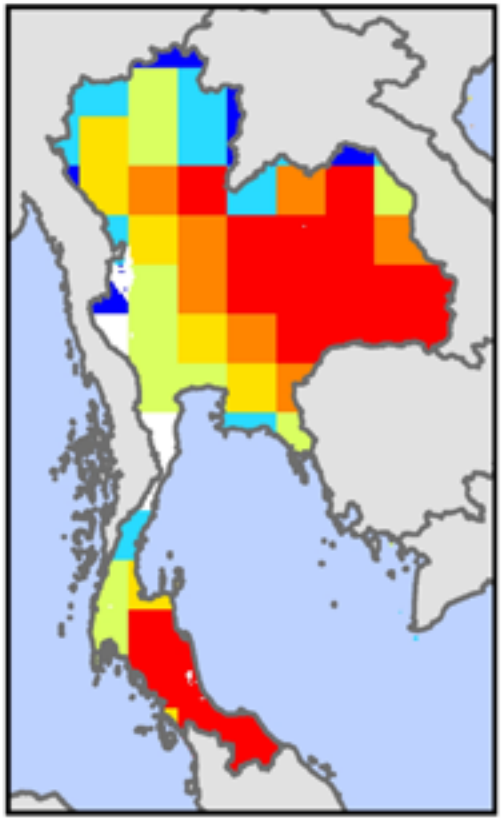
CHRR Data - Thailand

CHRR Relative Cyclone Frequency
0.5' x 0.5'

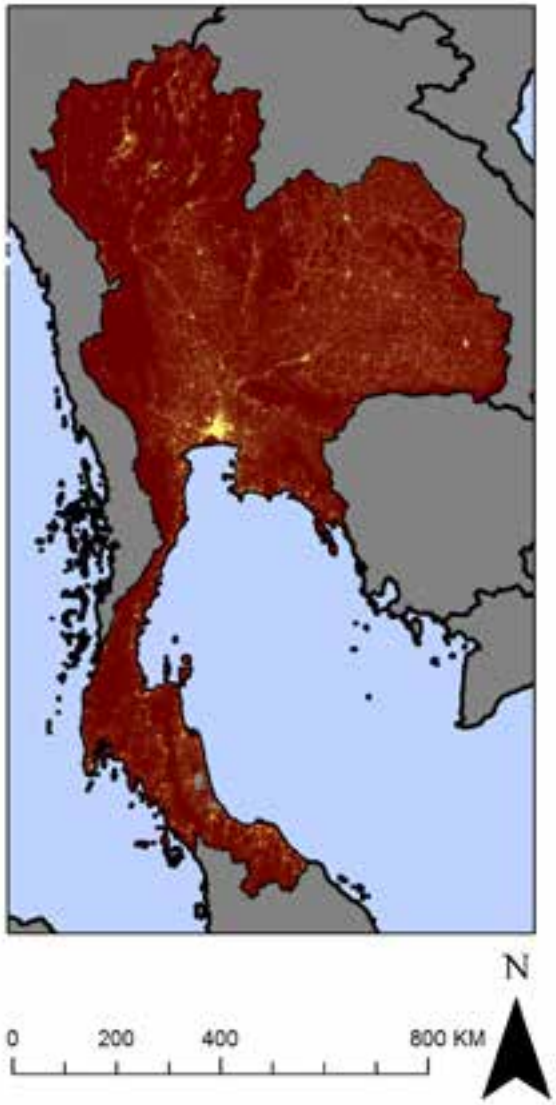


CHRR Relative Drought Frequency
2.5 x 2.5°

CHRR Relative Flood Frequency
1 x 1°



LandScan Data - Thailand



Ancillary data used:

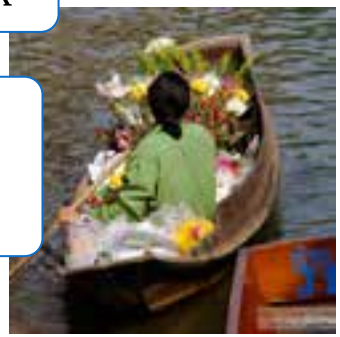
- Administrative boundaries
- Census Information
- Land cover
- Elevation, slope
- Roads
- Satellite imagery

Urban

- Greater access to health care
- Reliance on cash income
- Congested evacuation routes

Rural

- Increased community/social structure and network
- Decreased access to services, the market, transportation
- Reliance on subsistence agriculture



Sources:

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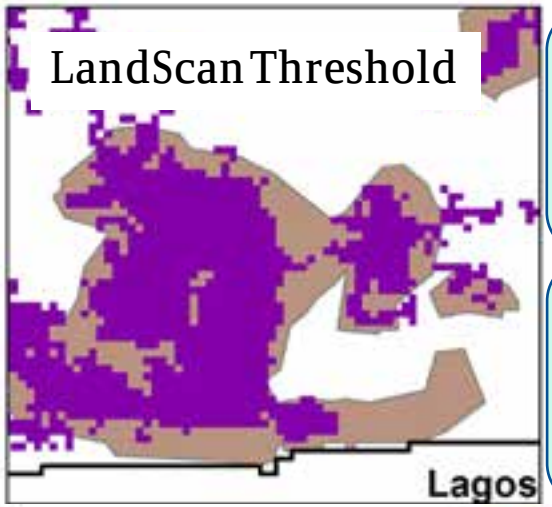
Cutter, S.L et al. Social vulnerability to environmental hazards. *Soc. Sci. Quart.* 2003.

Ruel, M.T. et al. The food, fuel, and financial crises affect the urban and rural poor disproportionately: A review of the evidence. *J. Nutr.* 2010.

Differentiating Urban-Rural

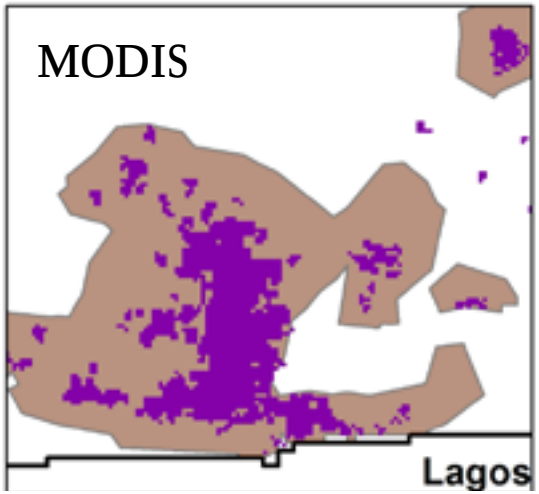


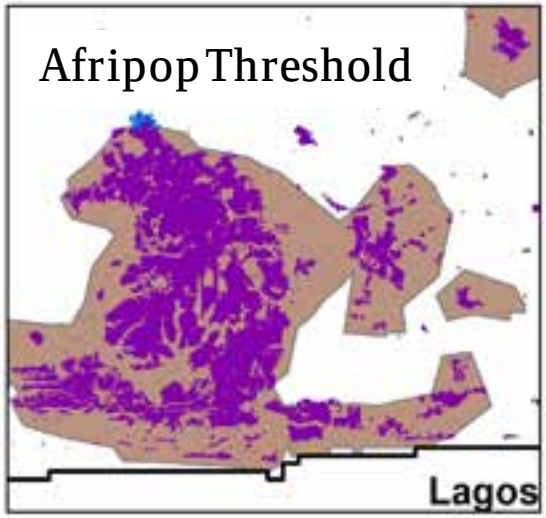
Remote Sensing Methods

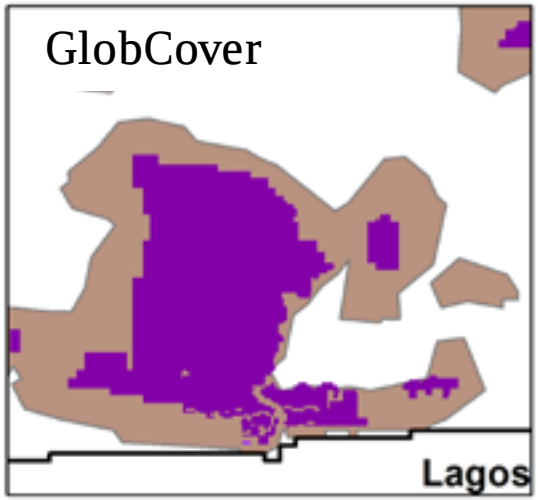
- Night-time lights
- Land cover
- Satellite imagery

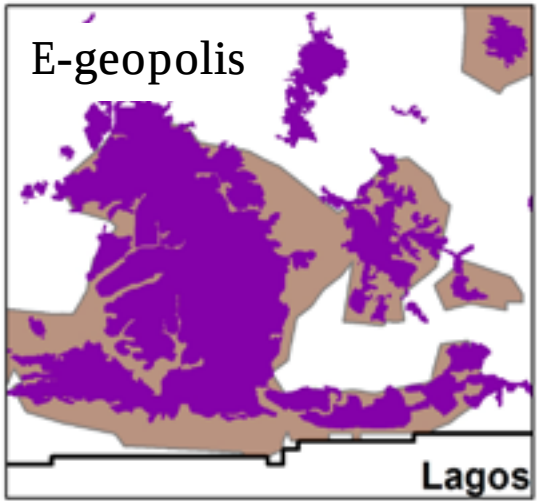
Ground Input Methods

- Census information
- Modeled population



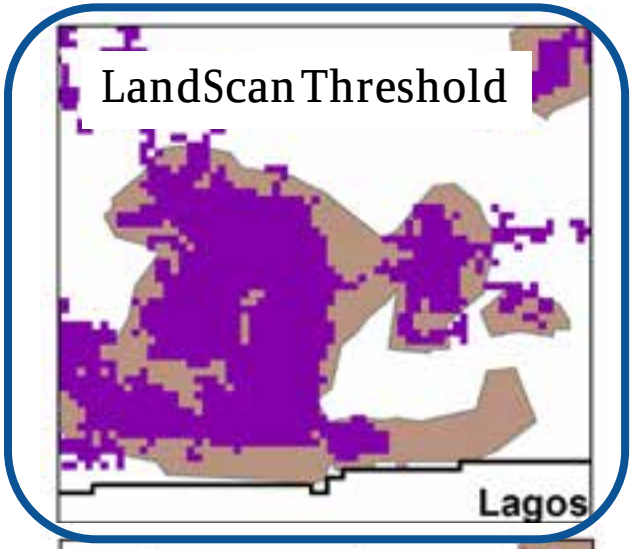


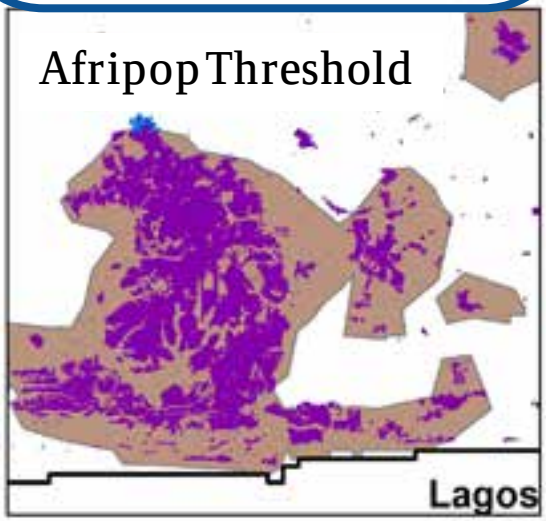




Source: Christenson et al. Examining the influence of urban definition when assessing relative safety of drinking-water in Nigeria. *Science of the Total Environment*, 2014.

Differentiating Urban-Rural





Ground Input Methods

- Census information
- Modeled population

Strengths

- Allows degrees of "urban-ness" to be calculated
- Incorporates multiple facets of urban definition
  - Built infrastructure, population size / density

Weaknesses

- Dependent on input population dataset
  - Spatial resolution
  - Modeled population method

Source: Christenson et al. Examining the influence of urban definition when assessing relative safety of drinking-water in Nigeria. *Science of the Total Environment*, 2014.

Defining a Population Threshold

United Nations World Urbanization Prospects

– country-specific estimates for proportion rural

Thailand Example:

- UN estimated proportion: 66% Rural
- Total LandScan population = 78,668,490

$$\% \text{ Rural} = \frac{\sum(\boldsymbol{Value} \times \boldsymbol{Count})}{\boldsymbol{Total\ Population}}$$

Vary LandScan population density threshold until % Rural matches the UN estimated proportion

Population Density (VALUE) Range:

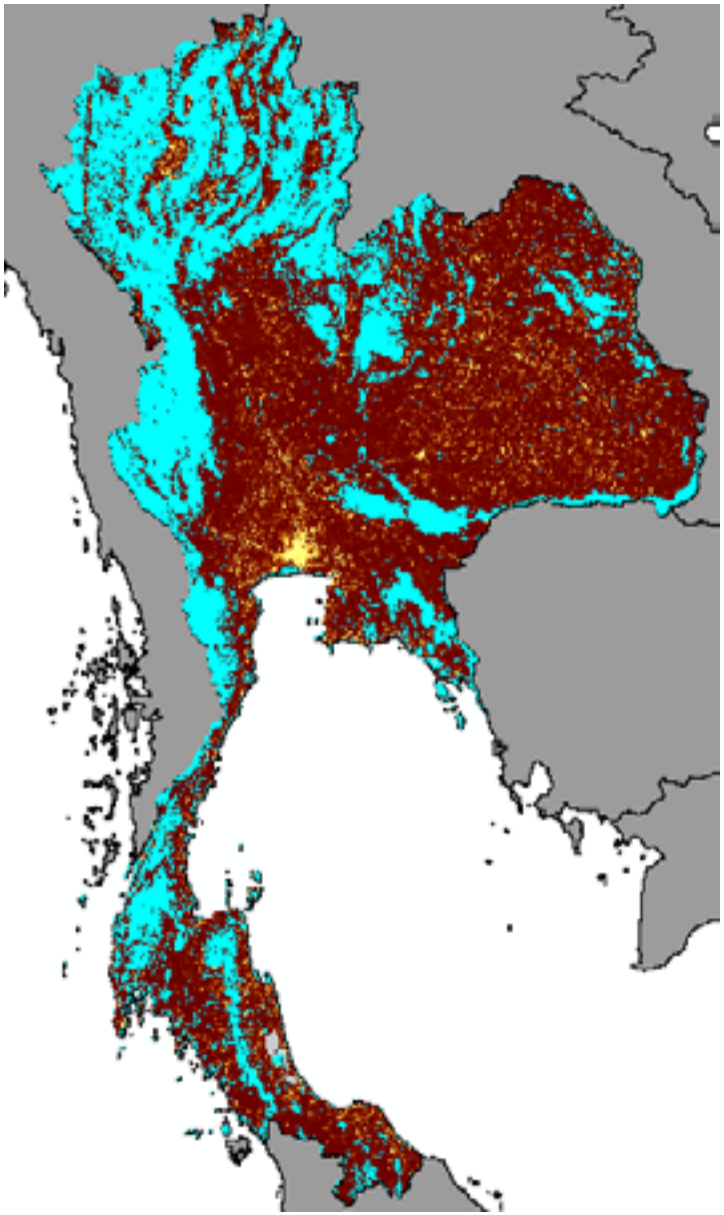
0 – 5

Population Threshold:

0.2 % Rural

Sorted population density values

VALUE	COUNT	POP
0	88549	0
1	56994	56994
2	25802	51604
3	16608	49824
4	12166	48664
5	2904	14520
6	6893	41358
7	7988	55916
8	7158	57264
9	6004	54036
10	3948	39480
11	3960	43560
12	4439	53268
13	3609	46917
14	5259	73626



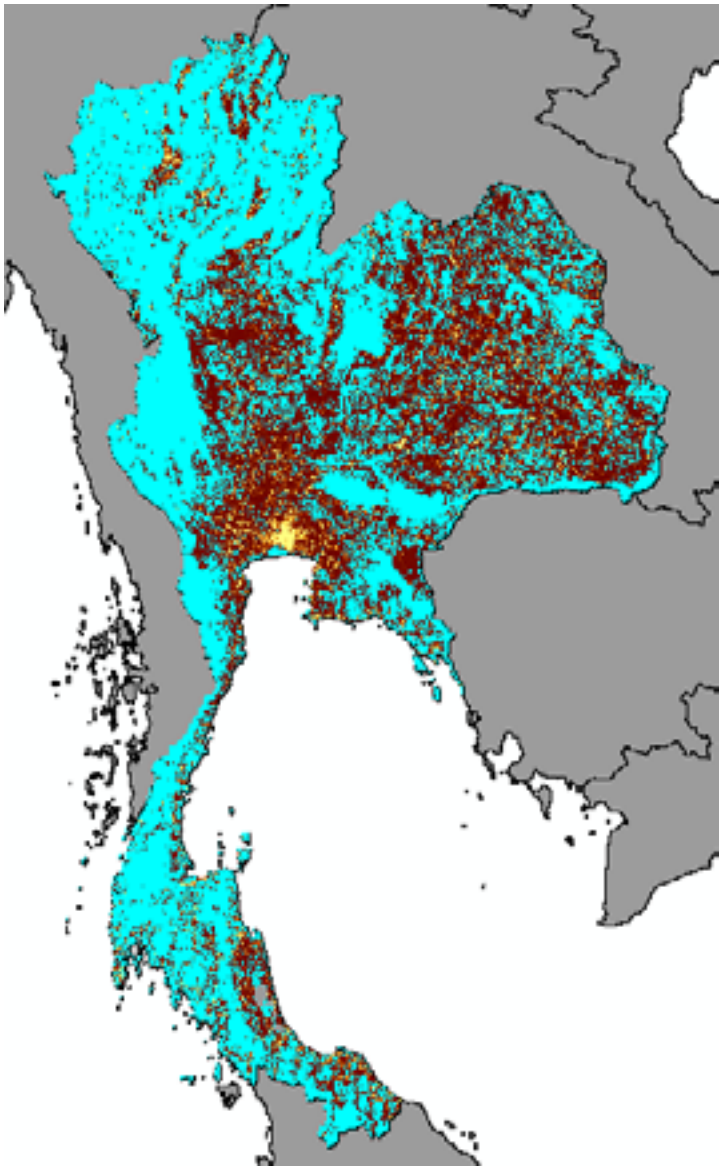
Population Density (VALUE) Range:

0 – 38

Population Threshold:

5% Rural

VALUE	COUNT	POP
30	6466	193980
31	5804	179924
32	6065	194080
33	4348	143484
34	3207	109038
35	4085	142975
36	5533	199188
37	5679	210123
38	4109	156142
39	3723	145197
40	3232	129280
41	4675	191675
42	5501	231042
43	4261	183223
44	3641	160204



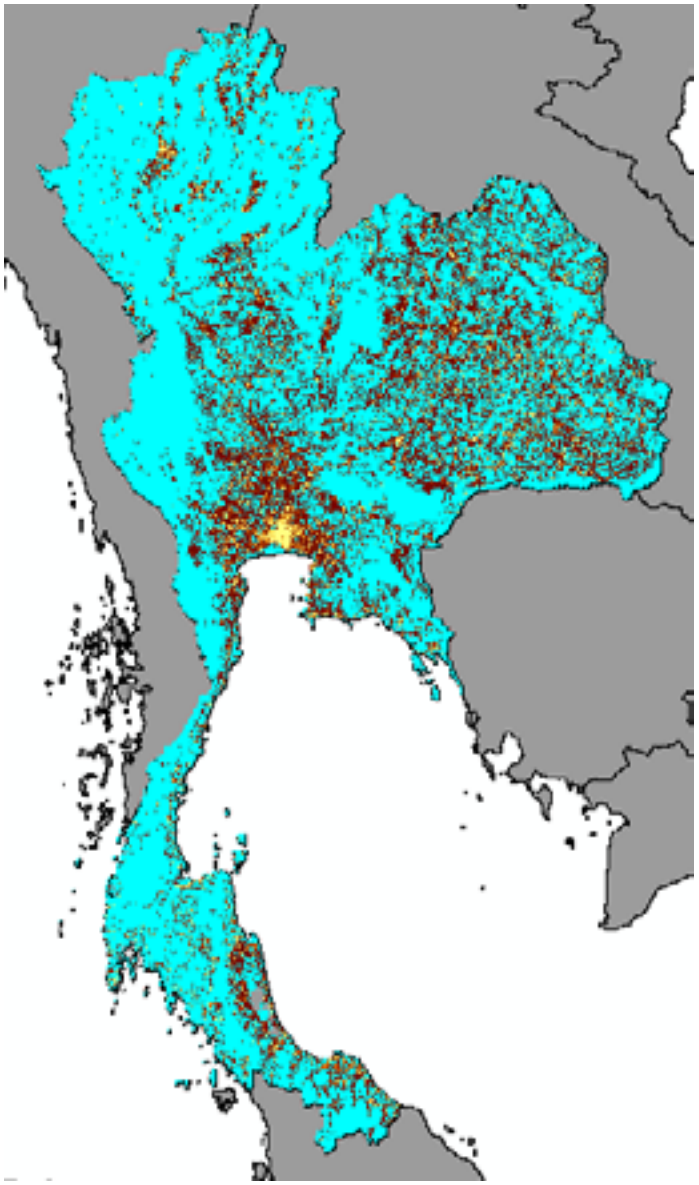
Population Density (VALUE) Range:

0 – 60

Population Threshold:

10% Rural

VALUE	COUNT	POP
49	3293	161357
50	2867	143350
51	2583	131733
52	2313	120276
53	4155	220215
54	4078	220212
55	3061	168355
56	3277	183512
57	3594	204858
58	3962	229796
59	4568	269512
60	5270	316200
61	4153	253333
62	3781	234422
63	5543	349209



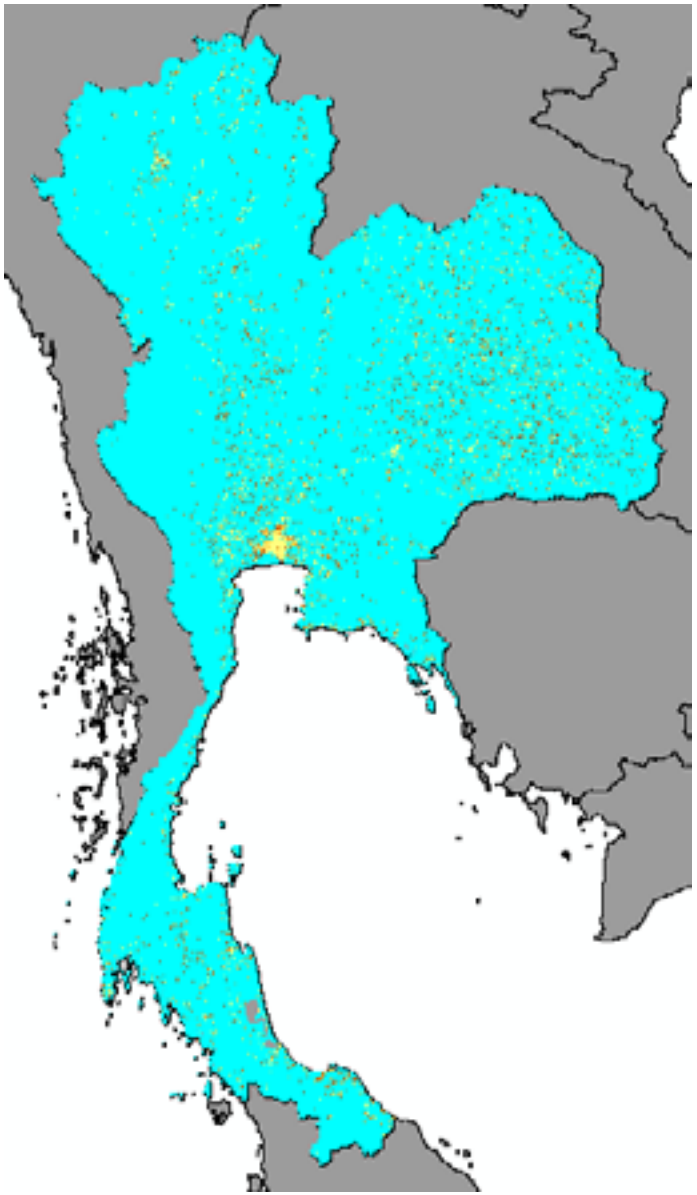
Population Density (VALUE) Range:

0 – 394

Population Threshold:

30% Rural

VALUE	COUNT	POP
388	78	30264
389	51	19839
390	52	20280
391	65	25415
392	52	20384
393	72	20296
394	114	44916
395	112	44240
396	44	17424
397	36	14292
398	61	24278
399	40	15960
400	36	14400
401	64	25664
402	30	12060



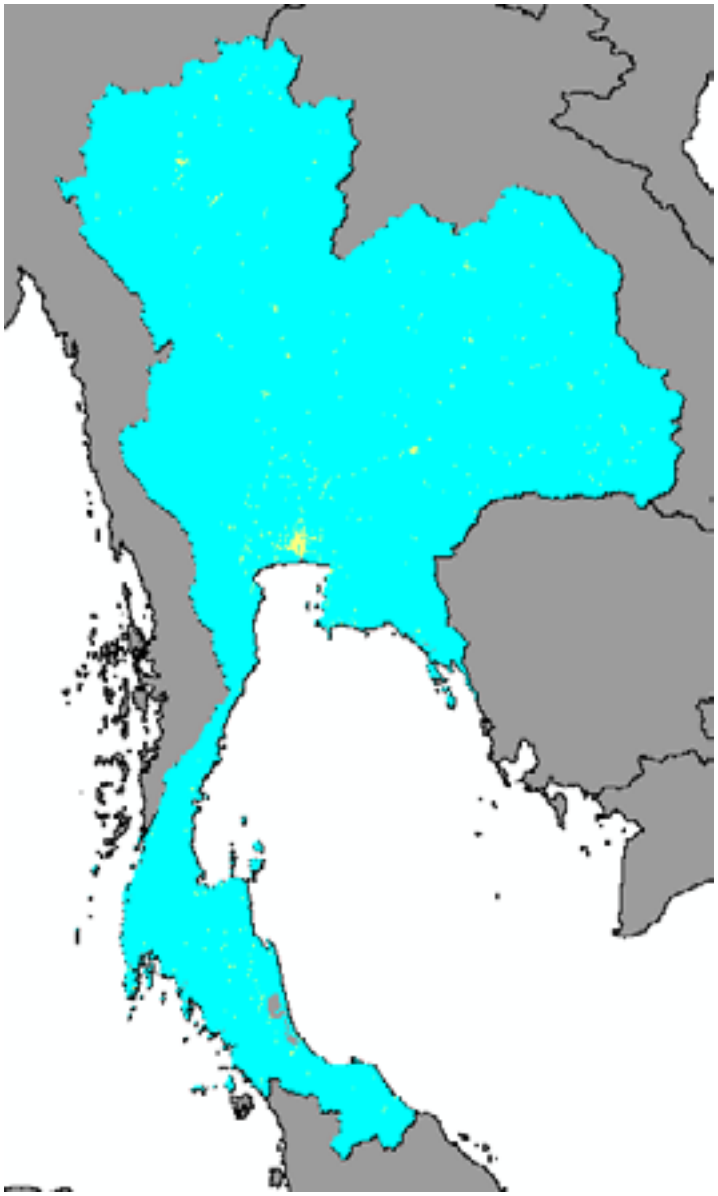
Population Density (VALUE) Range:

0 – 2471

Population Threshold:

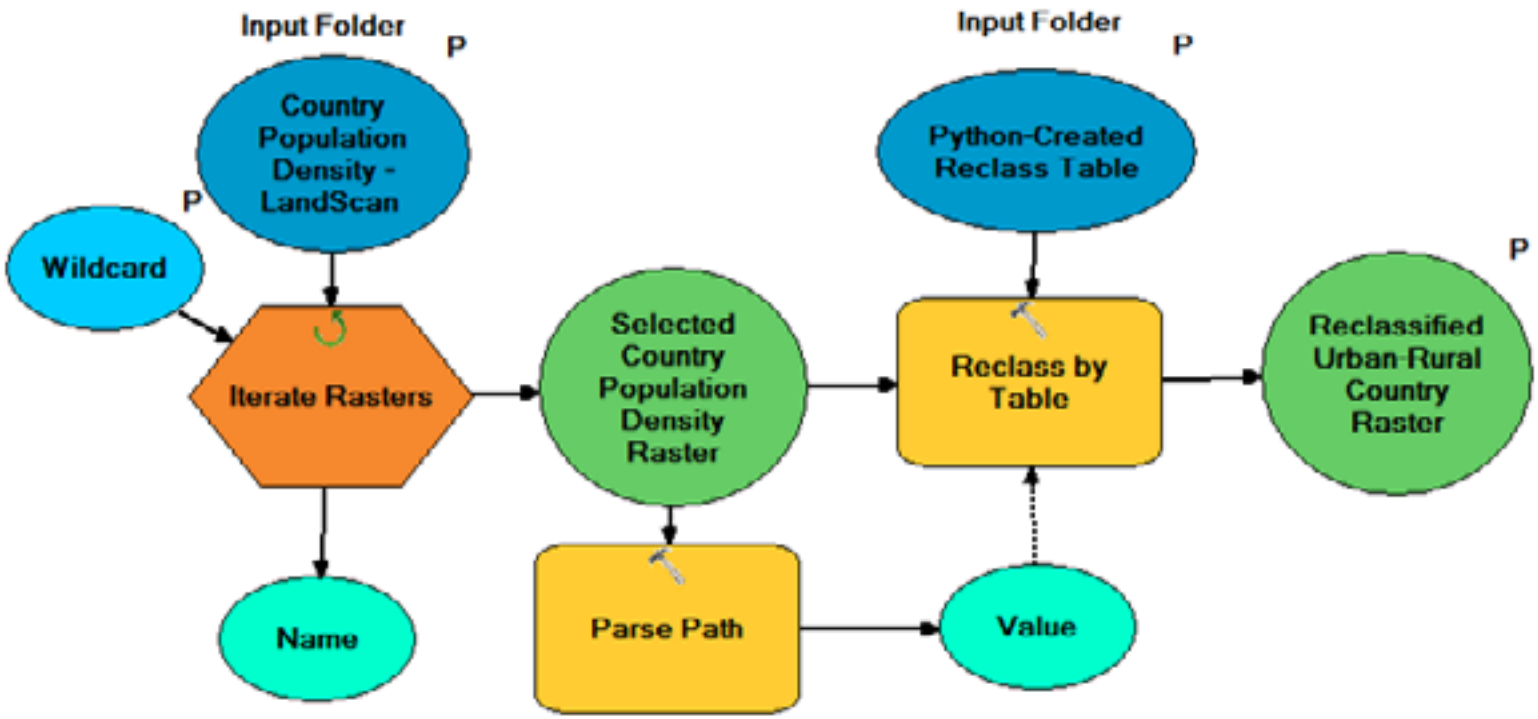
66% Rural

VALUE	COUNT	POP
2461	1	2461
2462	3	7386
2463	7	17241
2464	1	2464
2465	3	7395
2466	3	7398
2467	1	2467
2468	4	9872
2469	3	7407
2470	3	7410
2471	2	4942
2472	3	7416
2473	4	9892
2474	4	9896
2475	3	7425



Model Builder: Raster Reclassification

- Python script identifies each country's population density threshold and creates Reclass Table
- Model Builder: Iterative "Reclass by Table"

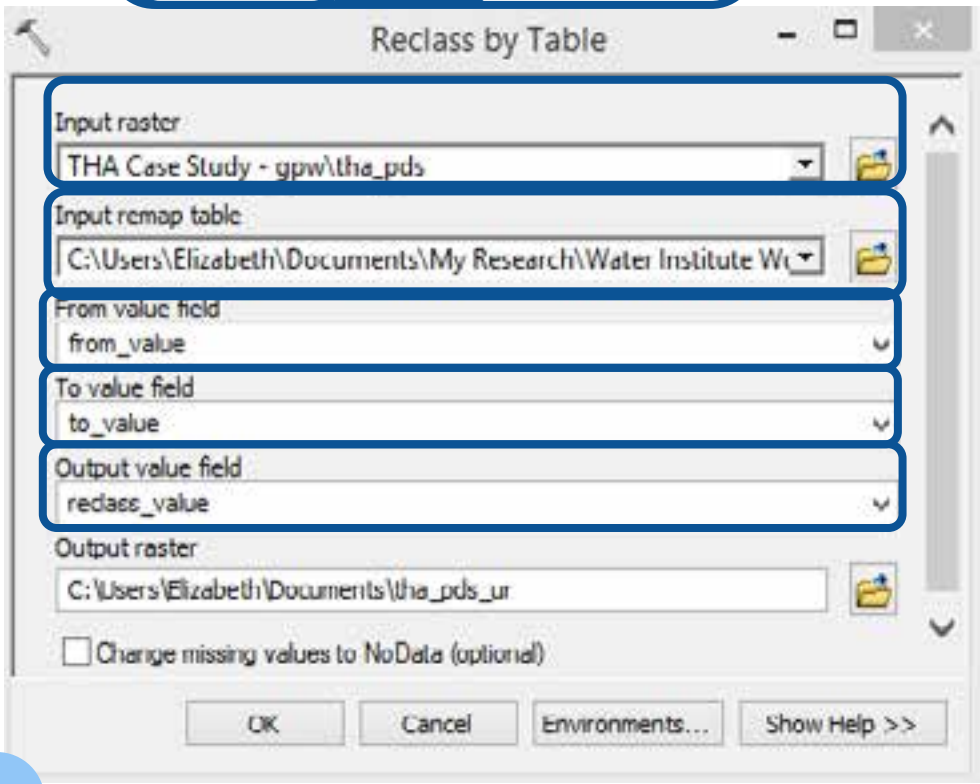


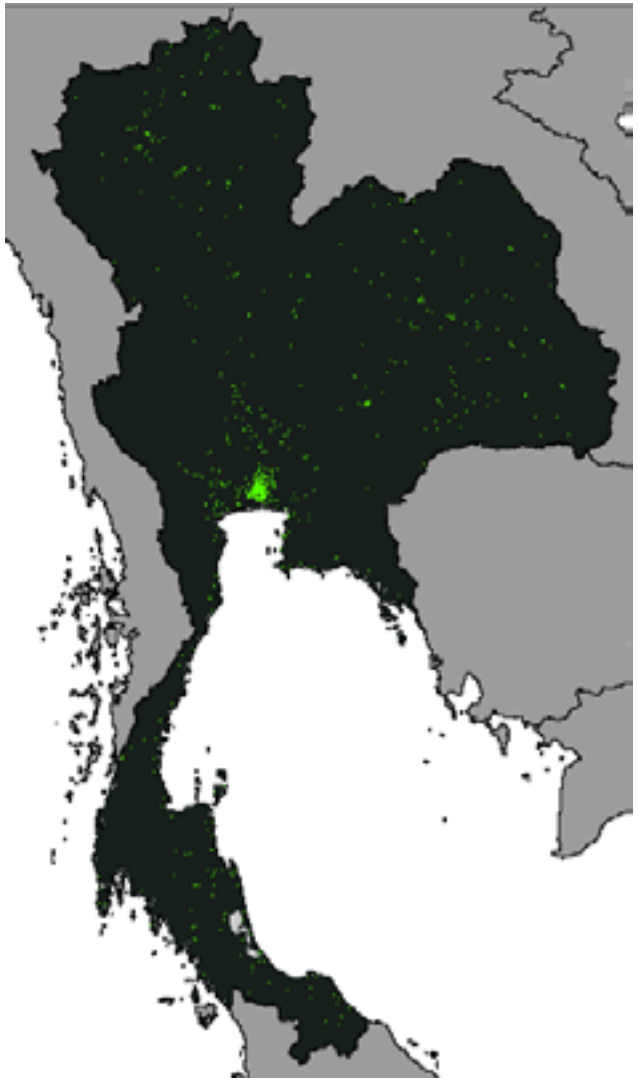
Urban-Rural Reclassification

Reclass Table

from_value	to_value	reclass_value
0	2471	1
2472	58343	2

Rural
Urban





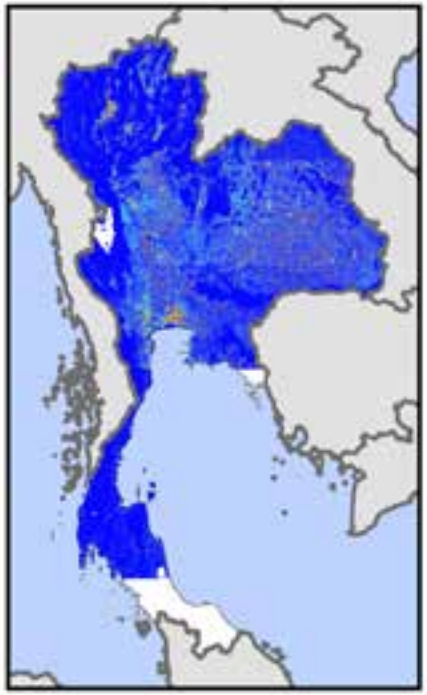
Cell Exposure Calculation

$$\boldsymbol{Cell\ Exposure}_{Hazard} = \boldsymbol{Population}_{cell} \times \boldsymbol{H}_{Hazard,cell}$$

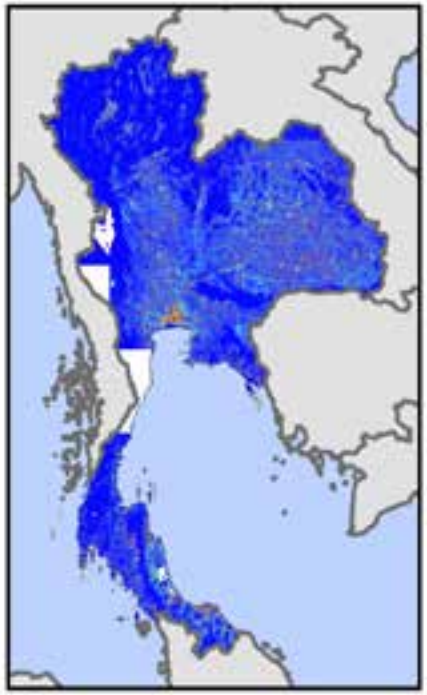
H is the hazard event likelihood

Cyclone Exposure

Drought Exposure



Flood Exposure



Urban, Rural, or Country Exposure

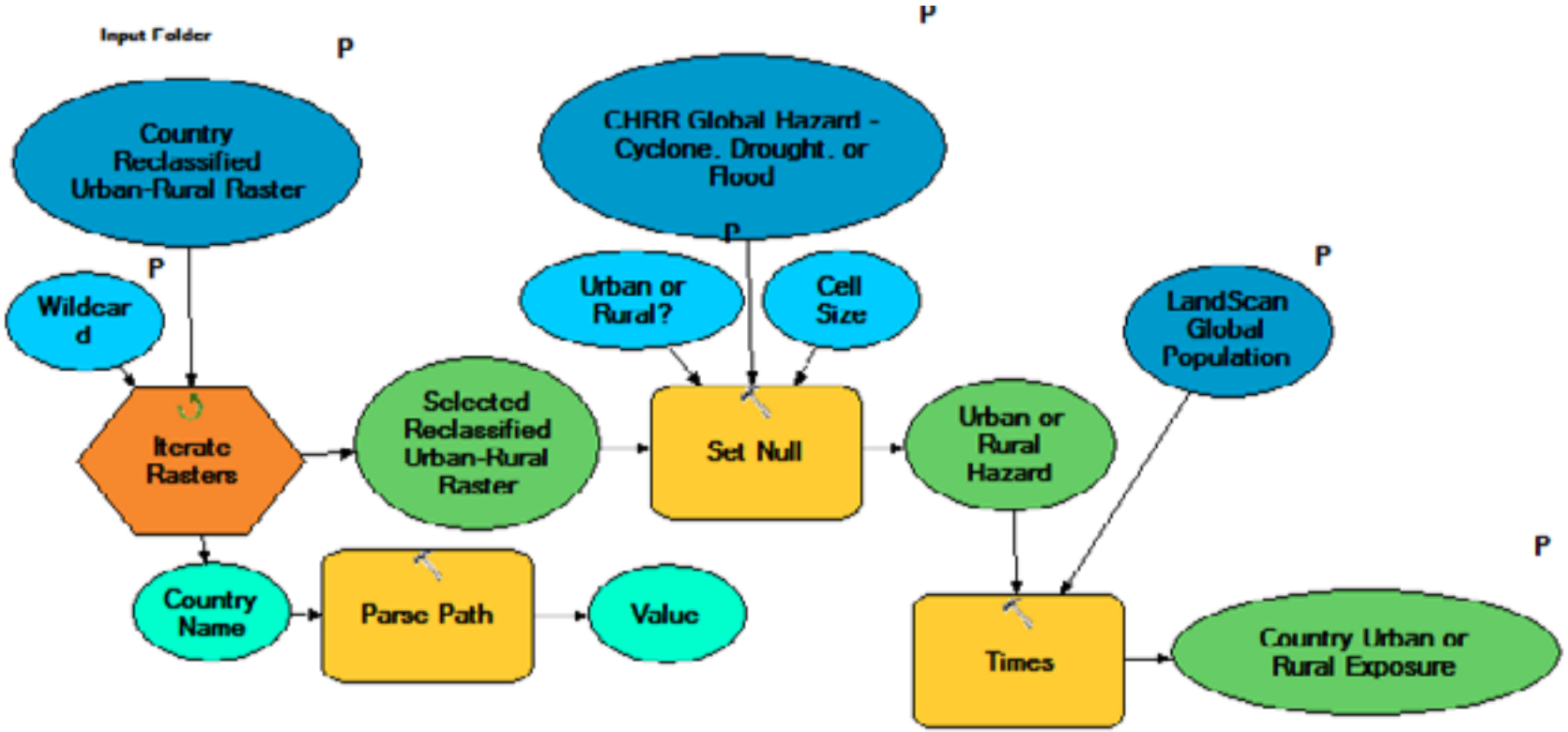
$$\boldsymbol{Average\ Population\ Exposure}_{Area}$$

$$= \frac{\sum \boldsymbol{Population}_{cell} \times \boldsymbol{H}_{Hazard,cell}}{\boldsymbol{Pop}_{Area}}$$

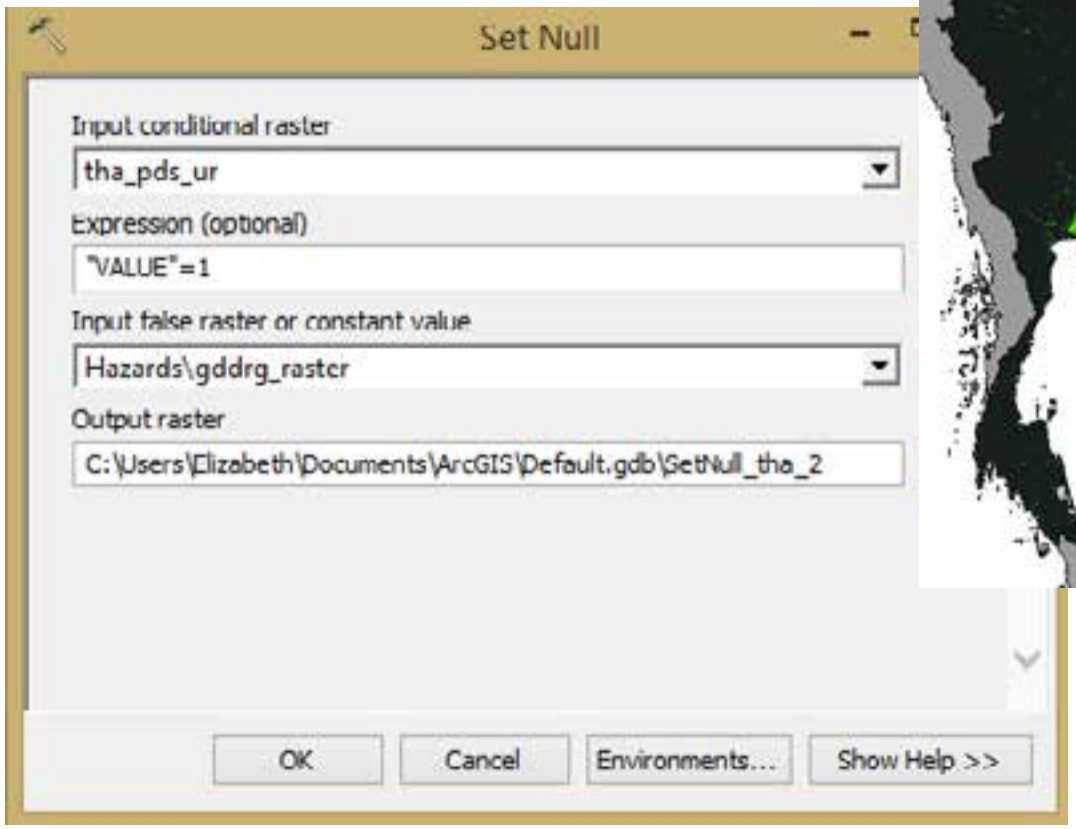
$$= \frac{\sum \boldsymbol{Cell\ Exposure}_{Area}}{\boldsymbol{Pop}_{Area}}$$

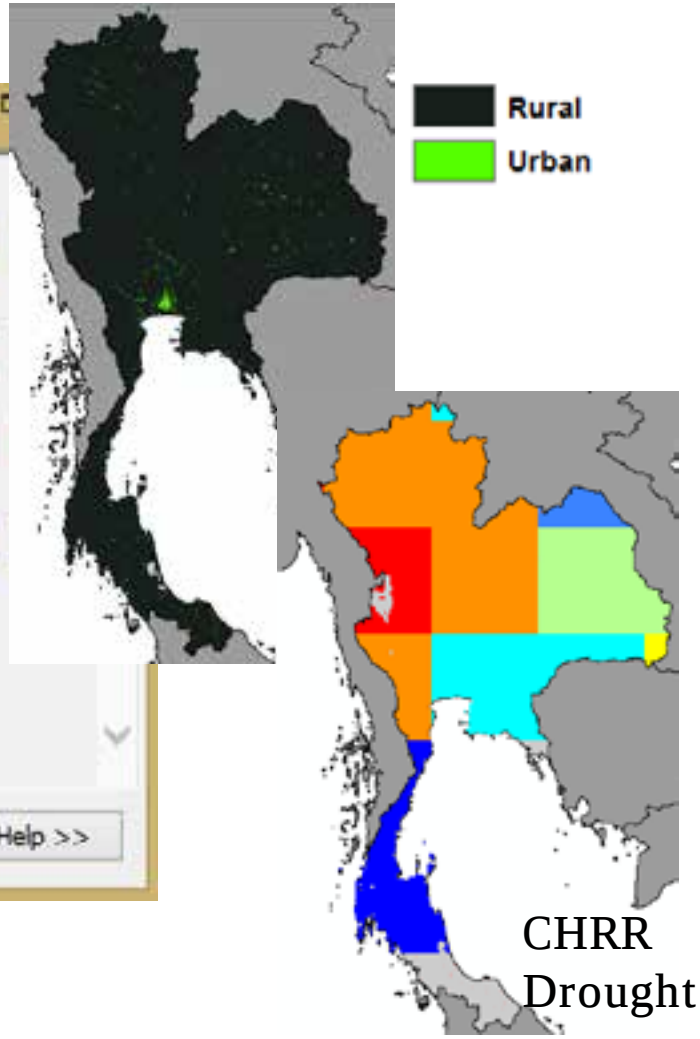
Area - Urban, Rural, or Entire Country

Model Builder: Urban, Rural Exposure



Urban, Rural Exposure

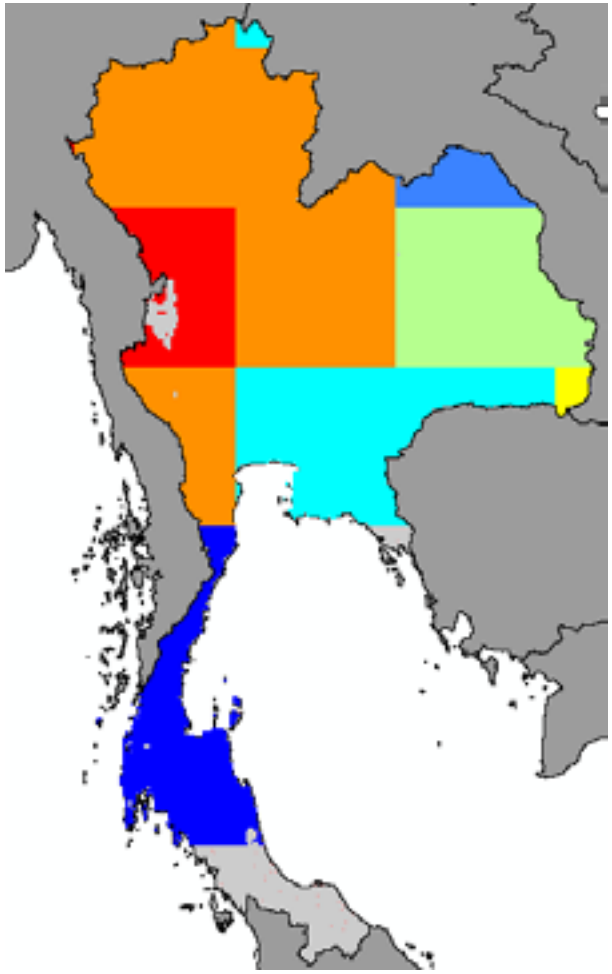




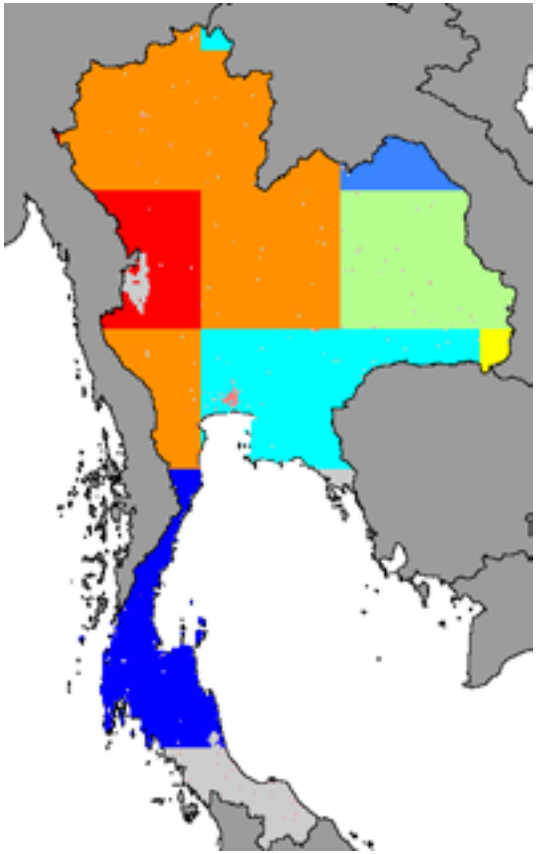
CHRR
Drought

Urban, Rural Drought (CHRR)

Urban



Rural



Average Urban Population Exposure to Drought

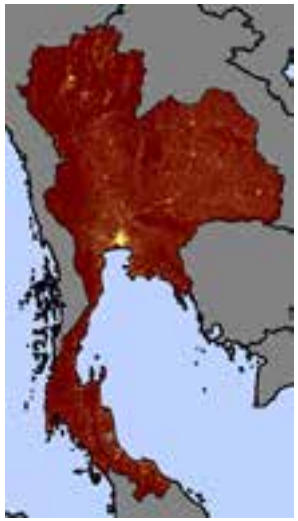
Selected Urban Area

$$\frac{\sum \text{Population}_{cell} \times H_{Drought,cell}}{\text{Total Urban Population}}$$

Average Rural Population Exposure to Drought

Selected Rural Area

$$\frac{\sum \text{Population}_{cell} \times H_{Drought,cell}}{\text{Total Rural Population}}$$

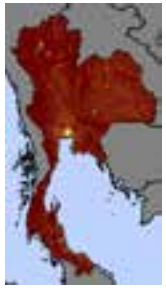


Average Country Population Exposure to Drought

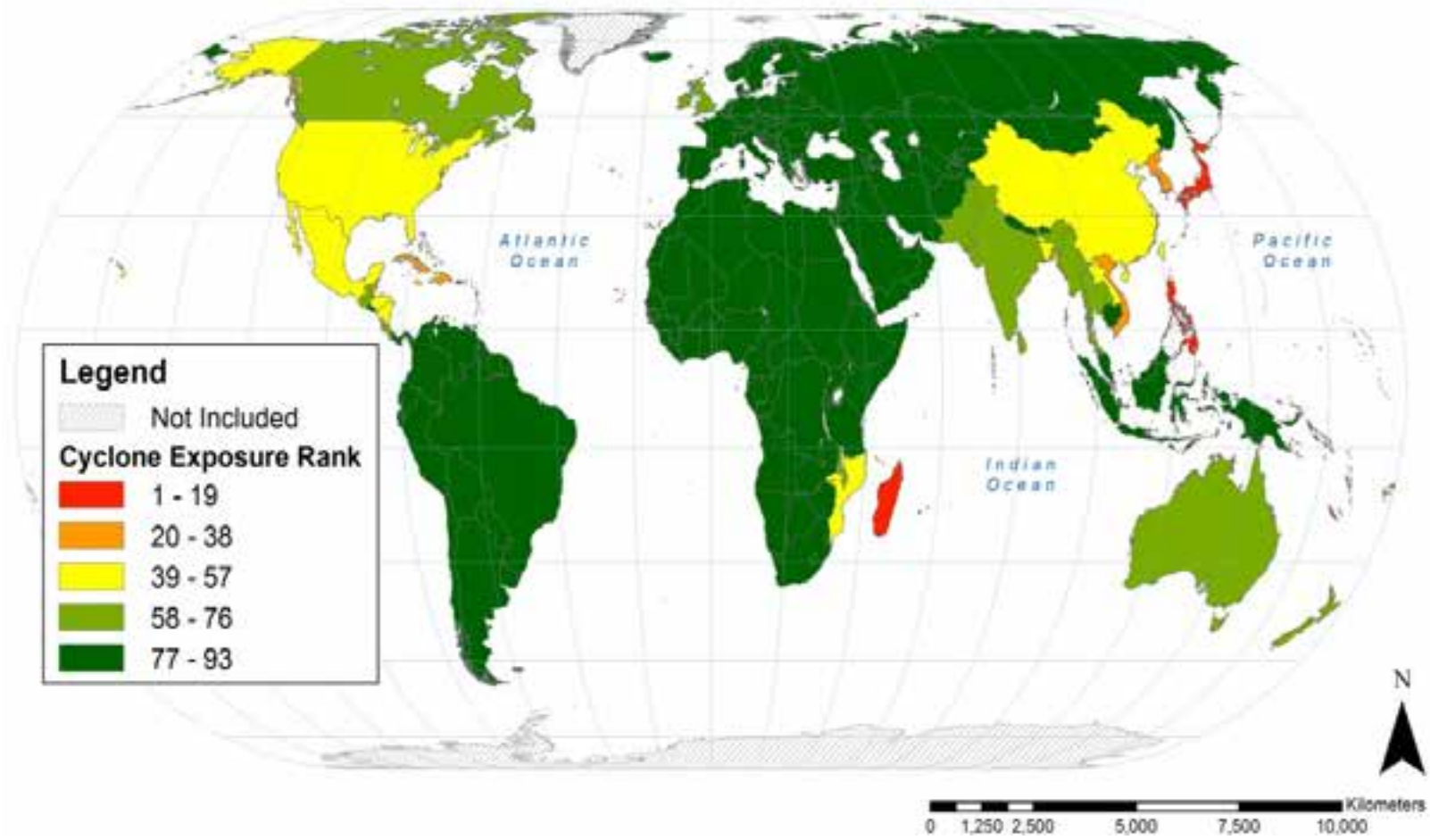
Selected Urban Area

Selected Rural Area

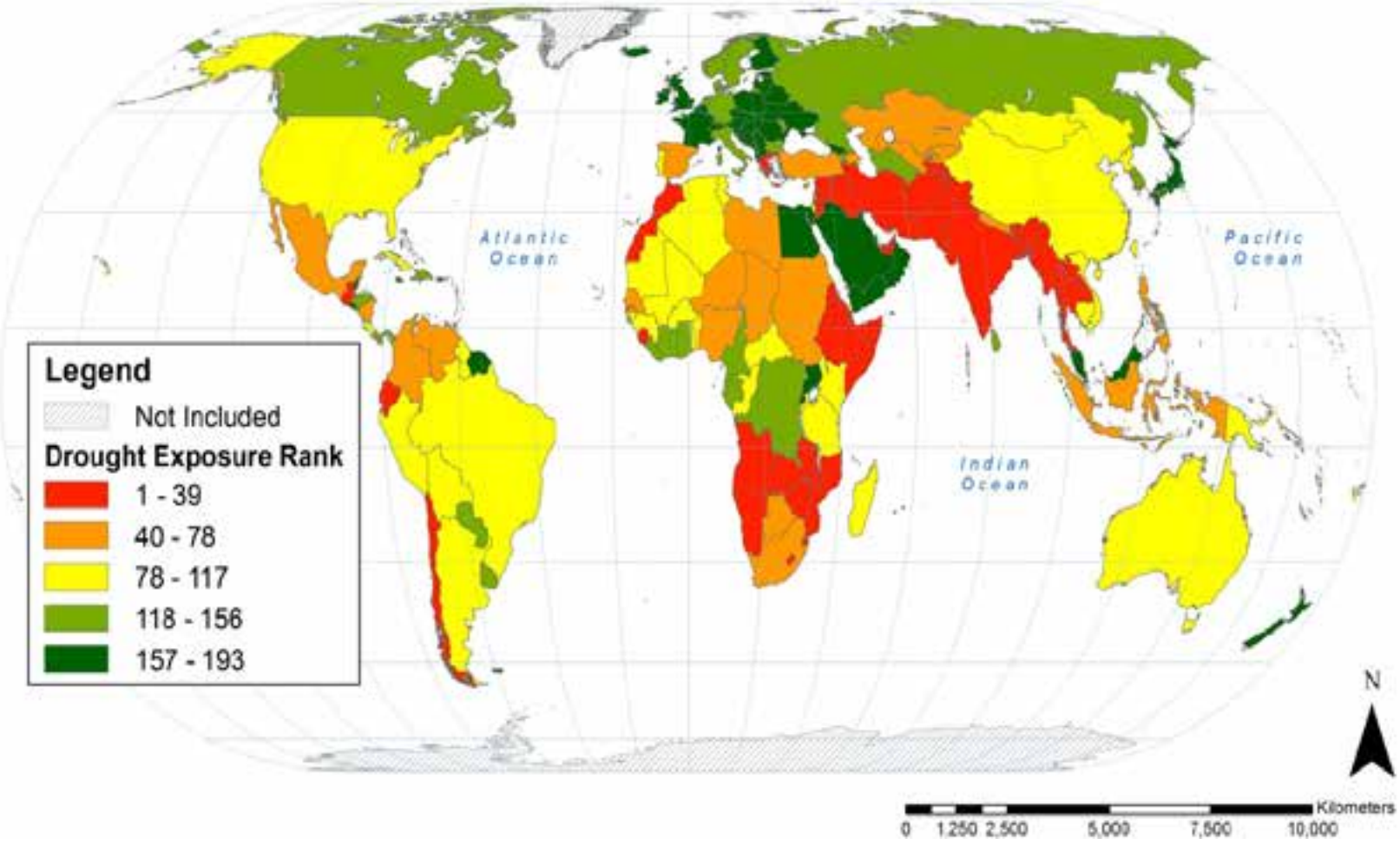
$$\frac{\sum \text{Population}_{cell} \times \sum H_{Drought,cell} + \sum \text{Population}_{cell} \times H_{Drought,cell}}{\text{Total Thailand Population}}$$



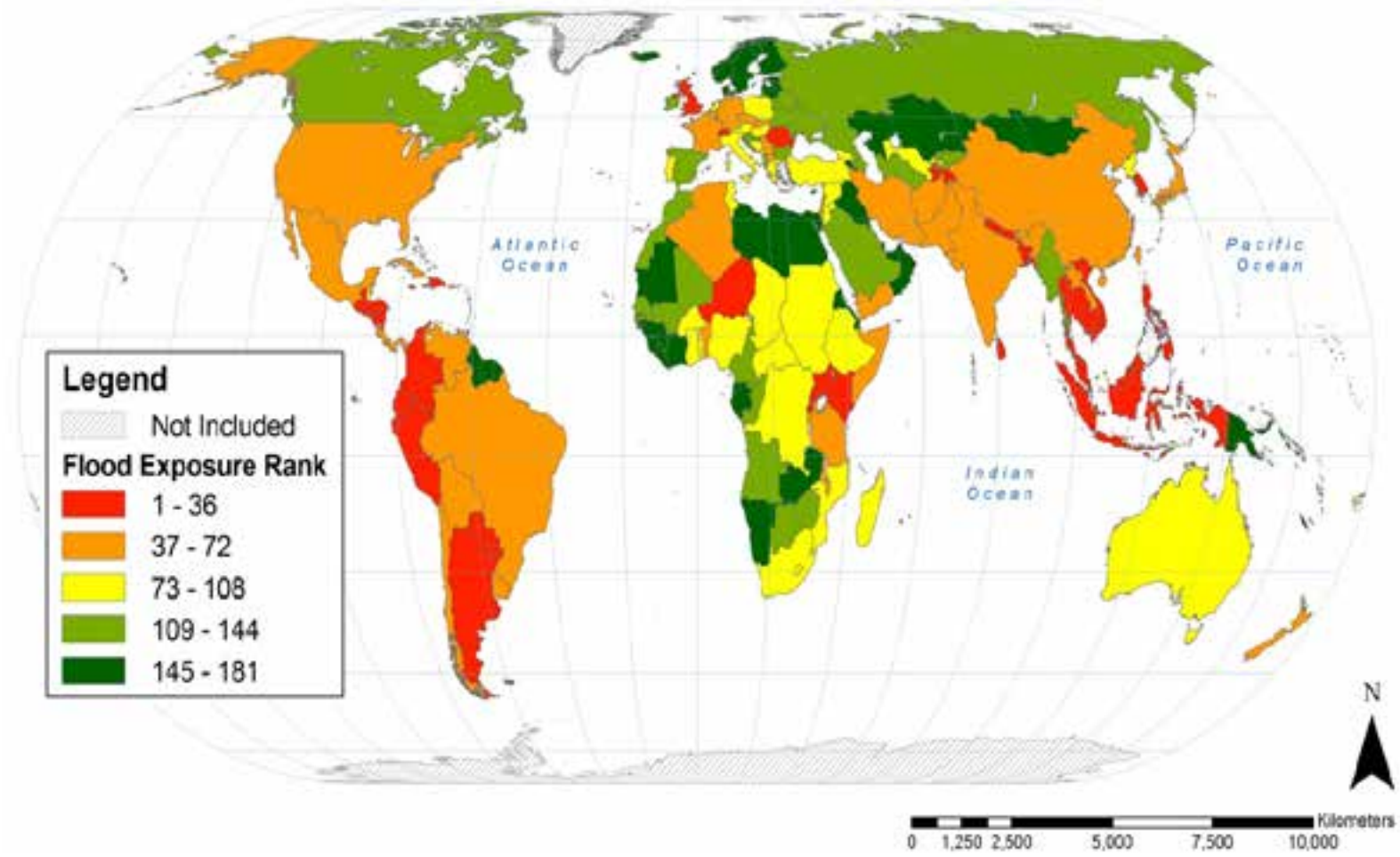
Average Cyclone Population Exposure



Average Drought Population Exposure



Average Flood Population Exposure



Limitations

- Hazard data is dependent on reported hazards
- Relative hazard frequency limited by ~20 year recording period
- Population data is modeled and uncertainty is dependent on resolution and age of census data
- Urban-rural binary definition

Next Steps

- Apply climate-related average population exposure results to specific vulnerabilities such as loss of drinking water
- Downscaling country-level exposure to regional models
  - Use higher resolution hazard data to validate whether differences in urban and rural exposure hold true at different spatial scales
- Urban-Rural gradient; identification of slums

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Thank you –
Elizabeth Christenson
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Questions?

Global Urban, Rural Average Exposure

- 40% higher global average exposure to cyclones for urban compared to rural
  - Cities and cyclones on coastlines
- 34% lower global average exposure to droughts for urban compared to rural
- No difference in global average exposure to flood
  - Many causes of floods (river vs. storm surge vs. snowmelt)