An aerial photograph of Freetown, Sierra Leone, capturing the city's dense urban sprawl. The buildings, a mix of colorful houses and larger apartment complexes, are built on a steep hillside, following the contours of the terrain. The city is surrounded by lush green vegetation, and a few roads are visible at the bottom of the hill.

Freetown - characterizing a city in a data sparse environment

12/03/2018

Team



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Pelagie Moudio

IEOR PhD

Freetown, Sierra Leone

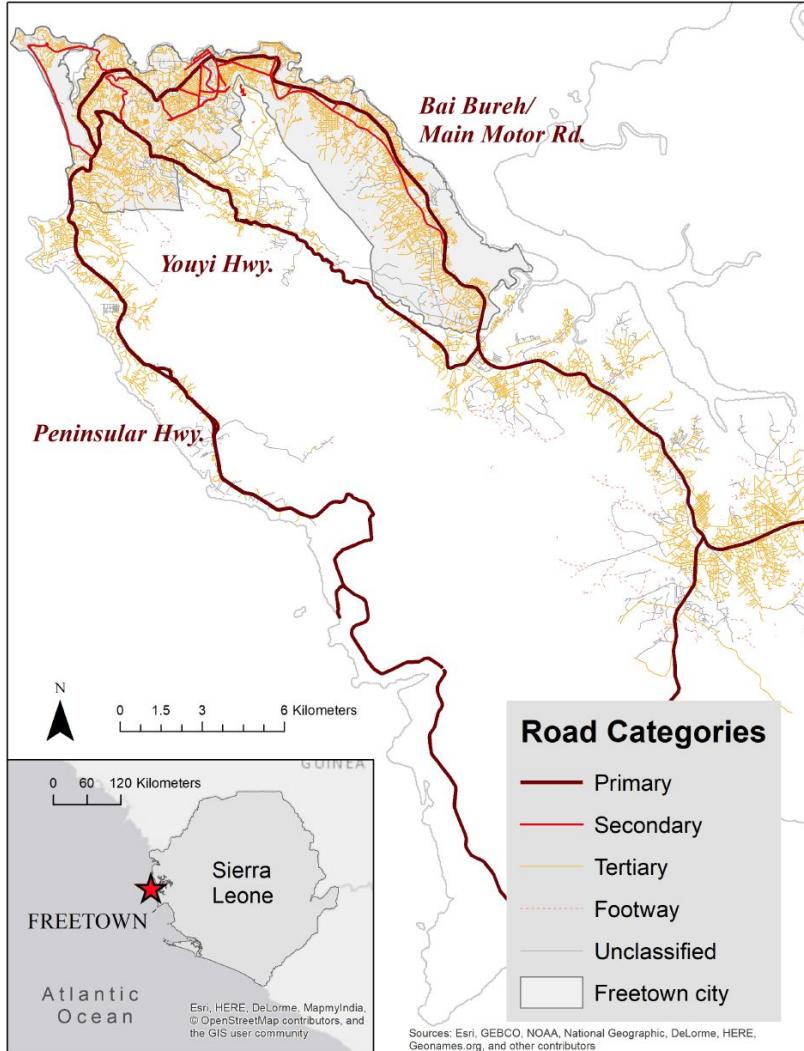
Freetown has a population of 802,639¹

One major coastal road with a smaller mountain bypass

One set of traffic lights in the city otherwise governed by traffic police

Few pedestrian facilities

Main modes - bus, poda poda, motorbike



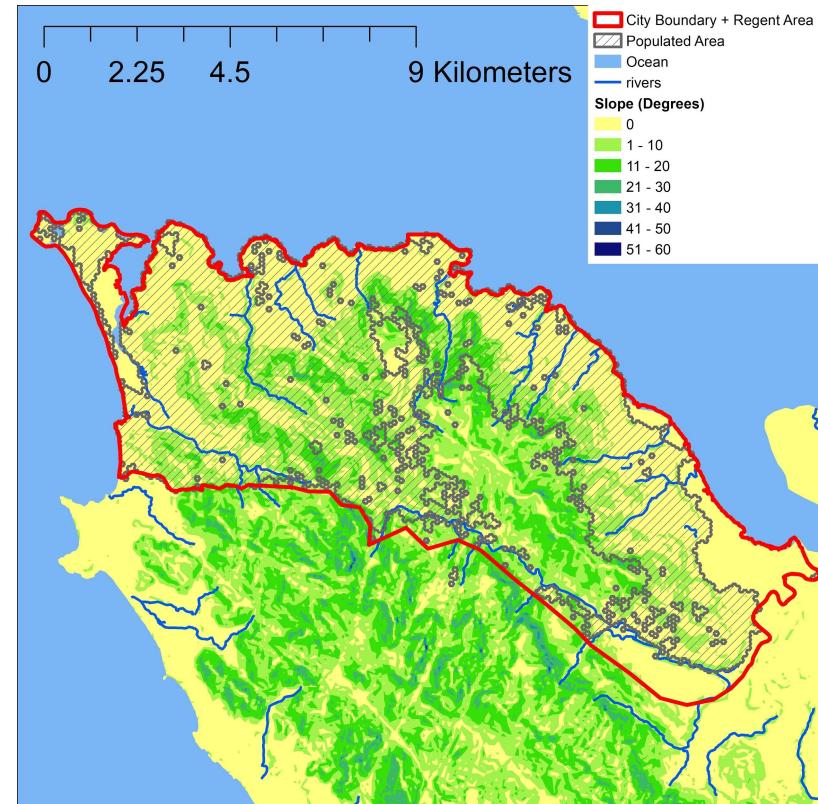
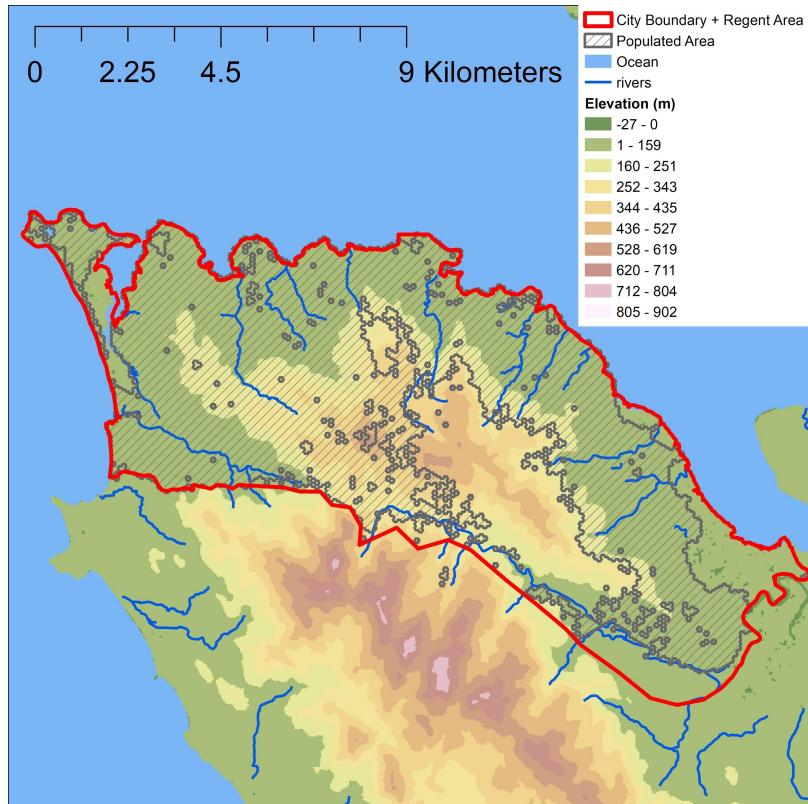
Motivation - Disaster in Freetown

August 2017 Landslide killed over 1,100 people, destroyed several km of roads and bridges

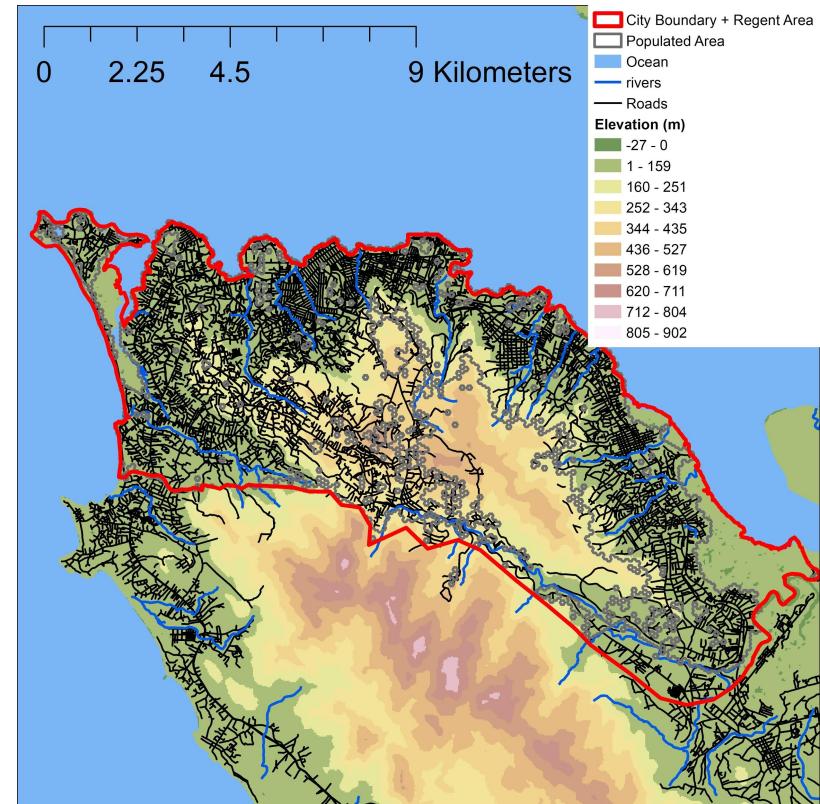
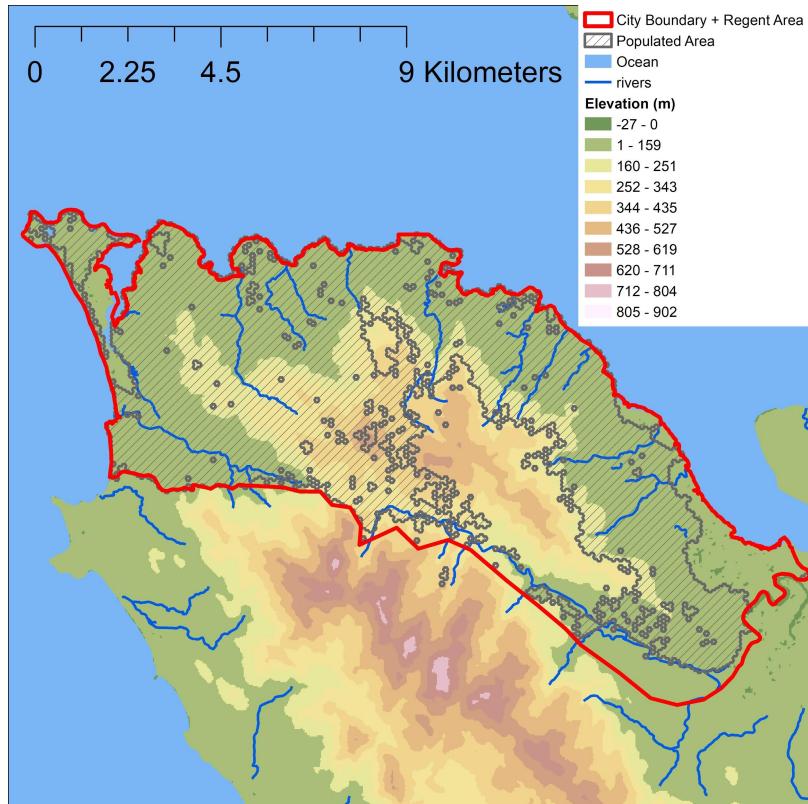
Causes:

- Seasonal rains, mudslides and floods
- Poor Infrastructure
- Low Elevation
- Deforestation for settlement

Freetown Geography - Settlement Patterns



Freetown Geography - Settlement Patterns



Description of Data

Three data sources:

- World Bank:
 - Population estimates from Arup building dataset (100m hexagons shapefile)
 - Administrative boundary (shapefile)
 - Cell Towers position (csv)
- Google Places API:
 - Scrapped POI, establishment type, position (csv)
- OSMnX:
 - Street network (graph/geodataframe)

Our data cleaning methods will be described in each section

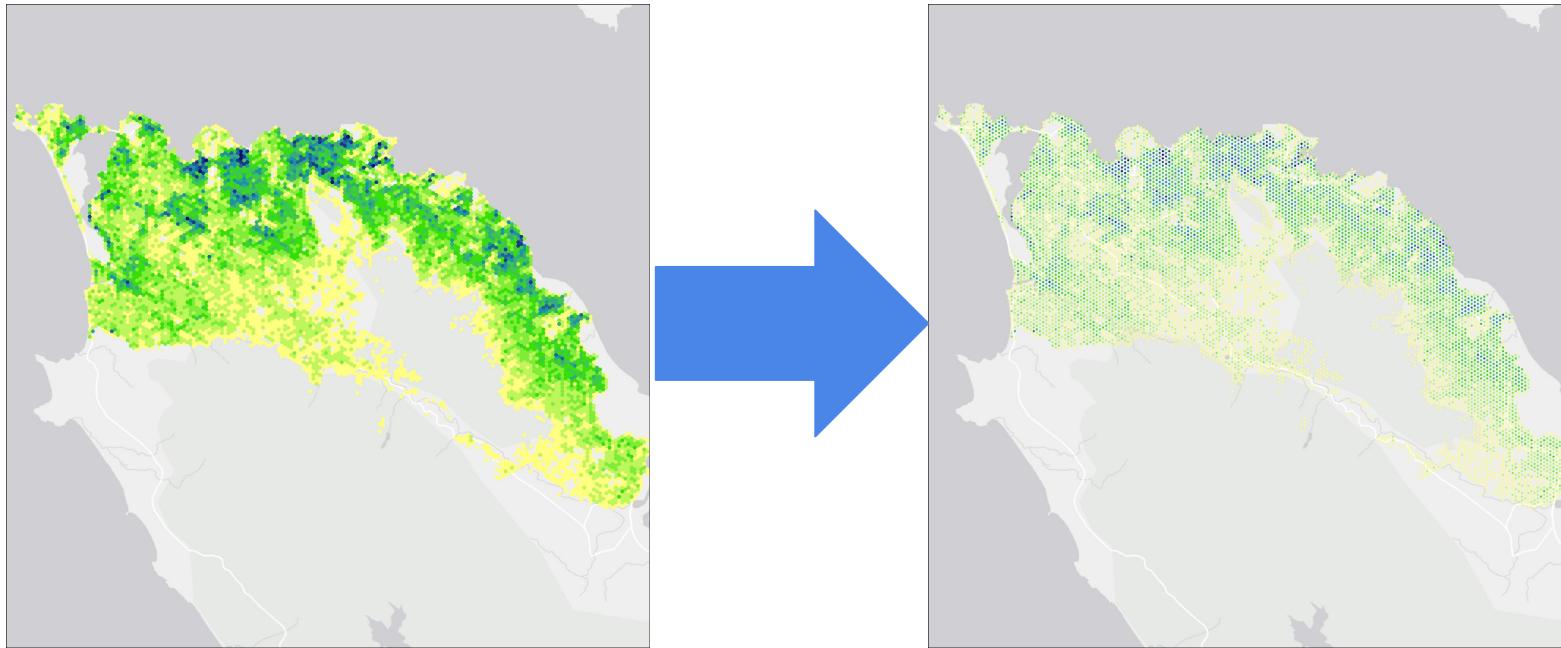
Urban form and WHERE people live



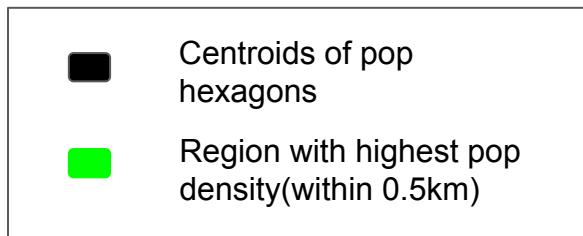
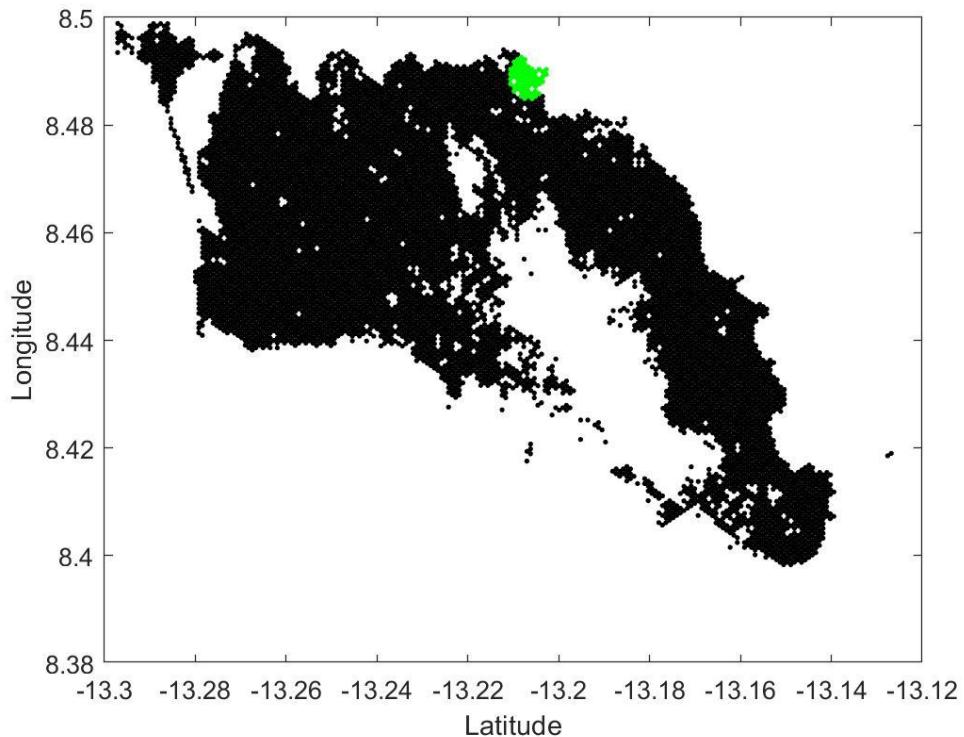
Data Cleaning - Percolation



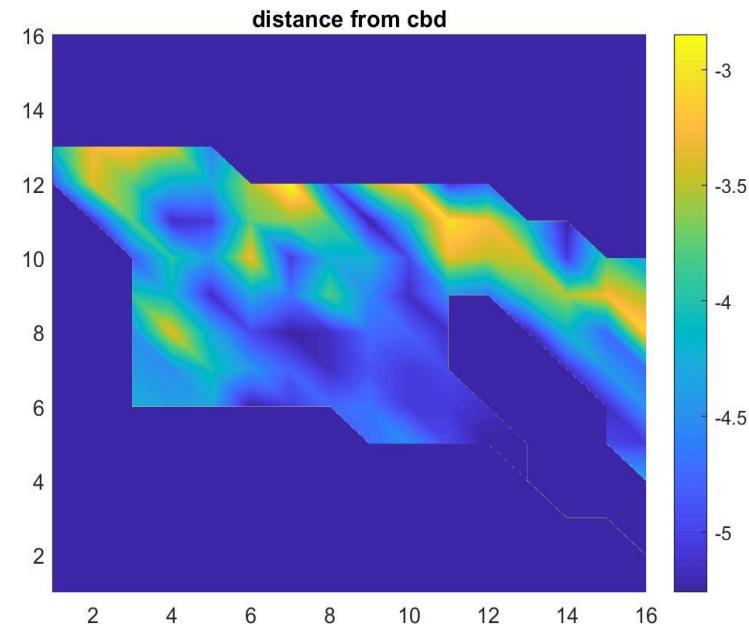
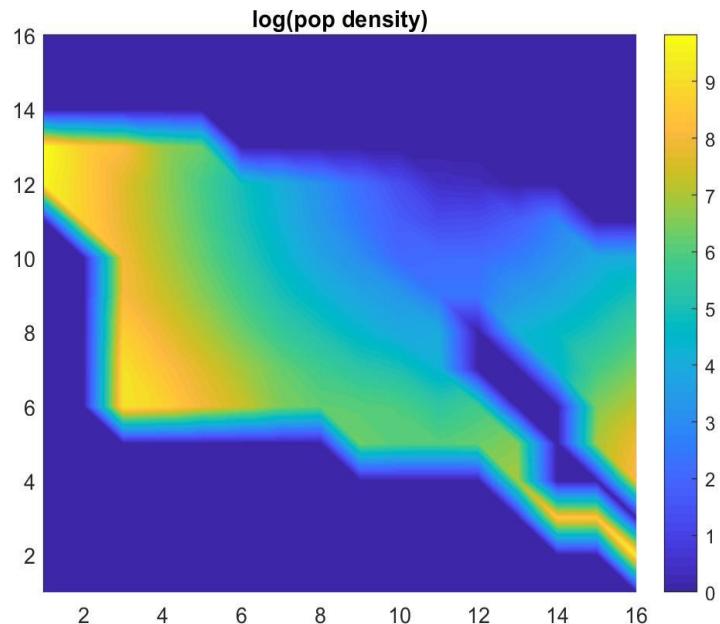
- Population hexagons shapefile aggregated to centroid points (ArcMap):



Freetown- Highest Population Density Region



Improper Resolution - using wrong dl



Percolation - Resolution Mapping

```
%%Transform Coordinates in pixels
LON=filtered_by_pop(:,1);
LAT=filtered_by_pop(:,2);
DAT=filtered_by_pop(:,3);
DIST=filtered_by_pop(:,4);
dl=0.001 % (minimun resolution between two points)
%pixlatrow=(LAT-min(LAT))/dl;
%pixloncol=(LON-min(LON))/dl;
R = makerefmat(min(LON),min(LAT),dl,dl); %%matlabfunction
[pixlatrow, pixloncol] = latlon2pix(R,LAT,LON); %%
figure
plot(pixloncol,pixlatrow,'.');
title('First Matrix with Pixels')
range=180; %decide matrix size based on resulting pixels
```

Estimated dl = 0.001

Lat Diff	Lon Diff
0.0018	0.0000
0.0009	0.0000
0.0009	0.0000
0.0018	0.0000
-0.0049	-0.0008
0.0009	0.0000
0.0009	0.0000
0.0009	0.0000
-0.0013	-0.0008

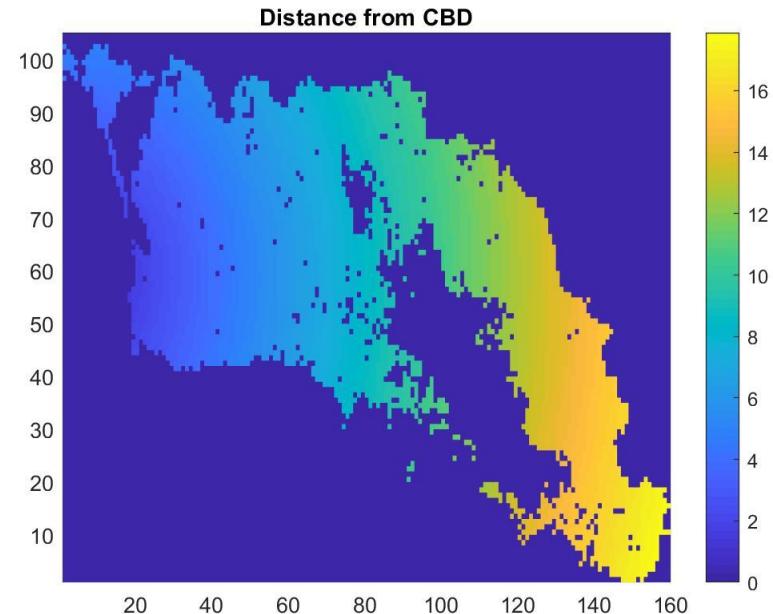
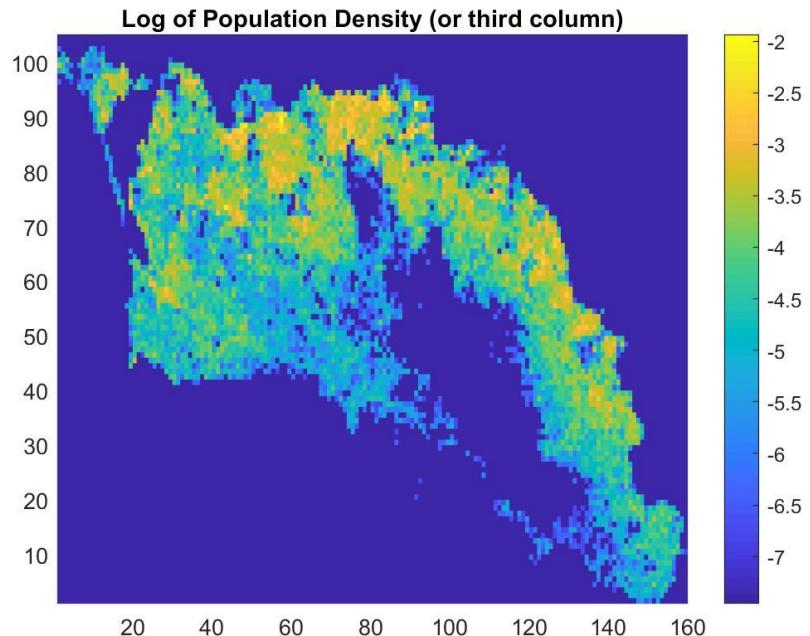
How to estimate dl

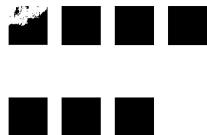
- Order longitudes
- Difference between adjacent LAT(Lat Diff) and adjacent LON (Lon Diff)
- dl = average Lat Diff

Same calc can be done by ordering latitudes instead

$dl = 0.001$

Percolation- Conversion to Pixel Images



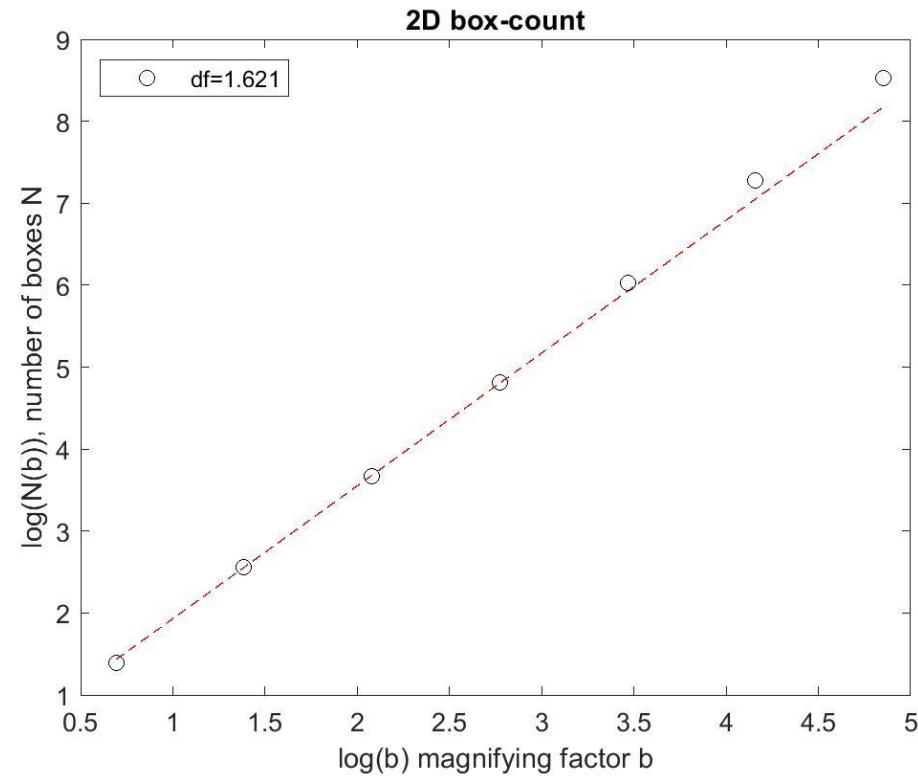


Fractal Analysis - Box Counting

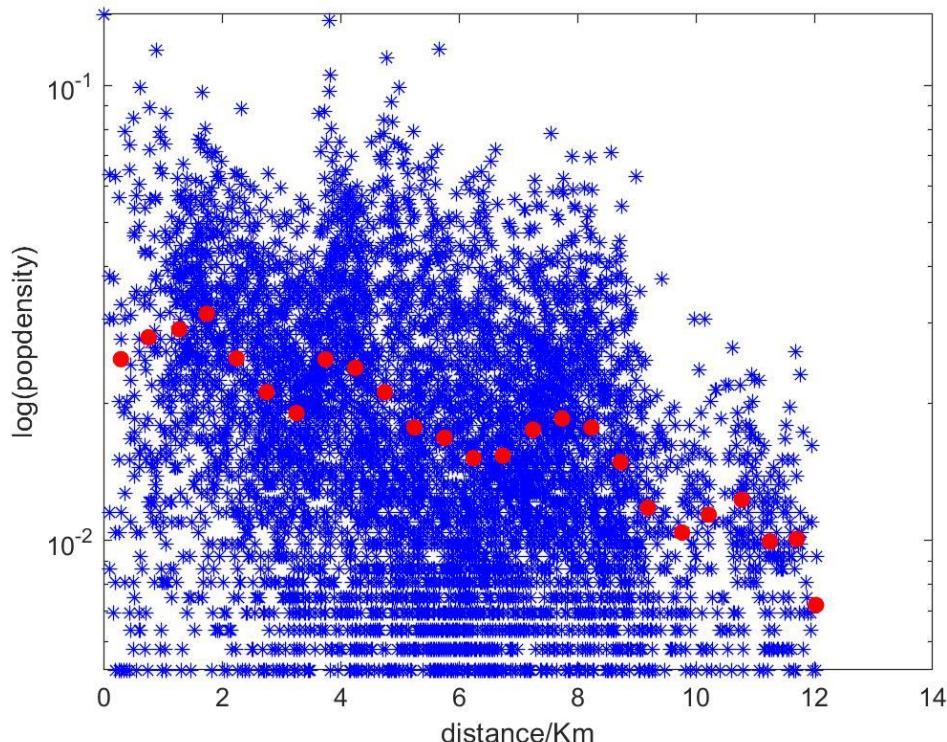
Box Counting : width = 128

2	->	4
4	->	13
8	->	39
16	->	123
32	->	413
64	->	1442
128	->	5044

Fractal Dimension = 1.621



Semilog Plot of Pop density of occupied area



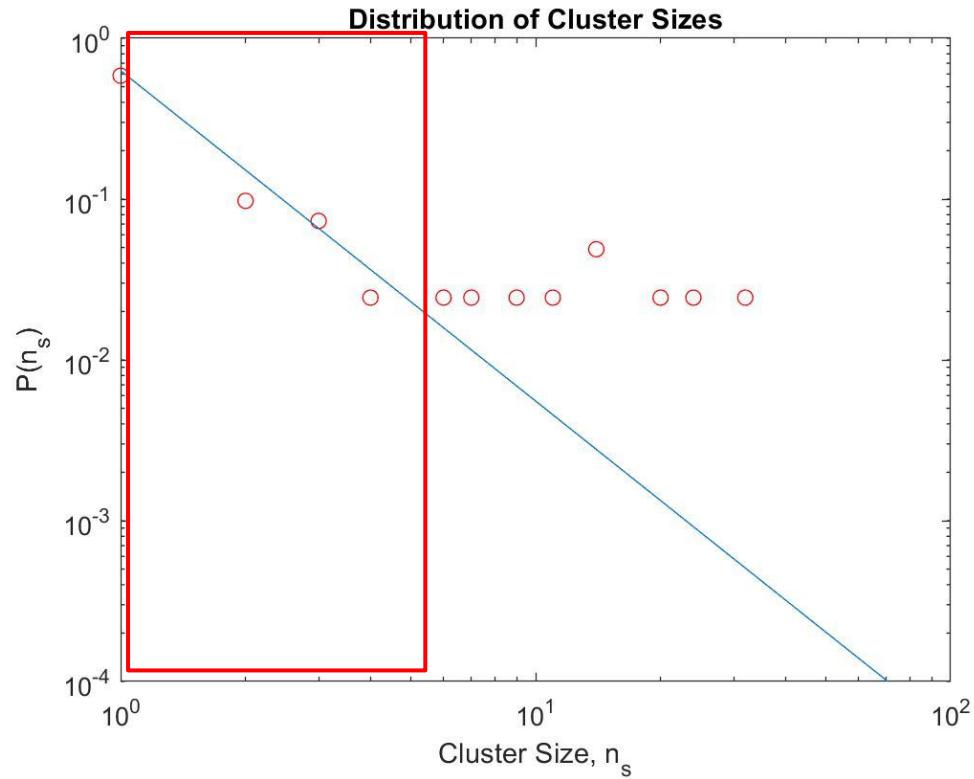
pop density $\geq .005$ people/m²

Cluster Size Distribution

$$N(A) \equiv \int_0^{p_c} n(A, p) dp \sim A^{-(\tau + 1/d_f \nu)}$$

Tau = 187/91 (theoretical value)

Does not exactly follow conventional power law



Describing Freetown's Urban Form

Alain Bertaud "The Spatial Organization of Cities: Deliberate Outcome or Unforeseen Consequence?" January 2004. Working Paper. IURD (Berkeley)

3 primary aspects of urban spatial structure

1. Daily trip pattern
2. Average built-up density
3. Density profile and density gradient

Daily trip pattern typologies

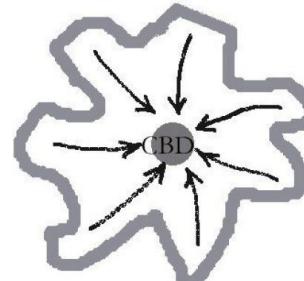
As cities grow, the original monocentric structure tend to transform into polycentric

Circumstances can accelerate or hold back the transition e.g. CBD with more/less amenities, topography, radial vs grid road networks

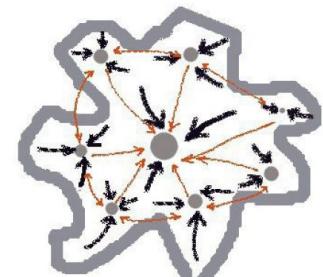
Trips in polycentric cities tend to be longer

Polycentric has gradient from the center of gravity rather than highest density point

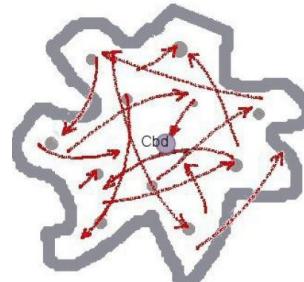
Schematic Representation of Trip Patterns within a Metropolitan Area



(a) The monocentric model

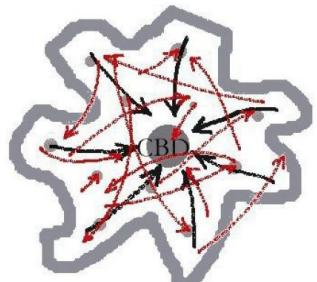


(b) The polycentric model:
The urban village version



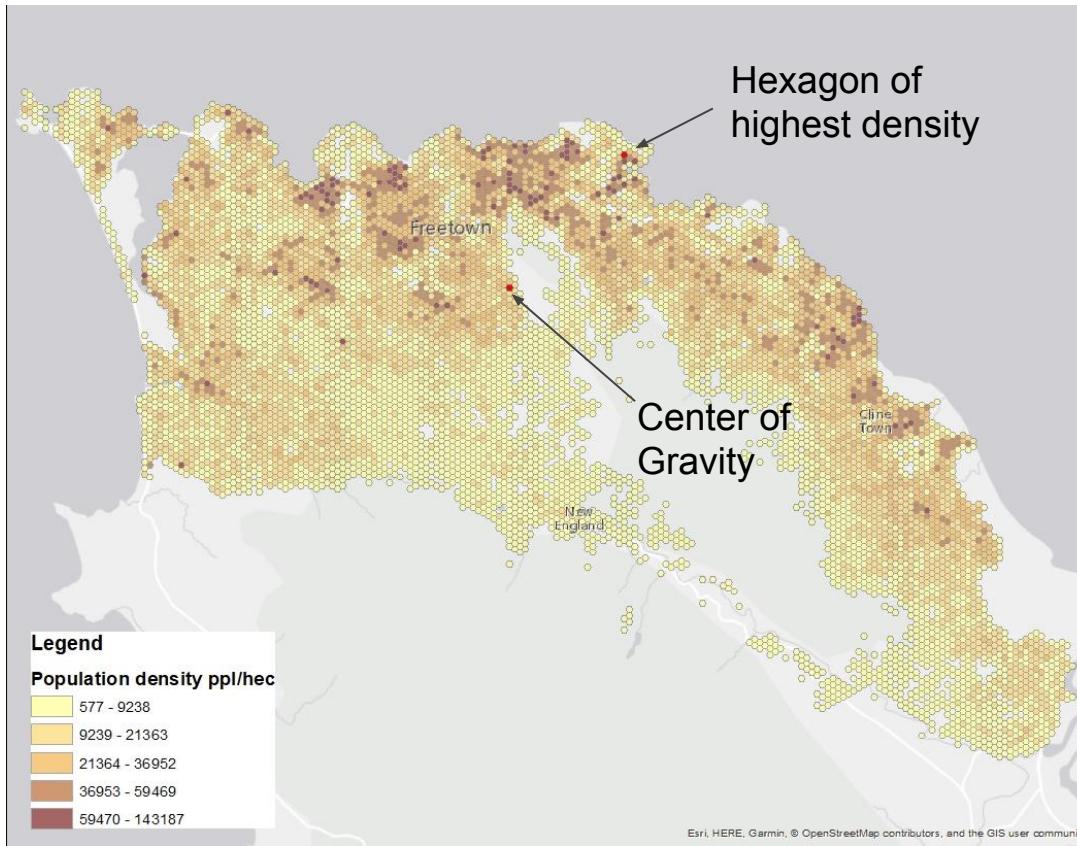
(c) The polycentric model:
The random movement version

— weak links
→ strong links



(d) The mono-polycentric model:
Simultaneous radial
and random movements

Daily trip pattern



Land consumption - density of the built up area

Sprawl as land consumption → inverse of pop density

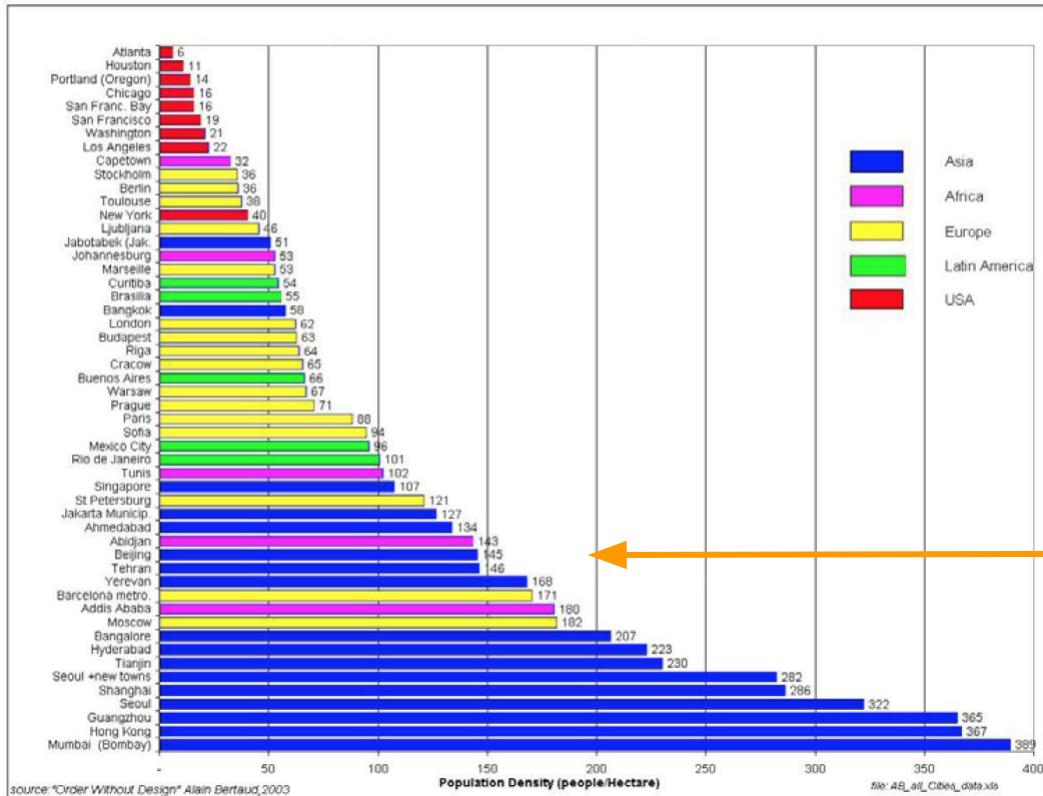
Area of land / population → Population / area of land

Density NOT correlated with income

population size

Average density of built up area

Figure 3. Average Population Densities in Built-up Areas
in 49 Metropolitan Areas



Can't compare Cities to
Metropolitan areas!

Without Metropolitan data on the
Freetown area, not as useful in
our analysis

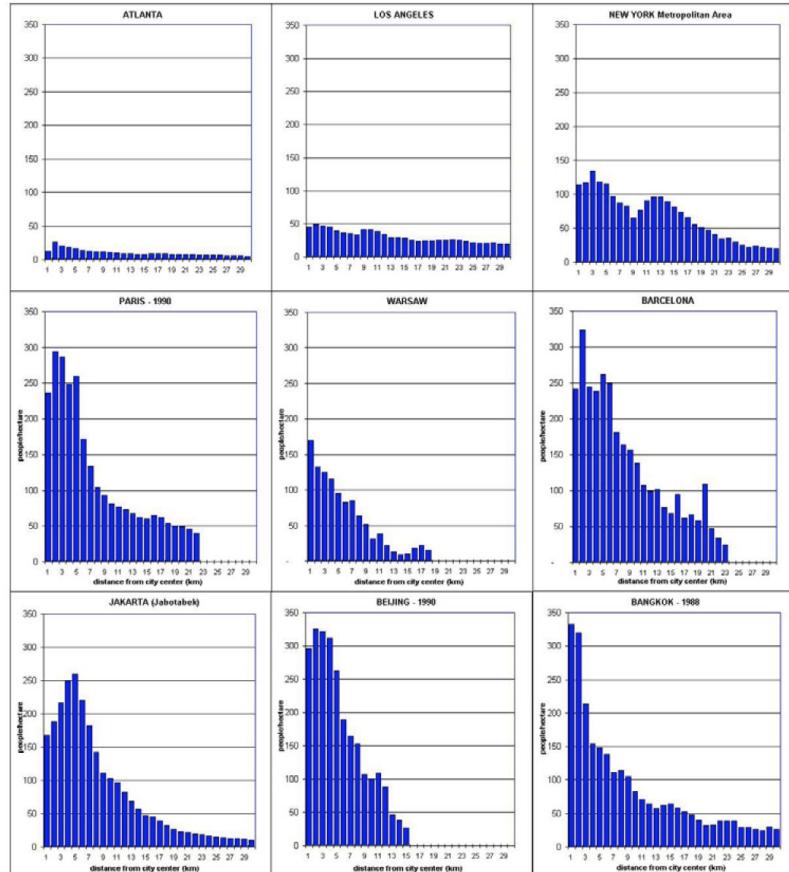
Freetown urban density
153 people/hectare

Density Profiles

Most cities follow a negative exponential curve

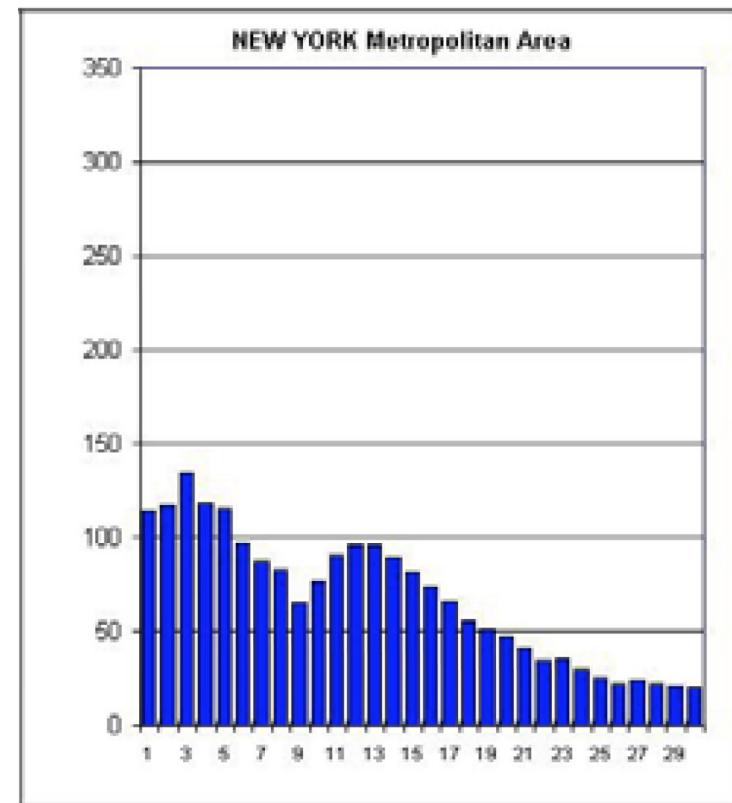
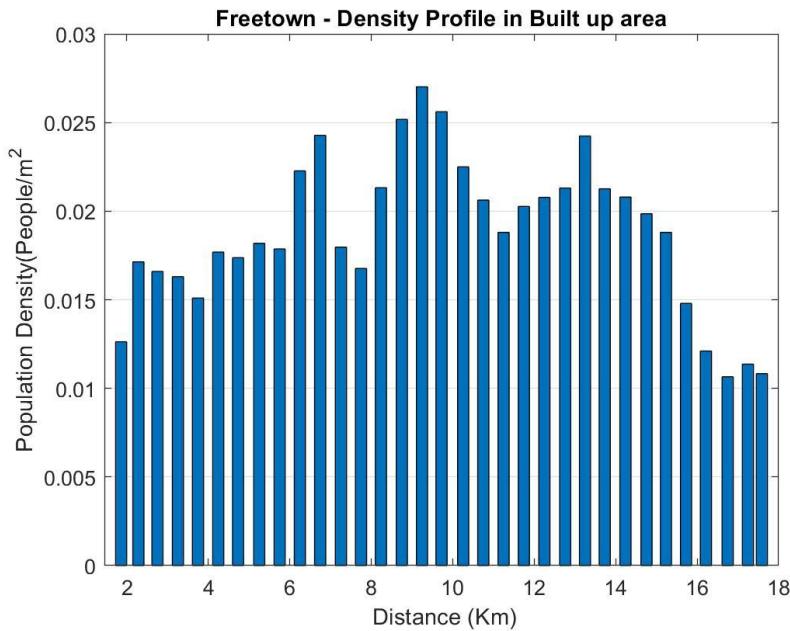
Market forces increase land value around CBD so higher density

Monocentric - higher density close to CBD



from "Order Without Design". Alain Bertaud, 2002

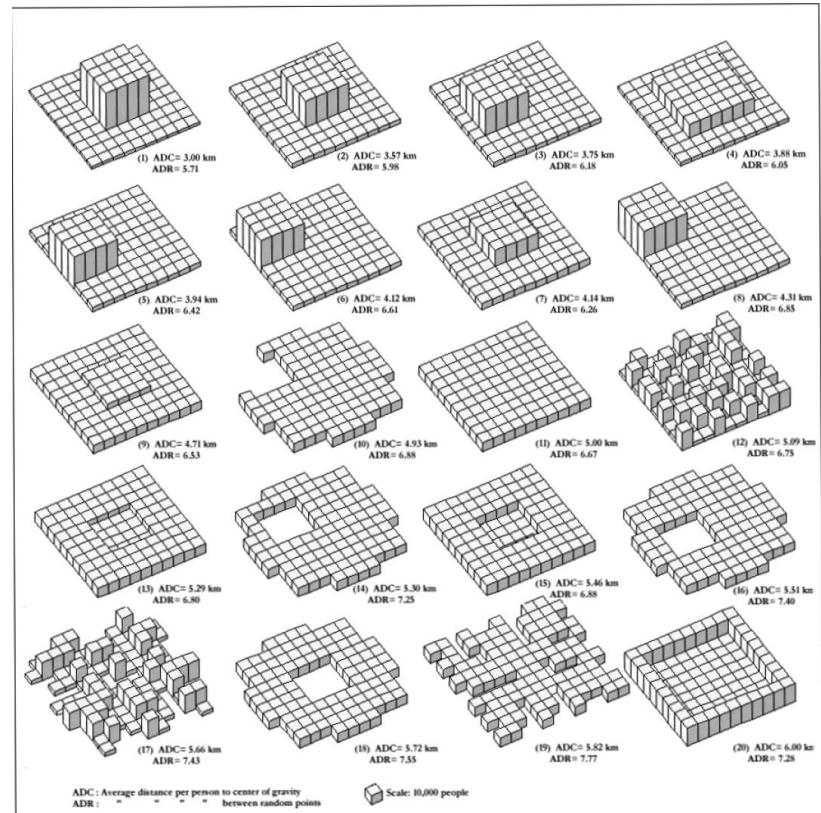
Closest match - New York Metropolitan Area



Distribution of density

Distribution of local densities determines length and cost of trips

2 characteristics - average distance to the centroid and average distance to a random person



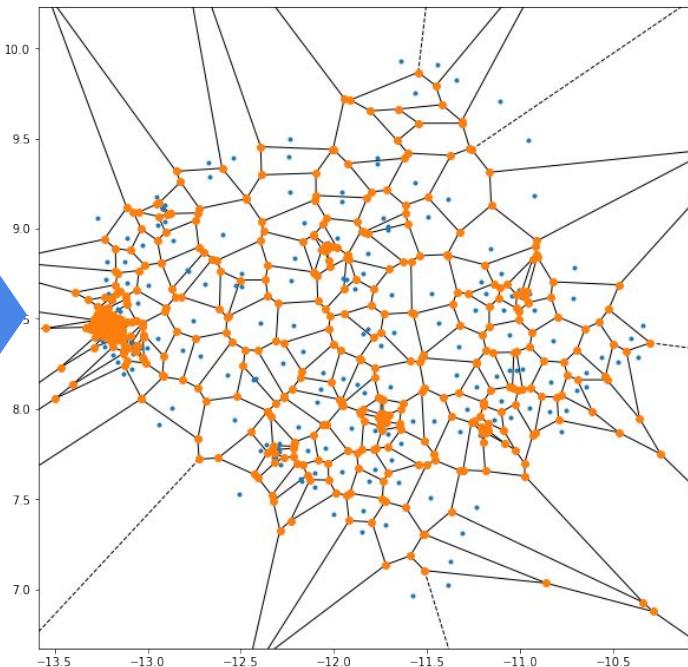
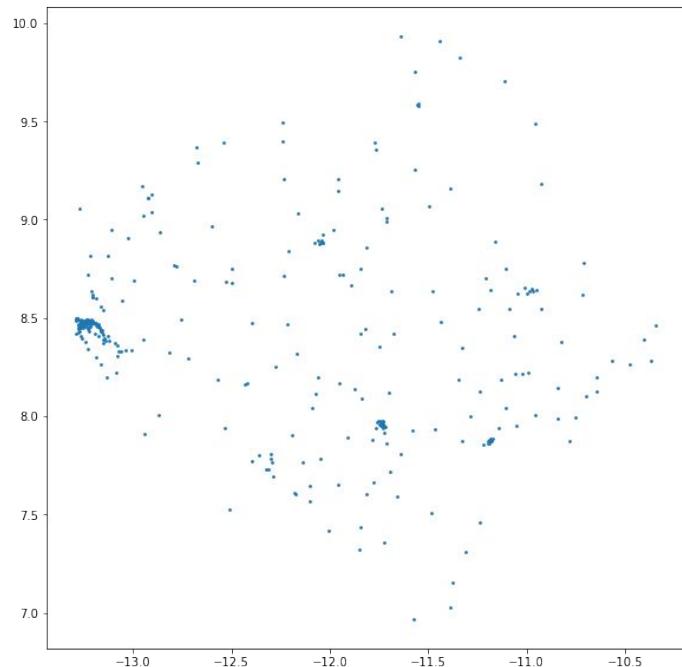


**Urban form
and WHERE
people live**

**Where are they
traveling?**

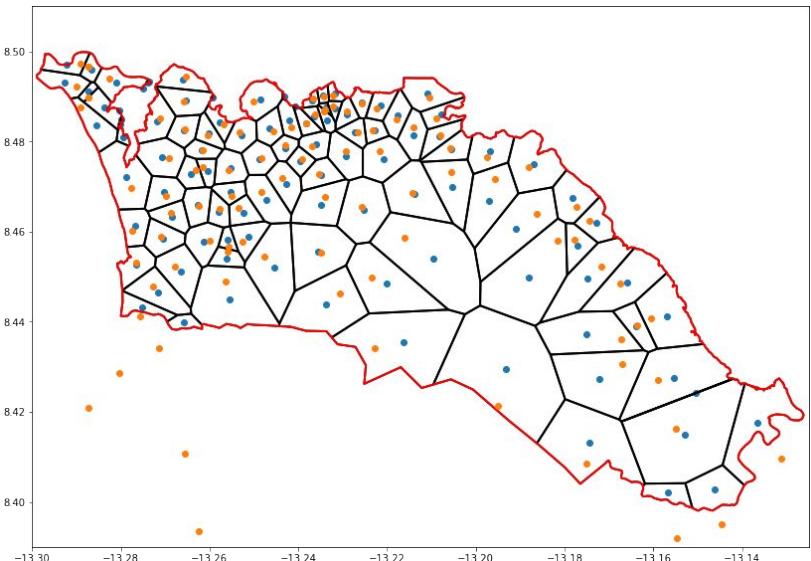
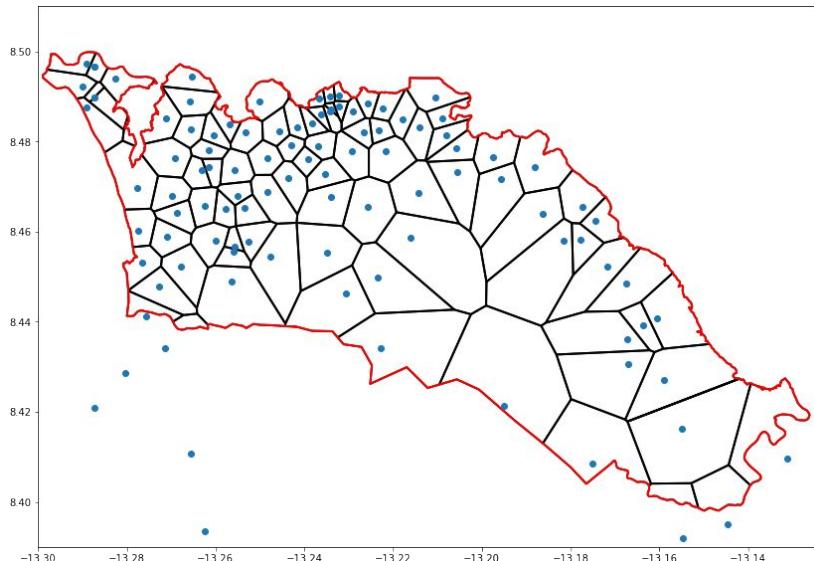
Data Cleaning - Trip Generation

- Generate voronoi diagram based on cell tower positions (Python3):



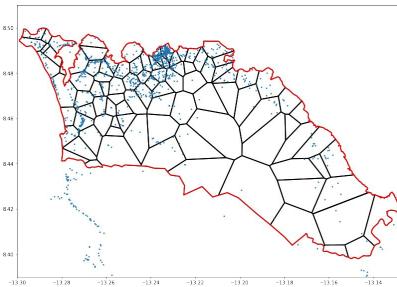
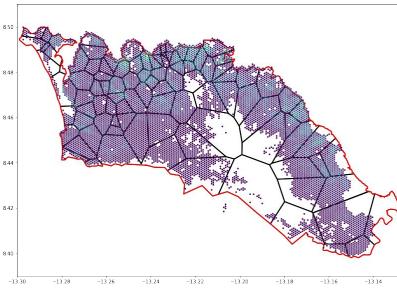
Data Cleaning - Trip Generation

- Clip to administrative boundary, calculate centroids (Python3):

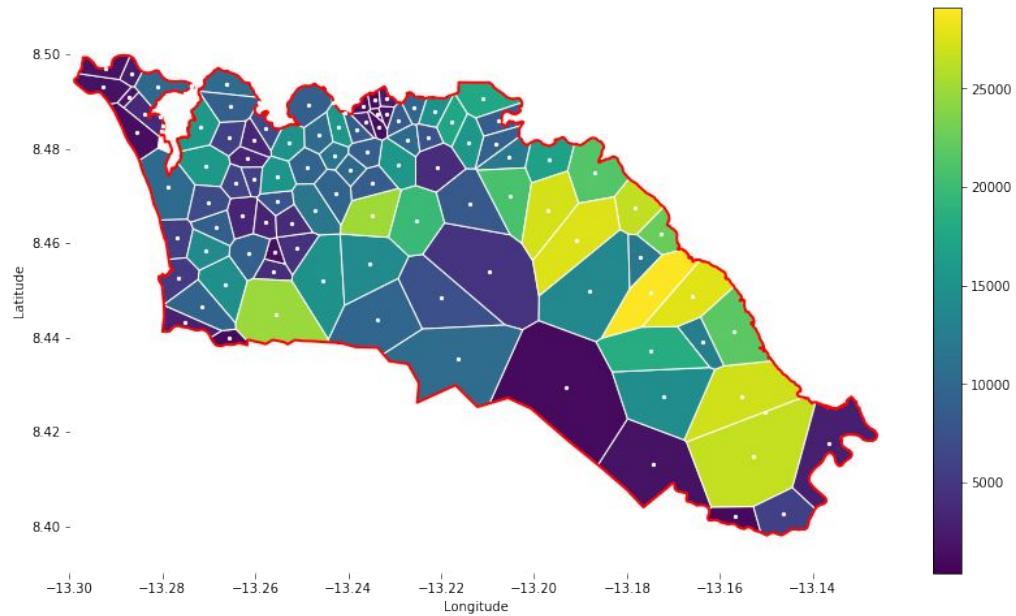


Data Cleaning - Trip Generation

- Aggregate population and POI data to voronoi polygons, map to centroids (Python3):

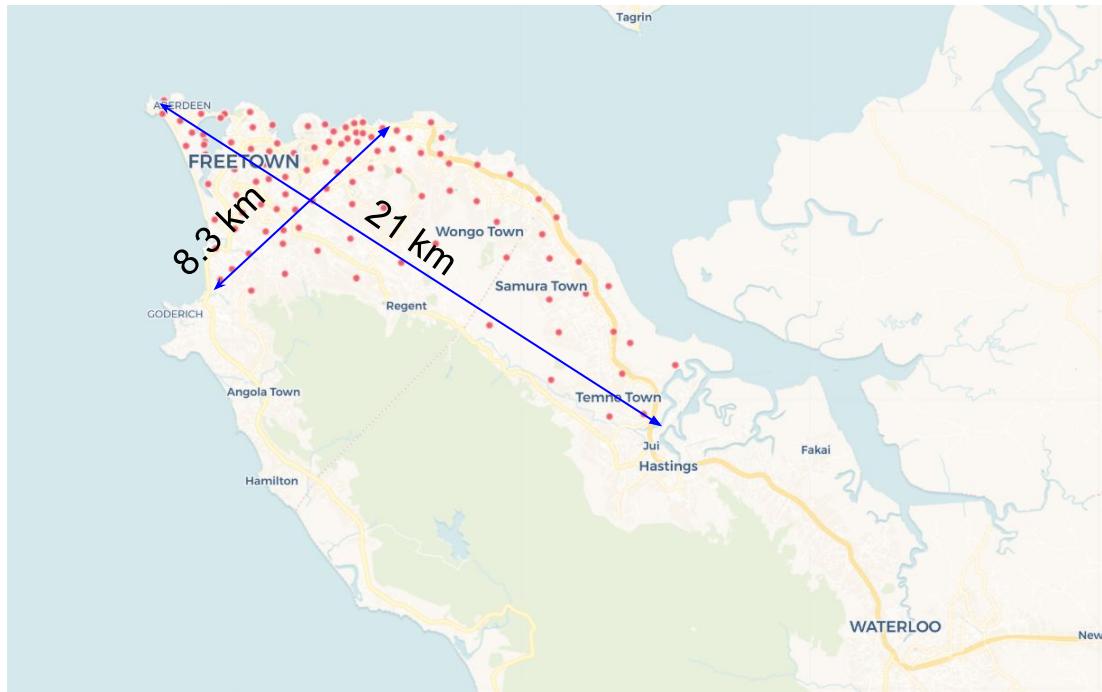


Freetown, Sierra Leone - Population by Orange Cell Tower Thiessen Polygon



- Process in MATLAB

Generate OD Matrix - Extended Radiation Model



Model based on population and POI of the area

Model Parameters:

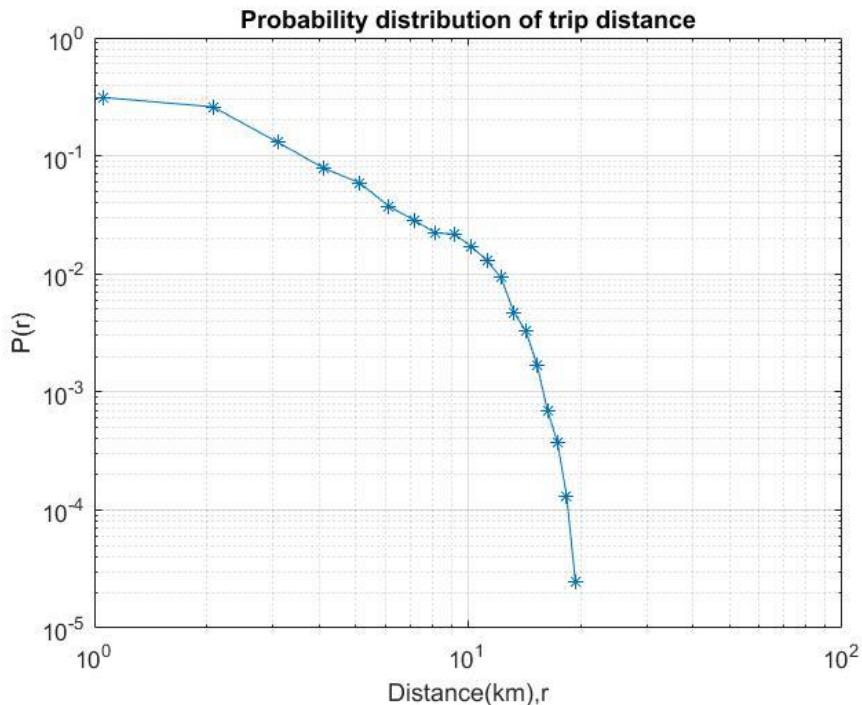
Model based on population and POI of the area

Resolution is so high , so alpha value is low.

$$\alpha = \left(\frac{l}{36[\text{km}]} \right)^{1.33}$$

alpha=0.0053

Trip distance probability distribution

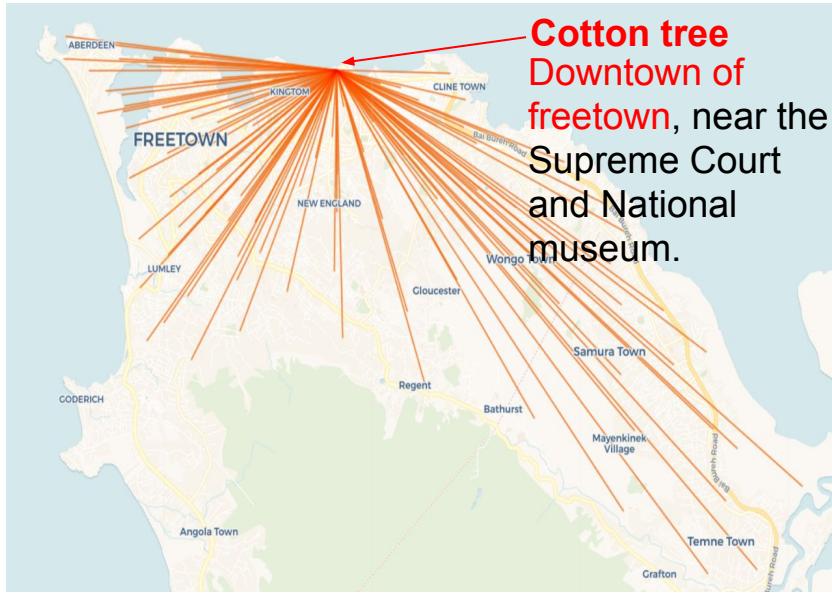


Comment:

- Probability is high when the trip distance is **within 3 km**.
- However, with the increase of trip distance, probability began to decrease.
- After **trip distance exceeds 10 km**, probability begin to drop dramatically.

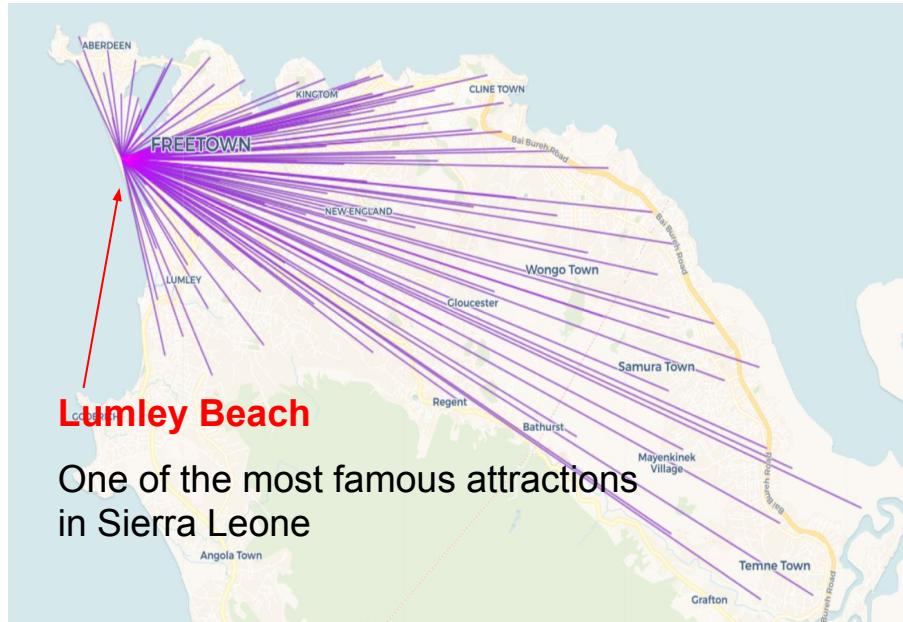
Place where most trips depart from

Location: Latitude-8.476458, Longitude--13.283681



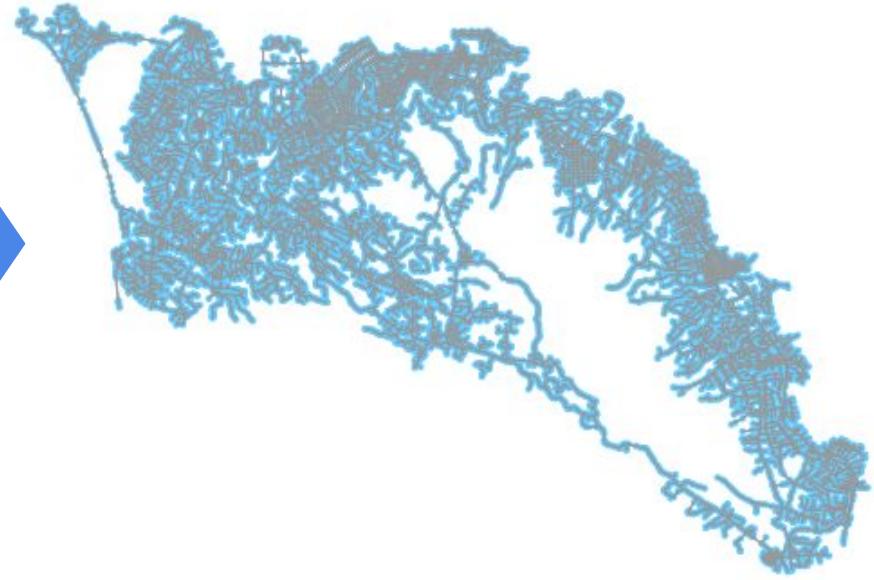
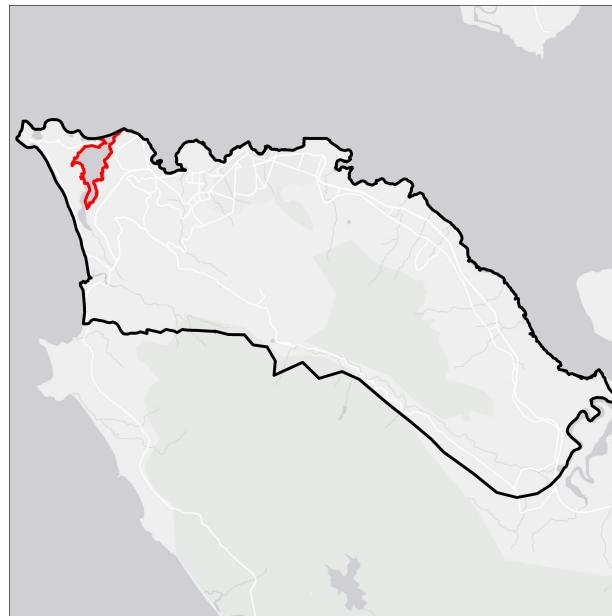
Place receiving the most trips

Location: Latitude-8.476458, Longitude--13.283681



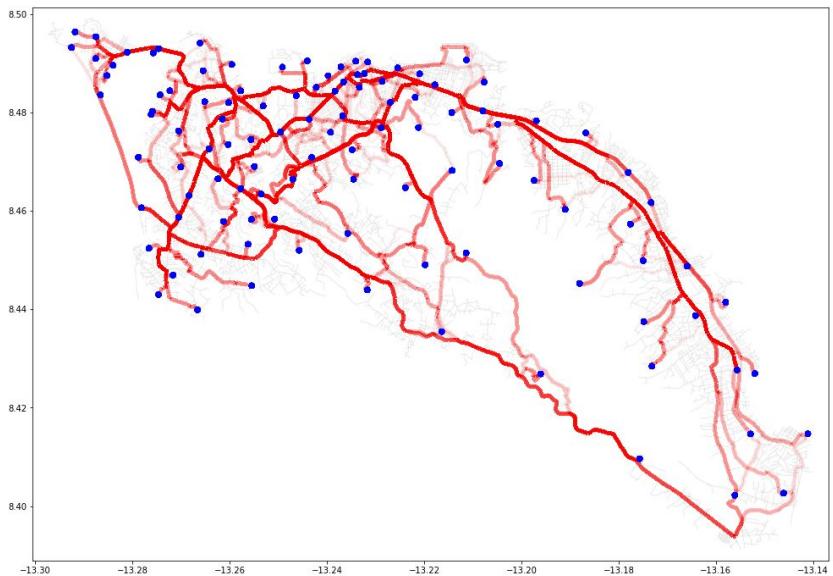
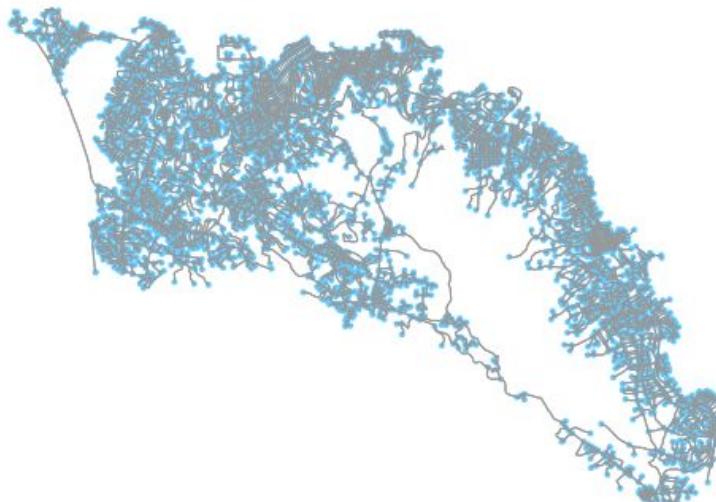
Data Cleaning - Network

- Edit administrative boundary to incorporate bridges (ArcMap), use geometry to access graph from OSMnX (Python3):



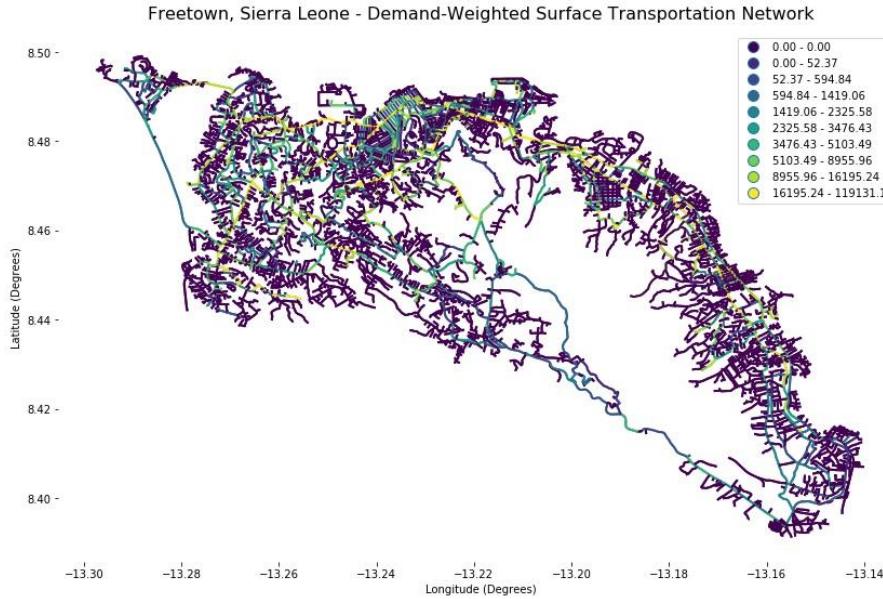
Data Cleaning - Network

- Use simplified OSMnX graph to calculate nearest nodes to each centroid position and routes for OD pairs based on dijkstra shortest paths (Python3):



Data Cleaning - Network

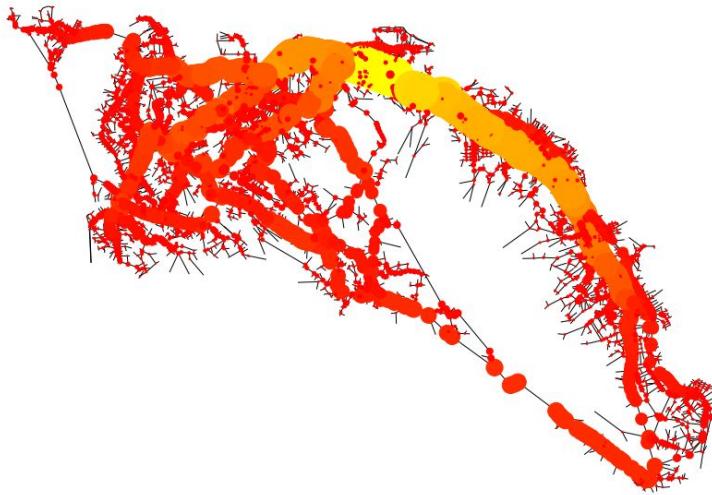
- Add weights to each link by looping through node pairs identified in each route and adding calculated trips (Python3)



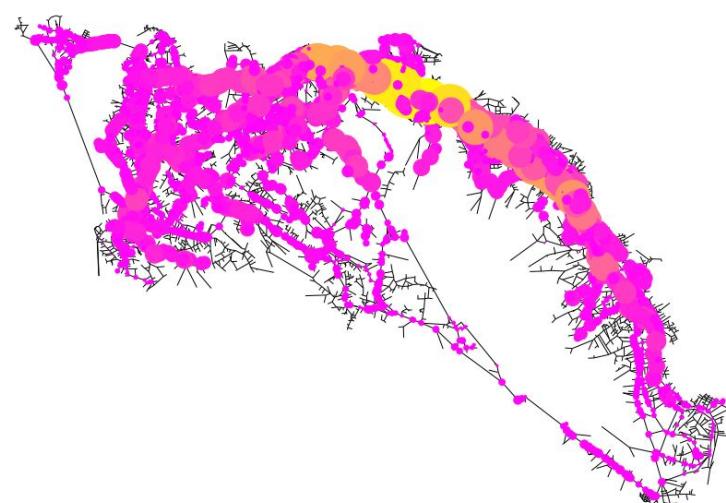
Data Cleaning - Network

- Export OSMnX graph nodes and links to GeoDataframe (Python3), use networkx to calculate centrality measures, create GeoDataframes for data analysis and visualization (Python2):

Betweenness Centrality



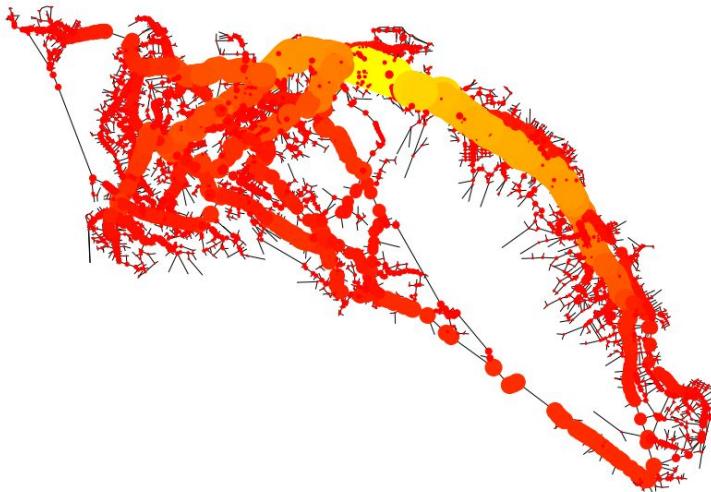
Weighted Degree Centrality



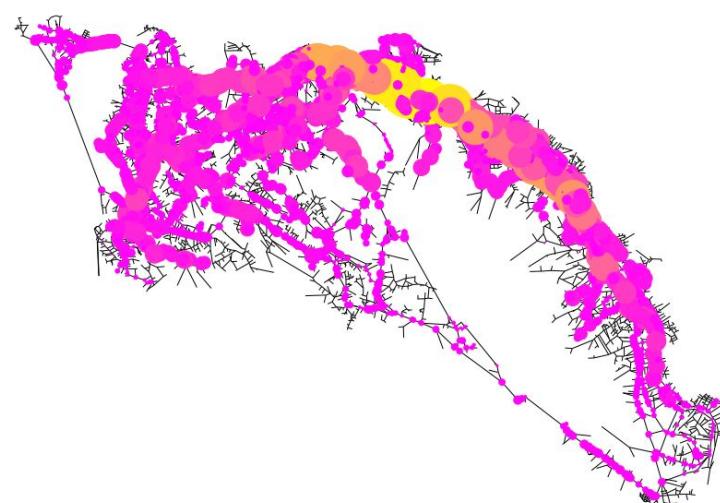
Analysis - Network

- Based on “The worldwide air transportation network” by Guimera et al., we sought to characterize roads by the relationship of betweenness centrality and weighted degree centrality

Betweenness Centrality



Weighted Degree Centrality



Analysis - Network

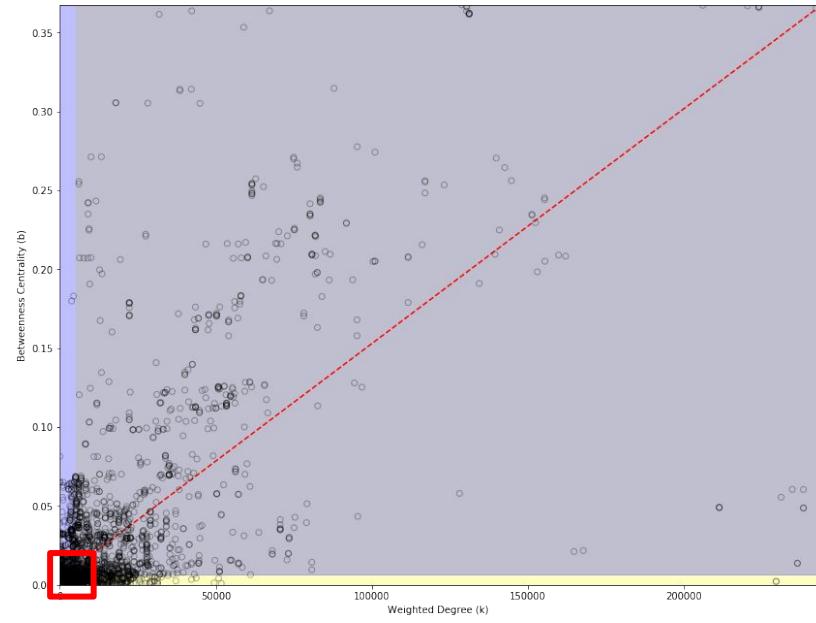
Nodes = 7,118

Edges = 8,747

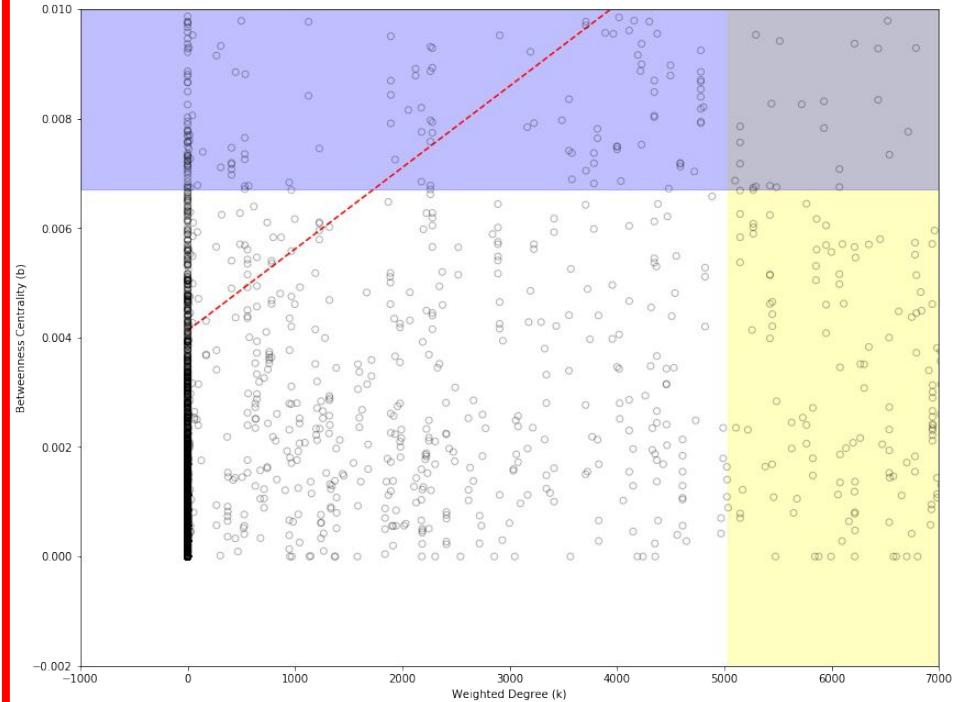
	Betweenness Centrality (b)	Weighted Degree (k)
min	0	0
.25 quantile	0	0
.5 quantile	0.001	0
.75 quantile	0.007	5,027.263
max	0.368	242,318.449
mean	0.014	6,882.069

Analysis - Network

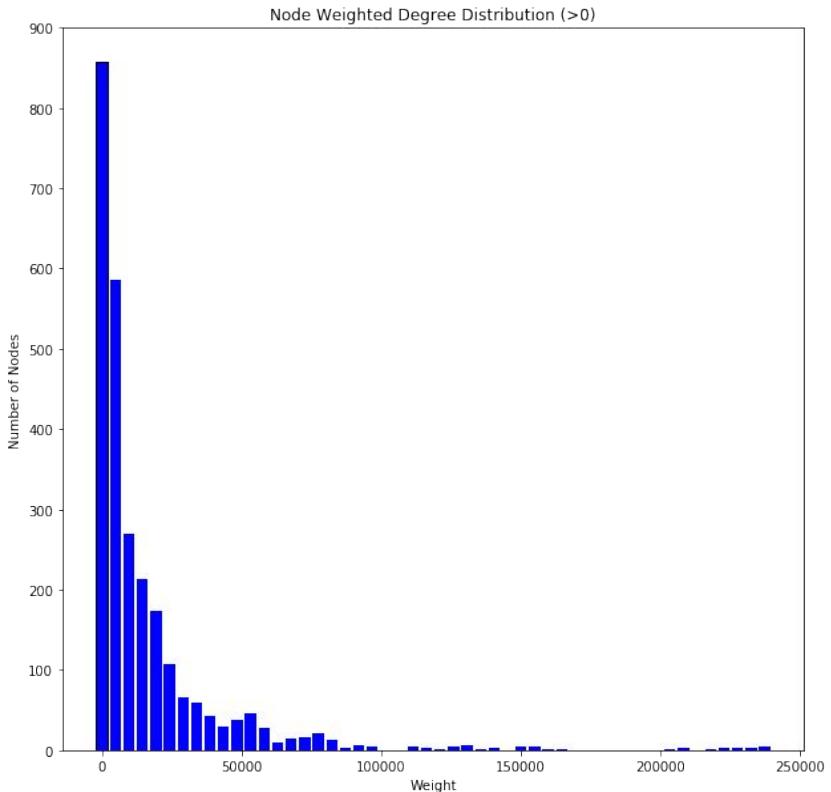
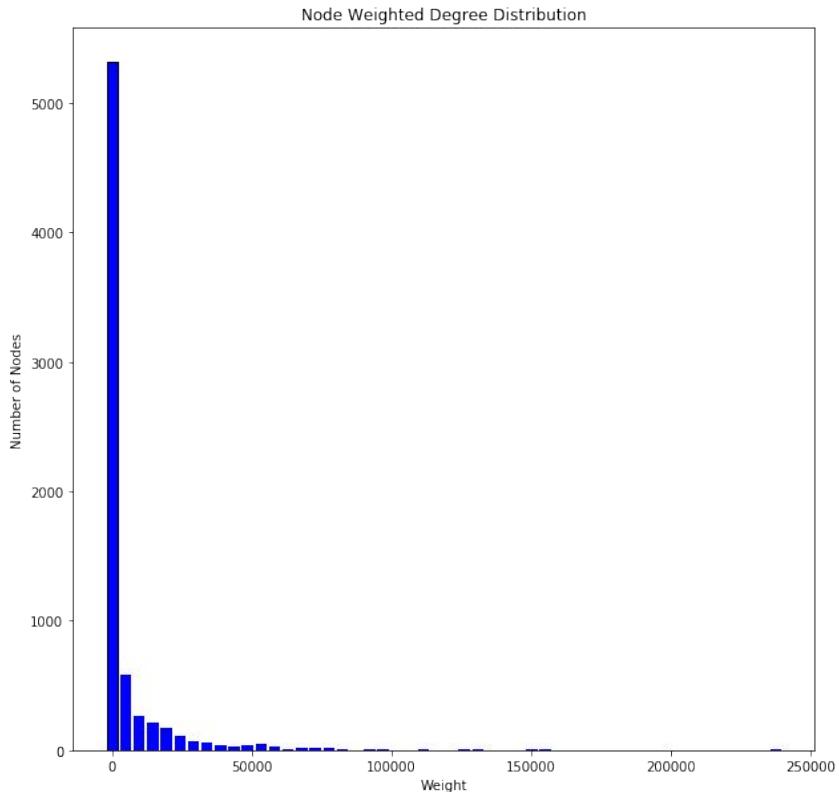
Freetown, Sierra Leone - Most-connected versus most-central nodes in the surface transportation network



Freetown, Sierra Leone - Most-connected versus most-central nodes in the surface transportation network

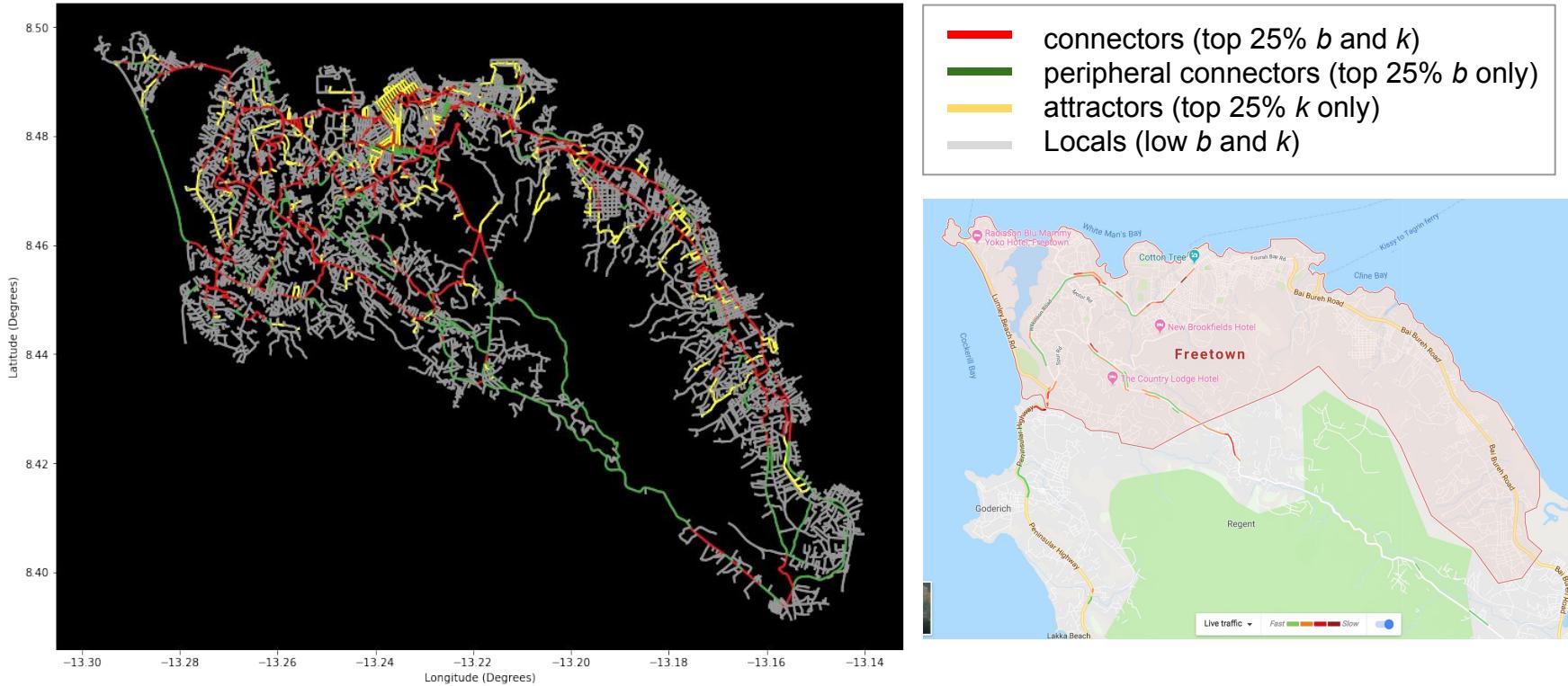


Analysis - Network



Analysis - Network

Freetown, Sierra Leone - Types of roads defined by betweenness centrality and demand-weighted degree



Future Work

- Validate Trip distribution estimate using real data (cell phone)
 - Compare weighted degree centrality from Extended Radiation Model to that calculated from cell phone data
 - Use cell phone data to define user types
 - Apply a route assignment model to distribute trips, taking congestion into account
- Compare population density profiles for different income brackets in Freetown
- Evaluate World Bank investment sites
- Incorporate updated network with natural hazard work to reevaluate critical nodes and running hazard simulations