Methodological Appendix for the Urban Environment and Social Inclusion Index

Version 1.0

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This Appendix provides further details into various aspects of methodology

1. Pilot city selection

   Recognizing data and time limitations for the first pilot edition of the UESI, we selected pilot cities based on the following criteria:
   - Different types of urban form based on the urban form typology developed by Huang, et al. (2007);
   - A range of economic development, from cities in least-developed countries from the most developed;
   - A mix of megacities (population over 10 Million) and large cities with population over 4 Million;
   - A mix of capital and noncapital cities.

Region	**City (Urban Form Cluster[1])**	**Population (Rank in Country)**	**Mean GDP Per Capita by Neighborhood (1000 USD)**	**Capital**
East Asia	Beijing (1)	21,705,000(2)	6.059	Capital
East Asia	Seoul (1)	10,178,395 (1)	50.392	Capital
East Asia	Tokyo (1)	9,143,041 (1)	46.582	Capital
Europe	London (4)	8,835,400(1)	77.477	Capital
Europe	Amsterdam	844,952 (1)	31.753	Capital
Europe	Paris (4)	2,220,445(1)	36.187	Capital
Europe	Copenhagen	576,423(1)	49.080	Capital
Europe	Barcelona (4)	1,610,427(2)	28.345	Noncapital
Europe	Berlin(1)	3,469,700(1)	15.093	Capital
Middle East	Tel Aviv	411,563(2)	NA	Noncapital

[1] Based on Huang, Lu, & Sellers (2007) study of 77 urban areas (which included none from the African continent). The studied urban areas were clustered into four groups based on six metrics of urban form. The clusters can be characterized as (1) relatively compact with little open space; (2) super dense with high centrality (i.e. few isolated patches); (3) medium density and centralized, but less so than group 3; and (4) low density fragmented with ample open space.

Middle East/North Africa	Casablanca	4,013,666(1)	NA	
Africa	Johannesburg	4,434,819 (3)	8.66	Capital
North America	Los Angeles	3,645,186 (2)	54.255	Noncapital
North America	Mexico City (1)	8,918,654 (1)	2.882	Capital
North America	New York	8,537,735(1)	60.887	Noncapital
North America	Chicago (4)	2,822,881(3)	47.249	Noncapital
North America	Detroit	683,443(18)	16.366	Noncapital
North America	Atlanta	495,377(40)	30.317	Noncapital
North America	Boston (4)	658,291(21)	32.610	Noncapital
North America	Montreal	1,961,019(2)	81.365	Noncapital
North America	Vancouver	633,190(3)	25.405	Noncapital
Oceana	Melbourne (4)	1,442,224(2)	56.145	Noncapital
South America	Buenos Aires (1)	3,103,763(1)	0.483	Capital
South America	Lima	8,890,792(1)	NA	Capital
South America	São Paulo (1)	11,253,503 (1)	8.22	Noncapital
South Asia	Bangalore (3)	4,330,976(5)	NA	Noncapital
South Asia	New Delhi (3)	10,440,249 (2)	NA	Capital
Southeast Asia	Bangkok	8,305,215(1)	4.867	Capital
Southeast Asia	Ho Chi Minh	7,123,330 (1)	NA	Noncapital
Southeast Asia	Jakarta	10,154,584 (1)	1.843	Capital
Southeast Asia	Manila	12,877,253(1)	2.534	Capital
Southeast Asia	Singapore	3,933,570 (1)	35.278	Capital

Table 1. Demographic characteristics of pilot UESI cities.

2. Sensitivity analysis

Political boundary definition - urban pixel vs. non-urban pixel count

Throughout the literature, there are two general approaches to defining urban areas - metropolitan area (politically-defined) and urban agglomeration (empirically defined):

Metropolitan Area

The metropolitan area is defined by the political boundaries of municipal governments, surrounding governments, and neighborhoods. A similar approach of combining spatial environmental datasets with politically-defined neighborhood boundaries was used by Kumar et al. (2016) to analyze climate change vulnerability of neighborhoods in Bangalore. Shapefiles of the metropolitan area were used to disaggregate data at the neighborhood level. These shapefiles may come from the cities themselves or other online data repositories. In some cases, data that are more granular than the neighborhood scale are available (e.g., block-level), but to be consistent as possible across cities, we selected for similar levels of neighborhood aggregation.

Urban Agglomeration

The urban agglomeration is defined absent political boundaries by using remotely-sensed land use classification (LUC). This data is available from MODIS (500 meter resolution) and Landsat 8 (30 meter resolution) products, and both have been used for analysis of urban form. Additionally, population density data are available on the global scale from the Columbia University Center for International Earth Science Information Network (CIESIN, 2011) in 1 kilometer resolution.

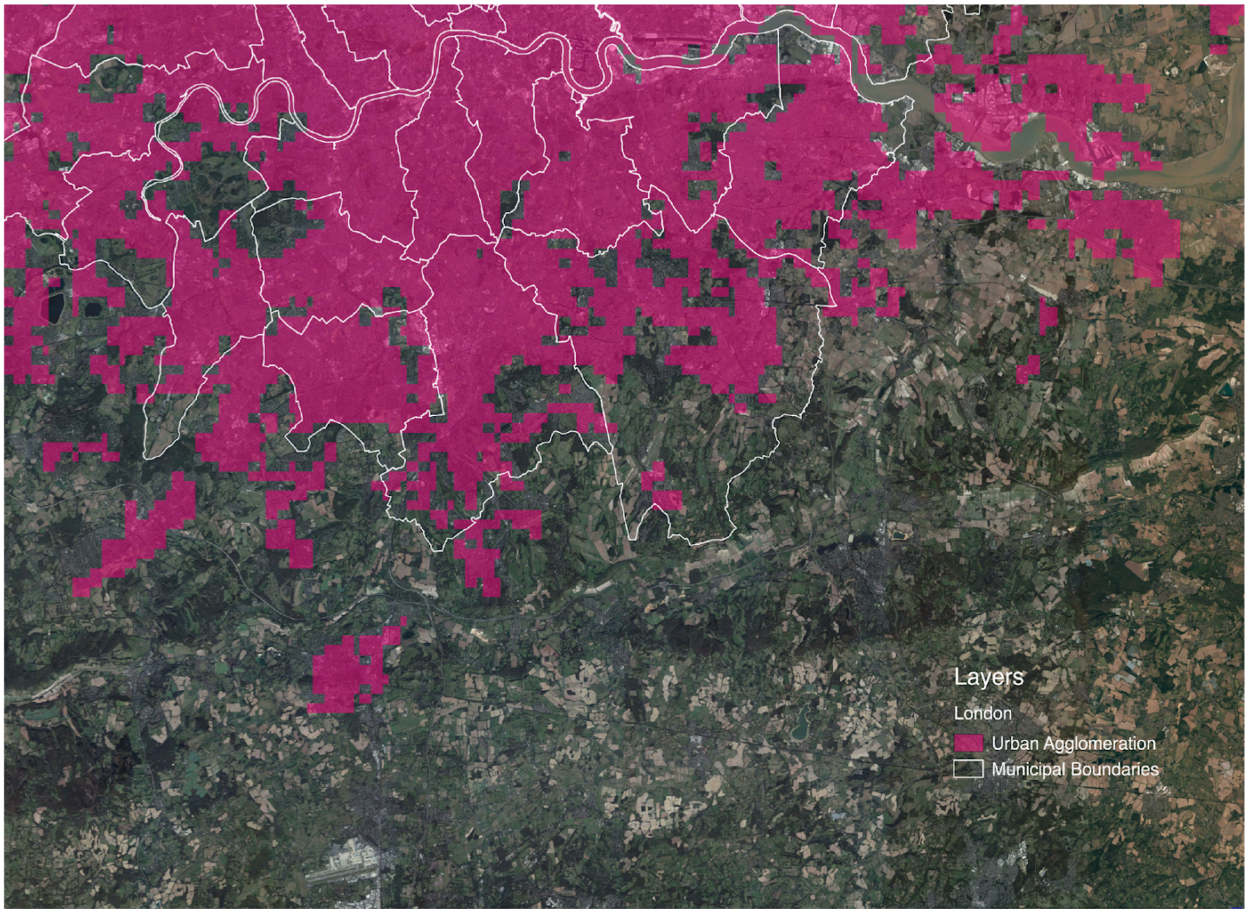


Figure 1. Comparison of London's municipal boundary and remotely-sensed urban extent.

Because our tool is aimed at policymakers, we determined using administrative boundaries for neighborhoods and the urban boundary defined by the governments themselves would be most useful for our target audience. How governments define neighborhoods themselves also varies and has implications for comparing environmental performance between and across neighborhoods. The neighborhood sizes themselves vary considerably between cities (Figure 2), where Beijing, for example, has much larger than average-sized neighborhoods (See Results: Box 2. Challenges in Evaluating Beijing's Large Urban Extent for more details).

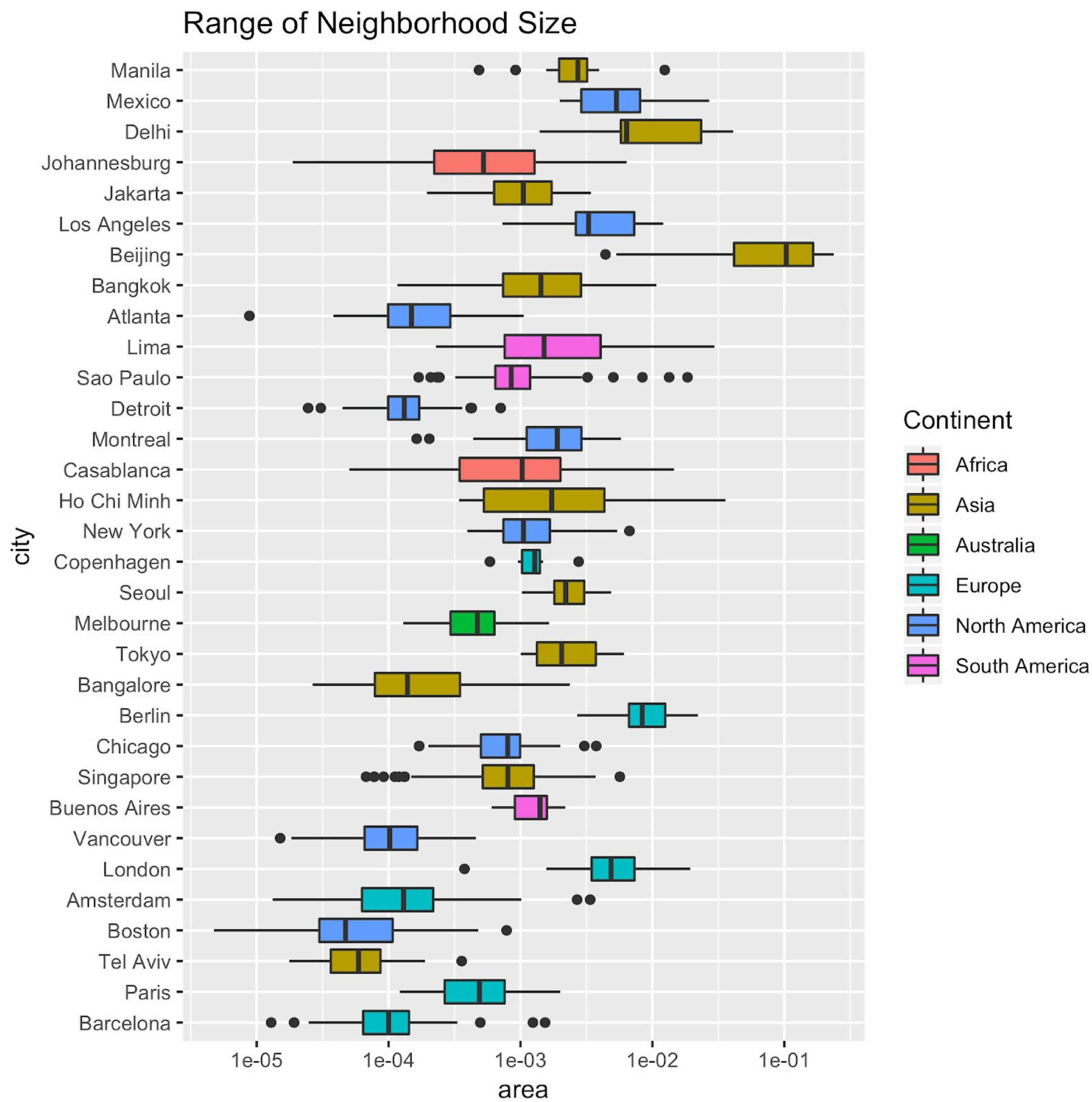
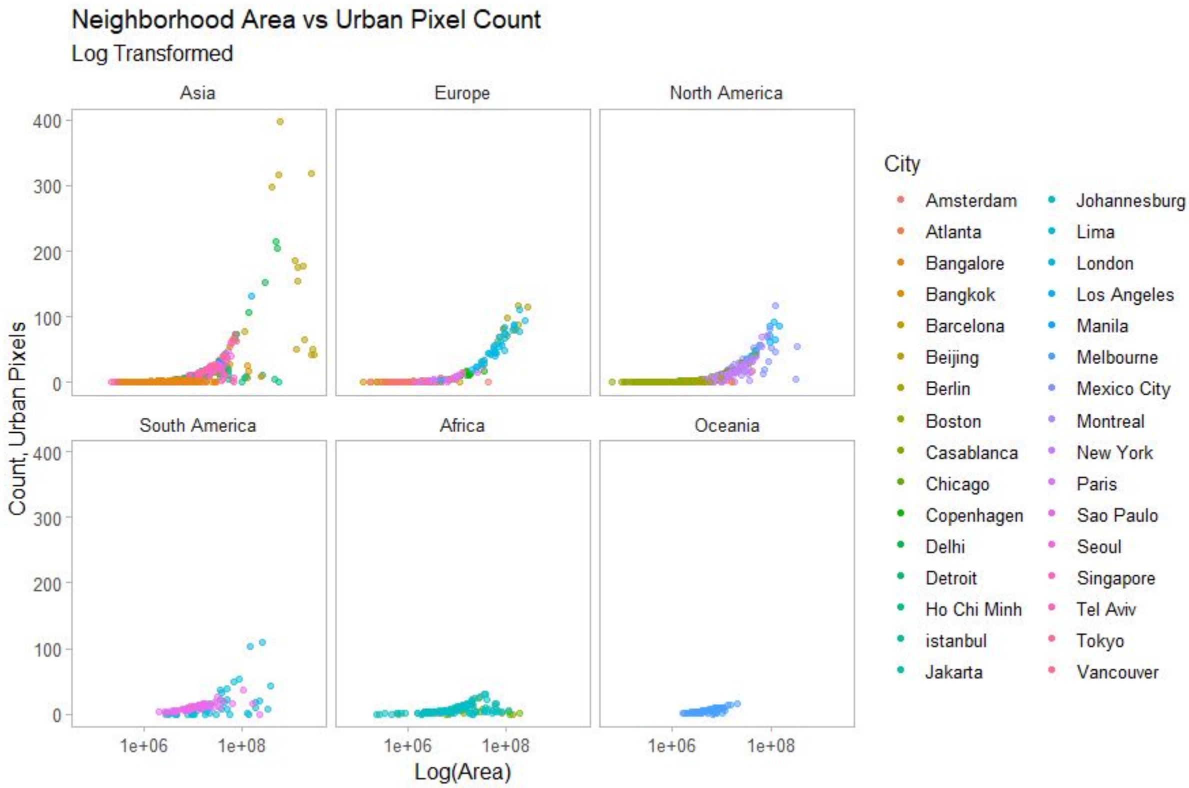


Figure 2. Boxplots of average neighborhood size in selected UESI cities.



3. Alternative Methods for Equity Calculations

While the UESI uses the most commonly known Concentration Index to assess the distribution of environmental outcomes within a city, other methods were explored to evaluate this distribution of this outcomes and its equity. One the approaches used by the UESI is based on the economic concept of elasticity, which indicates the sensitivity of one variable to a change in another variable. For the UESI the following formula was used:

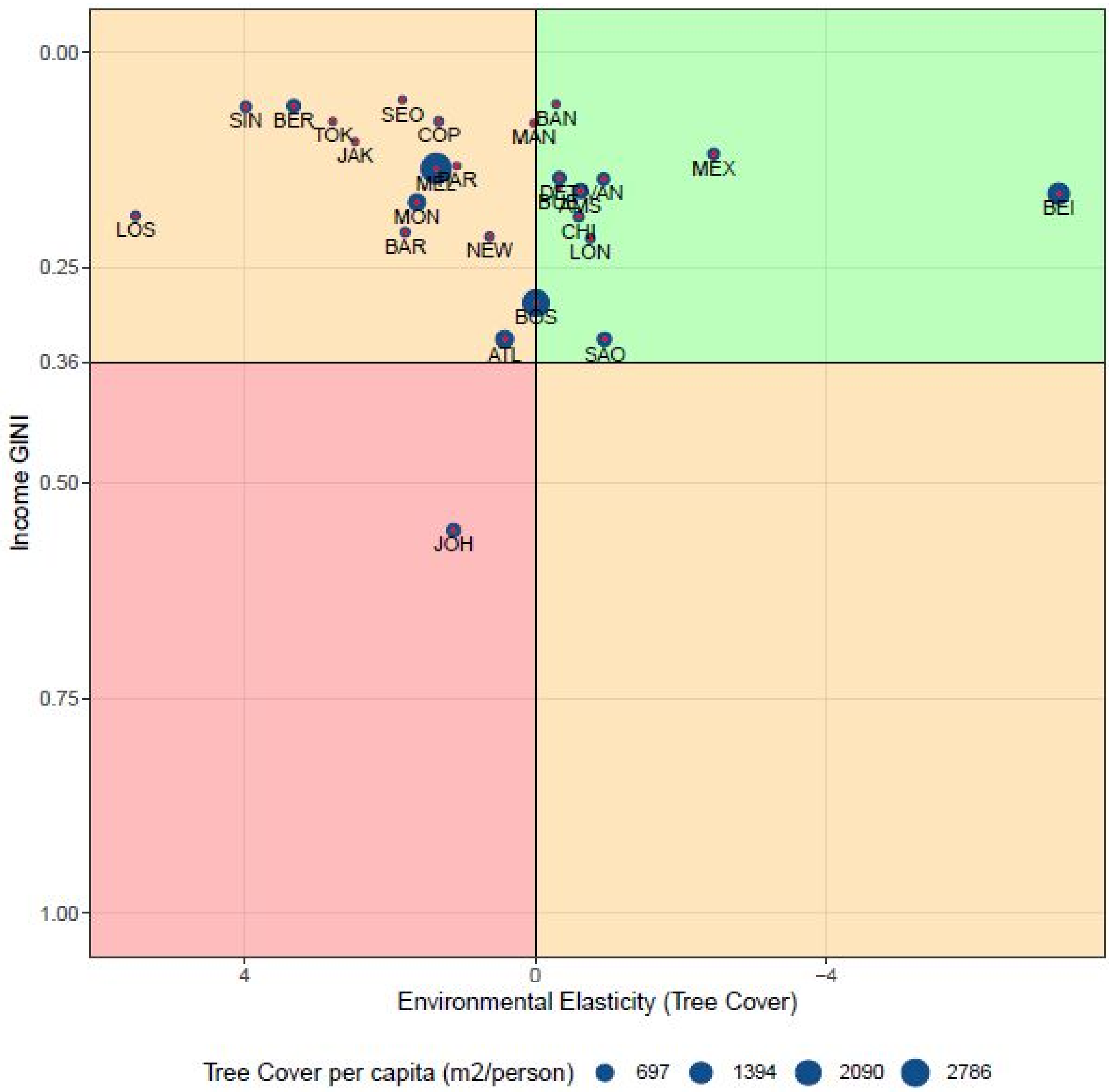
$$log(Env) \sim \alpha + \beta \times log(Income) + \varepsilon;$$

Where β is the partial elasticity that indicates the percent change in the Environmental Outcome (Env) for a 1 percent increase in Income. The interpretation of the partial elasticity is based on the definition of the Environmental Outcome (Env), similarly to the Concentration Index itself, in the following way:

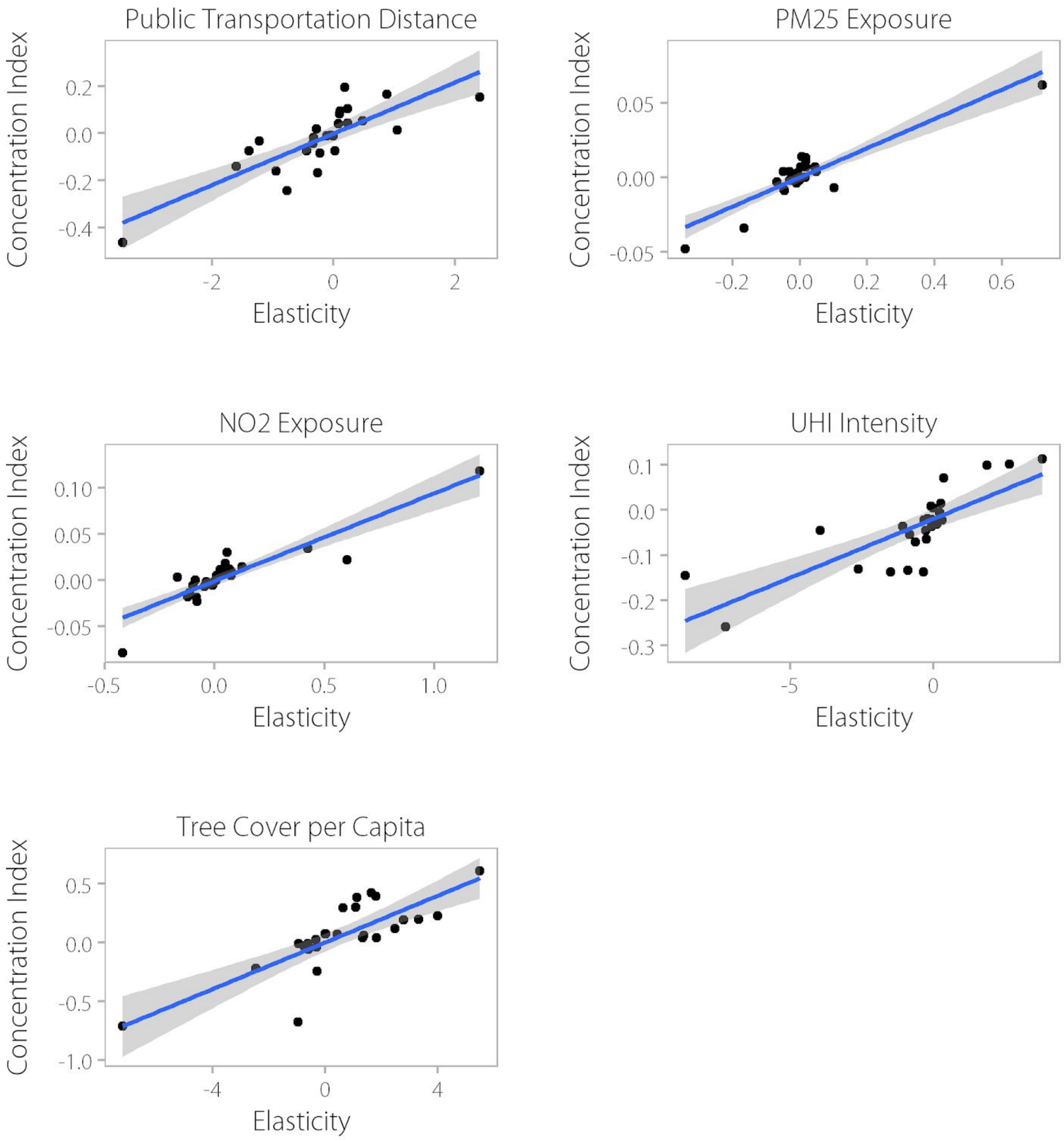
- When the Environmental Outcome is a burden then a positive elasticity value will indicate that as income increases, the exposure to environmental burden (PM 2.5 and NO2 Concentration, UHI Intensity, and Public Transportation Distance) also increases, suggesting that the distribution is benefiting the poor. On the other hand, if the elasticity value is negative, it indicates that as income increases, the environmental burden decreases, suggesting that the distribution is benefiting the wealthiest citizens.

- When the Environmental Outcome is positive (Tree Cover per capita) then a positive elasticity value will indicate that as income increases, the exposure to a positive environmental outcome also increases, suggesting that the distribution is benefiting the rich. On the other hand, if the elasticity value is negative, it indicates that as income increases, the positive environmental outcome decreases, suggesting that the distribution is benefiting the poorest citizens.

The results of assessing inequality using the Elasticity distribution for Tree Cover per Capita (Positive Environmental Outcome) are presented using the proposed quadrant plot showing the Gini Coefficient in the Y axis and the Elasticity Value in the X axis. The results, while different in magnitude - because the elasticity quantifies the numeric relation between income and the environmental outcome without any boundaries in the value - are very similar in relation to the location of specific cities in certain quadrants. For example, Los Angeles, Melbourne, and Montreal are still located in the upper left quadrant (Low Income Gini and Positive Elasticity) indicating that in those cities while there is low inequality in the distribution of income, there is inequality in the distribution of environmental benefits which might be a source of environmental pressure to the poorest citizens.



Overall, the results of using the partial elasticity method are similar in direction and interpretation to those using the Concentration Index method, presented in the main UESI report. This similarity in the results, provides additional confidence on the method used for the UESI, indicating that the concentration index properly reflects the distribution of environmental outcomes in relation to the distribution of income within a city.



References:

1. Wanner, W., Strahler, A. H., Hu, B., Lewis, P., Muller, J. P., Li, X., ... & Barnsley, M. J. (1997). Global retrieval of bidirectional reflectance and albedo over land from EOS MODIS and MISR data: Theory and algorithm. *Journal of Geophysical Research: Atmospheres*, *102*(D14), 17143-17161.
2. Danielson, J. J., & Gesch, D. B. (2011). Global multi-resolution terrain elevation data 2010 (GMTED2010) (No. 2011-1073). US Geological Survey.