UEP Advanced GIS Fall 2017
Final Paper
Judy Fung

A Suitability Analysis of Citywide Green Roofs Implementation in the City of Boston

Summary of topic

Studies have shown that vegetated green roofs are effective in reducing energy consumption of buildings, mitigating urban heat island effect and air pollution. Green covers also control stormwater overflow by increasing water retention with plants and reducing impervious cover. 40% of world-wide energy use is associated with the construction and maintenance of buildings. Buildings are also responsible for 33% of greenhouse gas emission globally (Berardi, GhaffaruabHoseini and GhaffarianHoseini 2014). A study on changes in tree cover and impervious cover in the City of Boston found that buildings account for higher percentage of increase in impervious cover amongst all. In the City of Boston, buildings from 2003 and 2008 accounted for 16.7% increase in impervious cover.

Apart from environmental concerns, another studies have found that socially vulnerable people such as people with disability, limited English proficiency, medical illnesses etc. have a disproportionate risk and a decreased ability to avoid potential harm to climate change and environmental hazards. However, most literatures look into the effectiveness of green roofs with an environmental lens and neglects the importance of connecting the social needs of vulnerable population with the benefits of green roofs. Green roofs are proven to be effective in improving public health by mitigating air pollution. A study by Yang et al shows that 1675 kg of air pollutants was removed by 19.8 hectare of green roofs in one year. Various other studies have also shown that green roof could remove up to 4000kg of particle matter (Vijayaraghavan 2016).

Objectives

In view of this, this analysis will take into account environmental and social vulnerability to discover areas suitable for green roofs development. This analysis develops two vulnerability indexes to prioritize areas in need of more green covers. Buildings with feasible structural capacity for vegetated green roofs are also selected to identify the most applicable sites. This analysis could inform policy makers what areas to be prioritized to develop green roofs and policy approaches to incentivize such development in a city-wide scale.

Selection of indicators

Social vulnerability

Looking into the locations of existing green roofs in Boston (Figure 1), most of them are clustered in the downtown Boston area. In neighborhoods such as Dorchester, Roxbury and Mattapan, where population of low-to-no income, population of disabled, population of medical illnesses are higher than the downtown area, there's only one existing green roof located in East Mattapan. It's clear that there's a disproportional distribution of green roofs in Boston. Studies have shown that social vulnerability factors are always accumulated to produce negative consequences before, during and after emergences and reduce social resilience to environmental hazards. As a result, it is valuable to develop an opportunity overlay based on social vulnerability to find out areas with potential to use green roofs as a mean to enhance climate resilience.

The social vulnerability index (SoVI) used was based on Climate Ready Boston, a report published by the City of Boston on enhancing climate resilience. The index was developed by a quantitative analysis of the relationship between social factors and vulnerability. The Social Vulnerability Index (SoVI) is the susceptibility of social groups to the impacts of hazards as well as their resiliency, or ability to adequately recover from impacts (framework). The index is developed by the Hazards and Vulnerability Research Institute at the University of South Carolina (Adaptation Clearing House).

Criteria for areas with high social vulnerability

- High population of Low to No Income
- High population of Disabled
- High population of Old Adults
- High population of Children
- High population of People of Color
- High population of Low English Proficiency

Environmental Vulnerability Index

The environmental vulnerability index used in this analysis was developed based on the research from the Climate-Smart Cities program. The program has chosen indicators to identify areas with high vulnerability to climate change. The indicators I chose are more directly related to land temperature and stormwater as green roofs are proved to be effective in tackling these two environmental concerns.

Therefore, it will be crucial to develop an opportunity (vulnerability) index that prioritize areas in need of more green covers.

Criteria for areas with high environmental vulnerability

- High Land Temperature
- High % of impervious cover

Ideal structural criteria for vegetated green roofs (Assume building tops are the only places to implement vegetated roofs)

Criteria for buildings suitable for green roofs is based on a Green Roof Planning Study for the City of Boston published in 2009.

Roof Slope	Less than 30 degrees

Building stories	Less than 15 stories
Roof size	Greater than 2,000 SF

Figure 1 Locations of existing green roofs in Boston

Key Data used

MassGIS Data – Impervious Surface

This dataset was created by Massachusetts Office of Geographic Information (MassGIS). This Impervious Surface layer is a raster layer.

MAPC Data - Land Surface Temperature and Vegetation Data

A set of rasters were created that show Land Surface Temperature in degrees Fahrenheit and a relative index of vegetation covering the entire MAPC region, including Boston.

Boston GIS Data - Climate Ready Boston Social Vulnerability

This dataset is a vector layer. Social vulnerability is defined as the disproportionate susceptibility of certain social groups to the impacts of hazards. Groups identified as being more vulnerable are older adults, children, people of color, people with limited English proficiency, people with low or no incomes, people with disabilities, and people with medical illnesses.

Metadata: https://www.arcgis.com/home/item.html?id=34f2c48b670d4b43a617b1540f20efe3

Boston GIS Data – Boston Buildings

This dataset is a vector layer. It is a dataset that shows building outlines. In the attribute table, information about building heights, roof type and structures could also be found.

Methodology

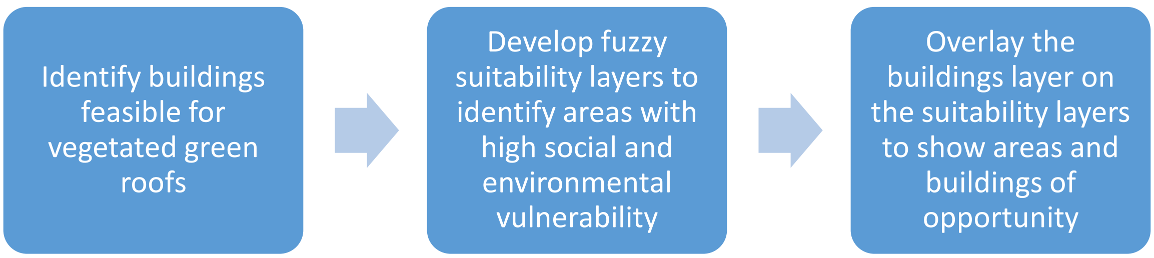


Figure 2 Methodology

1. **Use basic Query tool to select buildings that are suitable for green roofs.**
2. **Create a new layer that only shows those suitable buildings**
3. **I used the model builder to implement the suitability analysis**
4. **Weighted Overlays (Figure 4 & 5)**
    a. Two raster layers are put into the model builder: impervious cover and land temperature
    b. As the two layers have different attributes, both have to be reclassified to make sure that both layers can be compared with the same scale.
    c. Two Weighted Overlays are implemented. One layer has the weights set for impervious cover as 20% and land temperature as 80% and the opposite was set for another overlay. Two overlays were used as it could identify areas with the highest in each of the criteria.
    d. One overall equal weighted overlay was implemented on the two weighted overlays to determine areas with highest level in both layers.
    e. The same applies for the weighted overlays for social vulnerability
5. **Fuzzy Overlays (Figure 4 & 5)**
    a. For fuzzy overlays, the two layers are not required to be reclassified as fuzzy overlays addresses the inaccuracies between class boundaries. Fuzzy membership

is used to transform the data into 0-1 scale in which 0 and 1 represents full certainty and any values that fall between indicate some level of possibility.

b. Large is used as the Fuzzy Membership (Figure 3) because in my data layers, higher values represent higher vulnerability.

6. Choosing the suitable buildings in priority areas

a. As overlay layers is a raster but the buildings layer is a polygon layer, the raster has to be reclassified and transformed to polygon.
b. I used reclassify tool to apply values on priority areas and non-priority areas.
c. Use Raster to Polygon to transform the layer to polygon layer
d. Use Clip to clip the new polygon layer with the suitable buildings layer to identify suitable buildings on the priority areas.

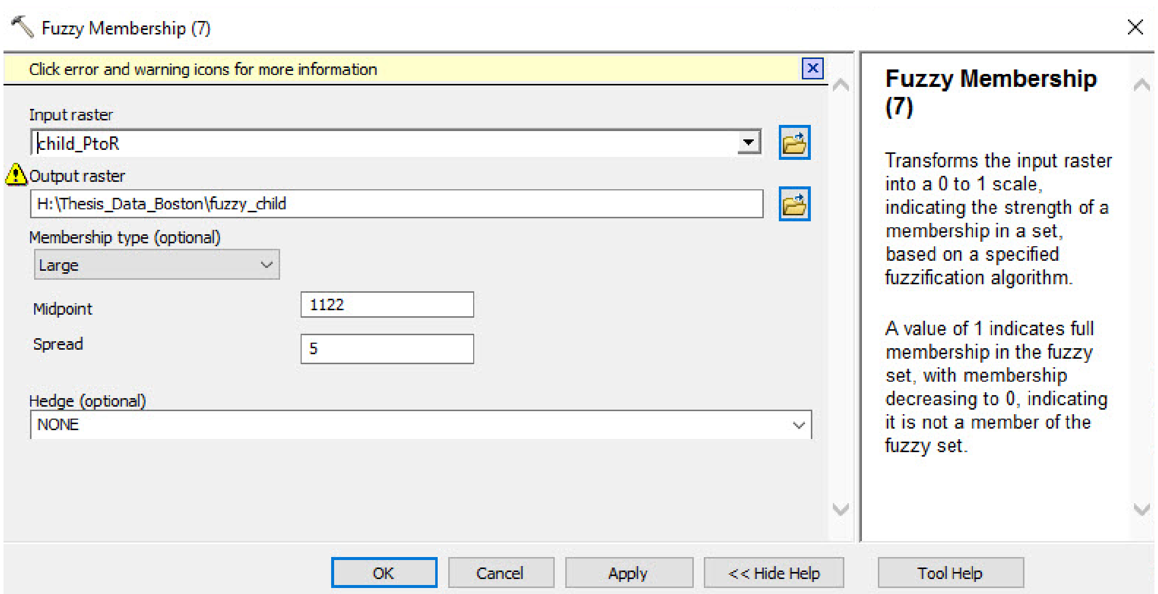


Figure 3 Fuzzy Membership

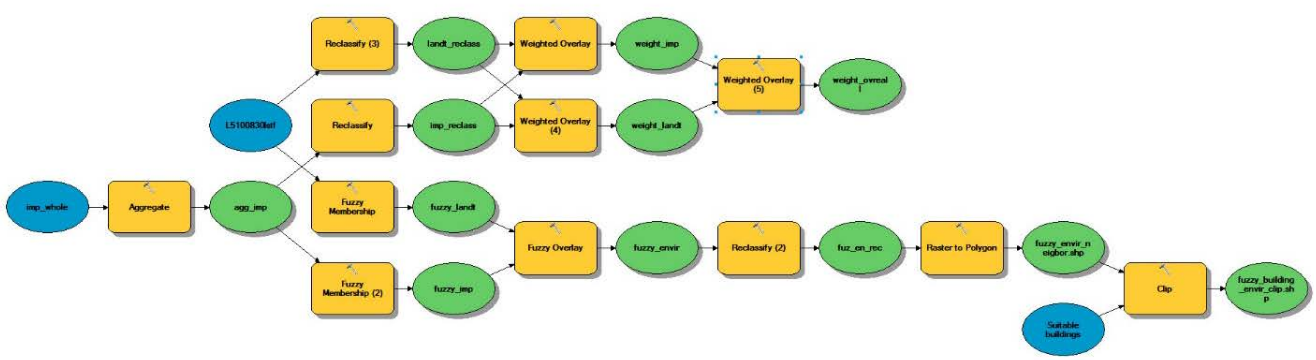
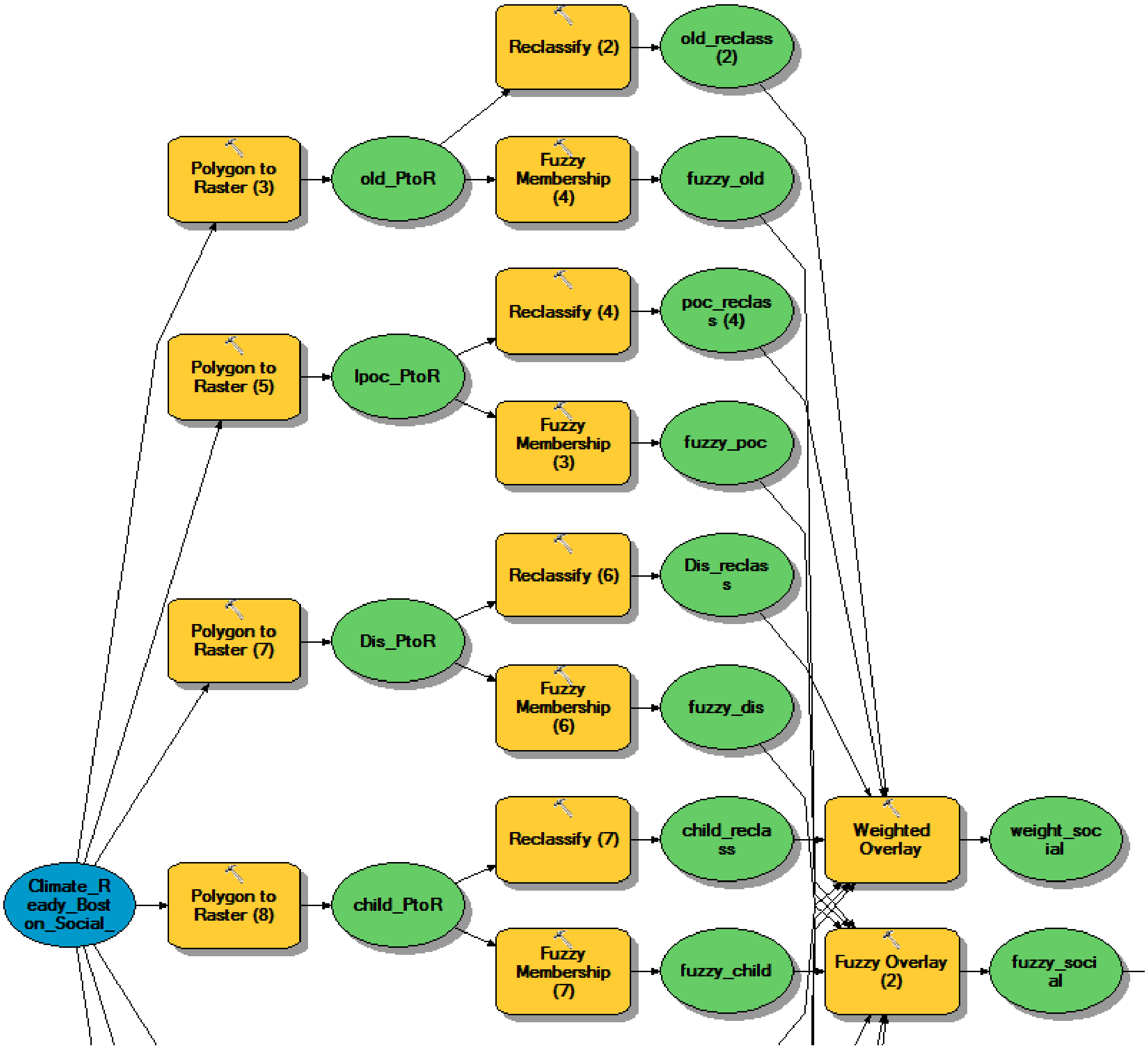


Figure 4 Model for environmental vulnerability


Reclassify (2)
old_reclass (2)
Polygon to Raster (3)
old_PtoR
Fuzzy Membership (4)
fuzzy_old
Reclassify (4)
poc_reclass (4)
Polygon to Raster (5)
lpoc_PtoR
Fuzzy Membership (3)
fuzzy_poc
Reclassify (6)
Dis_reclass
Polygon to Raster (7)
Dis_PtoR
Fuzzy Membership (6)
fuzzy_dis
Reclassify (7)
child_reclass
Weighted Overlay
weight_social
Climate_Ready_Boston_Social_
Polygon to Raster (8)
child_PtoR
Fuzzy Membership (7)
fuzzy_child
Fuzzy Overlay (2)
fuzzy_social

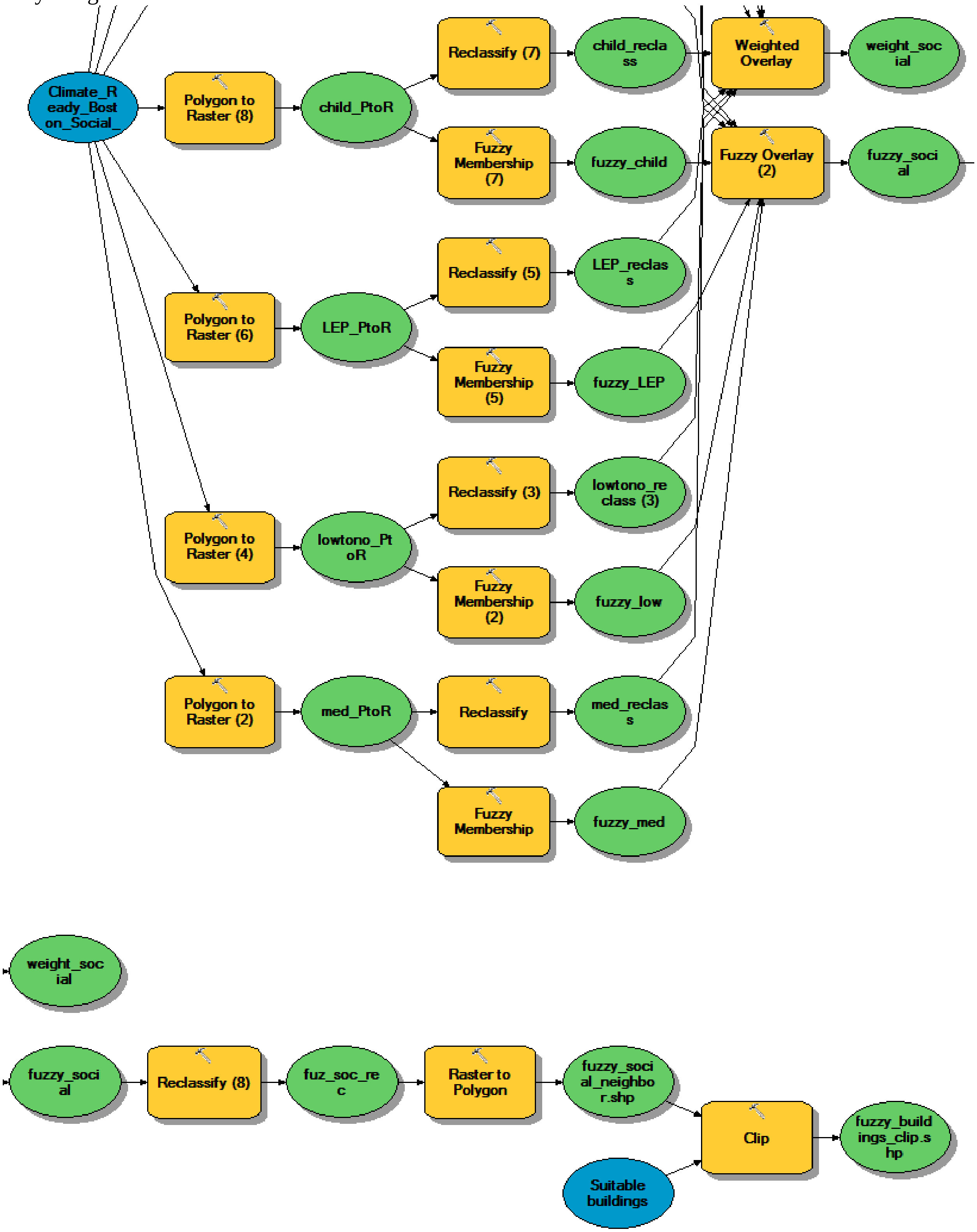


Figure 5 Model for social vulnerability

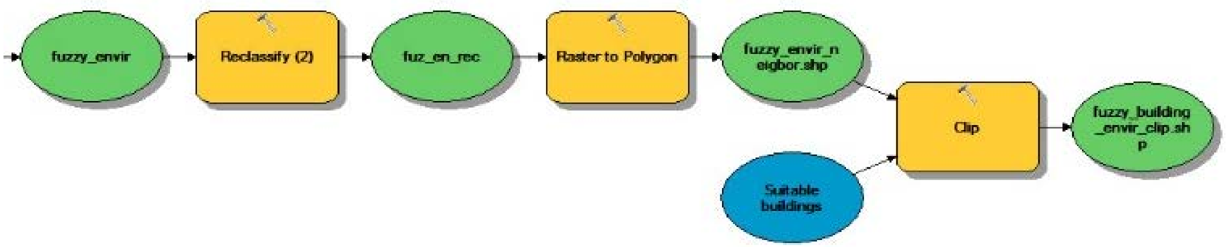


Figure 6 Choosing suitable buildings in priority areas

Weighed Overlays VS Fuzzy Overlays

Comparing the four maps showing weighted overlays and fuzzy overlays, it is clear that the fuzzy overlays identify areas more precisely. If we compare Figure 7 and 8, Figure 7 shows that most areas in Boston have high social vulnerability and it is hard for a policy maker to prioritize areas for green roofs. But when fuzzy overlay is used (Figure 8), areas with the highest vulnerability could be clearly seen and should be the areas that get prioritized.

For environmental vulnerability, the situation is a bit different. The fuzzy overlay shows more areas with high vulnerability in general but scattered spots could be easily seen in Dorchester and Roxbury. Compared to the weighted overlay (Figure 9), those spots could not be clearly seen in neighborhoods other than downtown. In a policy sense, the fuzzy overlays create a clearer results for prioritization.

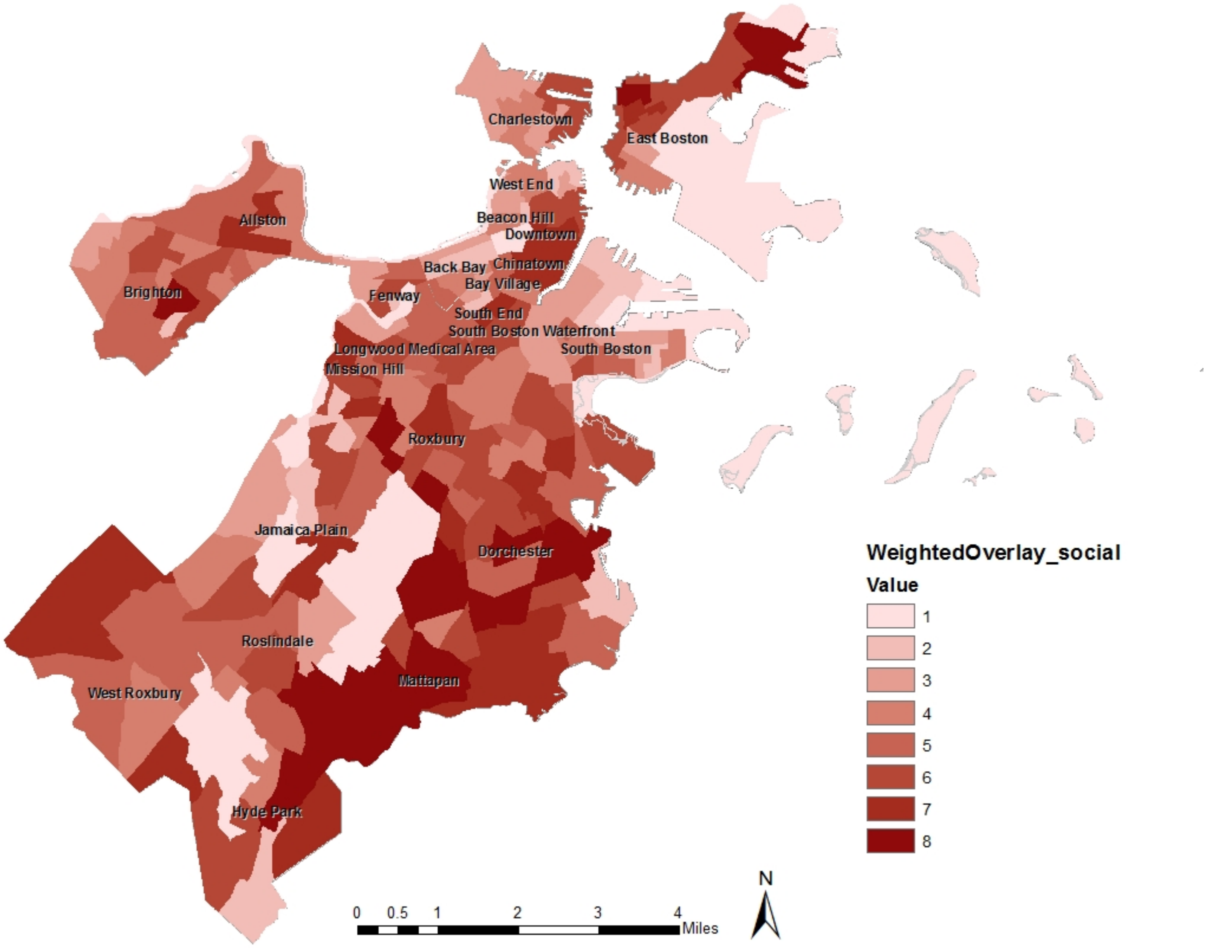


Figure 7 Weighted Overlay (social vulnerability)

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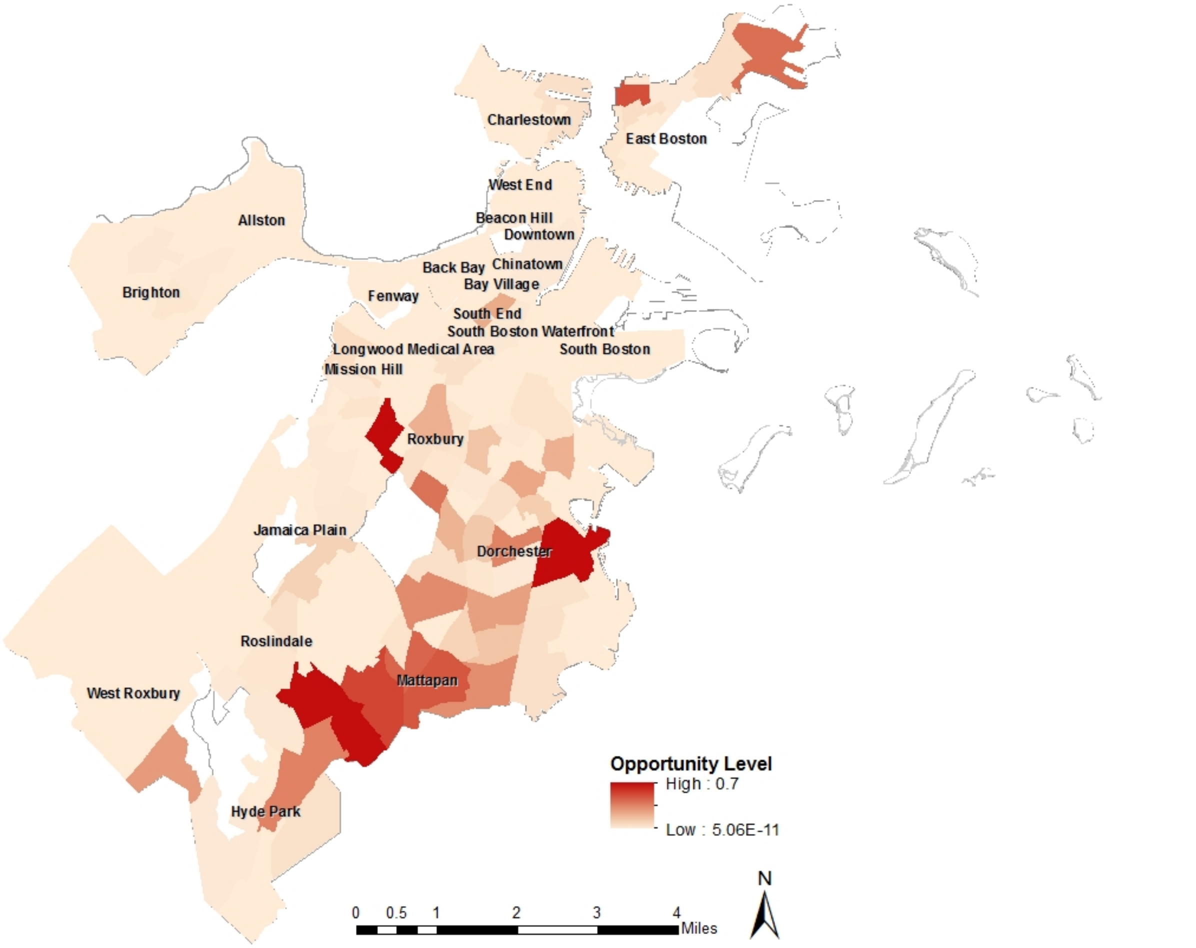

Figure 8 Fuzzy Overlay (social vulnerability)

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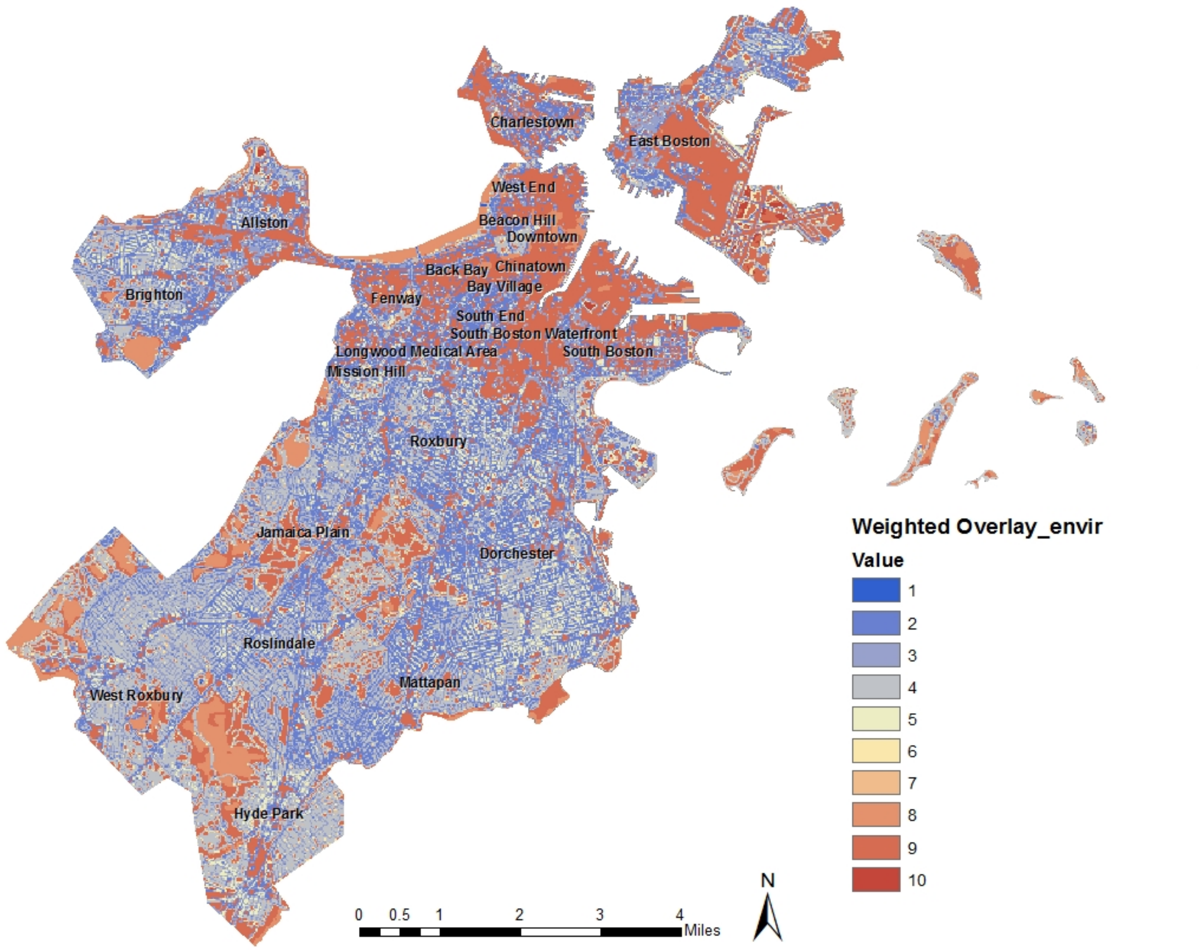

Figure 9 Weighted Overlay (environmental vulnerability)

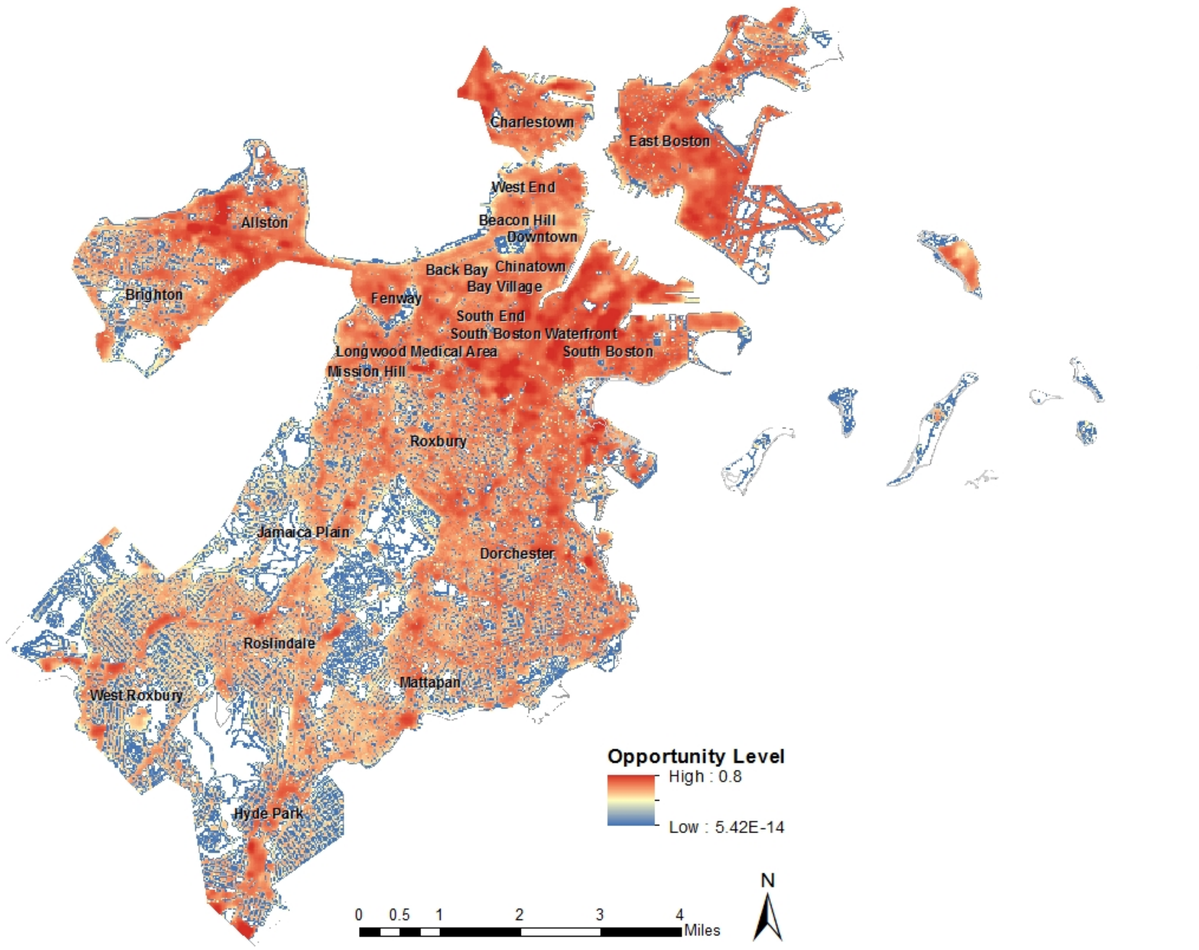

Figure 10 Fuzzy Overlay (environmental vulnerability)

Conclusions and Implications

We can see a distinction between areas with high social and environmental vulnerability with a few overlapping. According to the social vulnerability map (Figure 8), areas with the highest social vulnerability are located in Roxbury, Dorchester and Mattapan. Areas with the second highest level of social vulnerability is East Boston and the areas bordering Roxbury and Dorchester.

According to both fuzzy maps (Figure 8 & 10), **East Boston** turns out to be socially and environmentally vulnerable. Unfortunately, if we refer back to Figure 1, there is only one green roof in the area. In terms of social vulnerability, **Dorchester** is the most vulnerable neighborhood.

For environmental vulnerability, area with the highest vulnerability is located in the downtown area and East Boston, meaning that areas with highest land temperature and percentage of impervious surface are located in downtown, Allston and East Boston. This result is not surprising as the downtown area is the most urbanized. Other areas of high environmental vulnerability are scattered around Dorchester.

Regarding priority areas, **East Boston, Dorchester and Mattapan should be prioritized** for green roofs implementation. East Boston and Dorchester are high in both social and environmental vulnerability. Mattapan should be prioritized over South Boston because it is one of the areas with high social vulnerability but currently there is no green roofs around the area.

According to the statistics results, **the total number of buildings suitable for green roofs is 14,515**. The total number of suitable buildings in environmentally sensitive areas is 12,514 while the total number of suitable buildings in socially vulnerable areas is 2,001. In Dorchester, there are a total of 3,165 buildings eligible to implement green roofs. In East Boston, there are total of 1,980 suitable buildings. In Mattapan, there are a total of 331 suitable buildings.

Most of the suitable buildings are multi-family residential buildings. In spite of enhancing resilience on a neighborhood scale, prioritizing multi-family residential buildings could be beneficial to a community in a way that households could reduce overall energy consumption and enhance the longevity of rooftops in the long run as well.

To conclude, this analysis shows us a mismatch of places needed green roofs and places where existing green roofs are located. Also, the total number of suitable buildings suggested that there are plenty of opportunities to implement green roofs in an area-wide or neighborhood scale. The City of Boston should consider using green roof technology to tackle environmental concerns and enhance climate resilience. Different green roof neighborhood plans could be developed according to respective neighborhood characteristics and resources. Incentive programs could also be incorporated to incentivize private implementation of green roofs.

Challenges and Limitations

This analysis is based on the assumption that building tops are the only places to develop vegetated green roofs. However, in reality there are other areas in a building that could build vegetated green roofs. There are a lot of examples of vegetated green roofs located at a roof deck of a building. This analysis failed to identify roof decks because such database is not available. If roof decks are taken into account, there would be more opportunities for implementing green roofs in an area-wide scale.

Another challenge I encountered is the way to accurately calculate the total number of buildings. After the reclassify process, most suitable buildings in priority areas are captured, but it is uncertain whether Clipping is the best way to accurately calculate the total number of suitable buildings. More research should be spent to determine the best way to identify suitable buildings in each area.

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