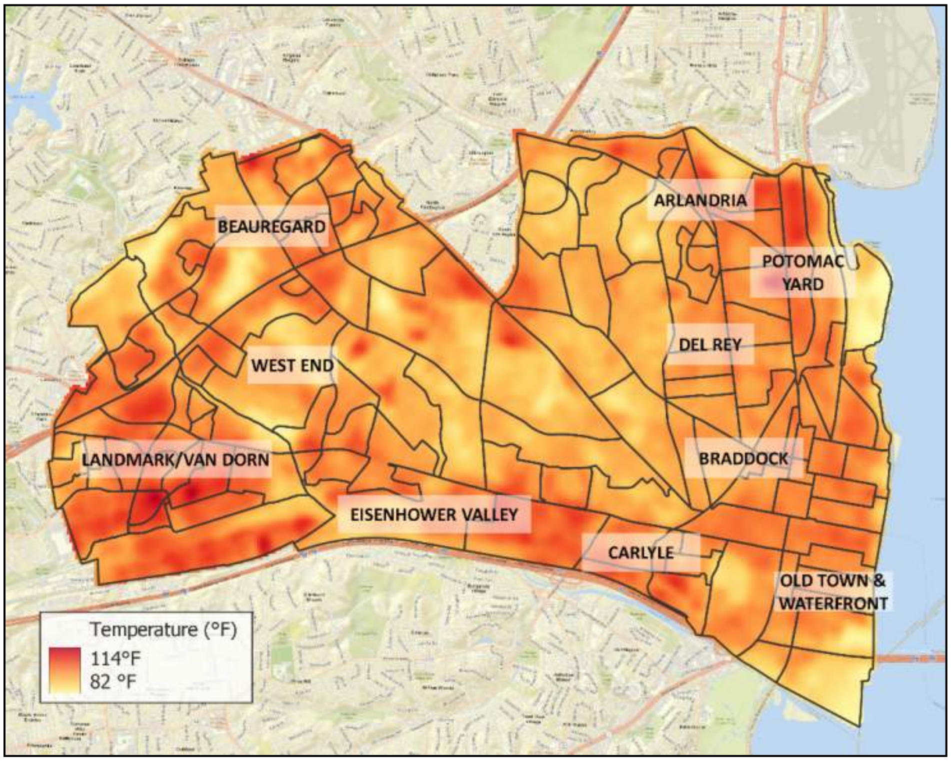
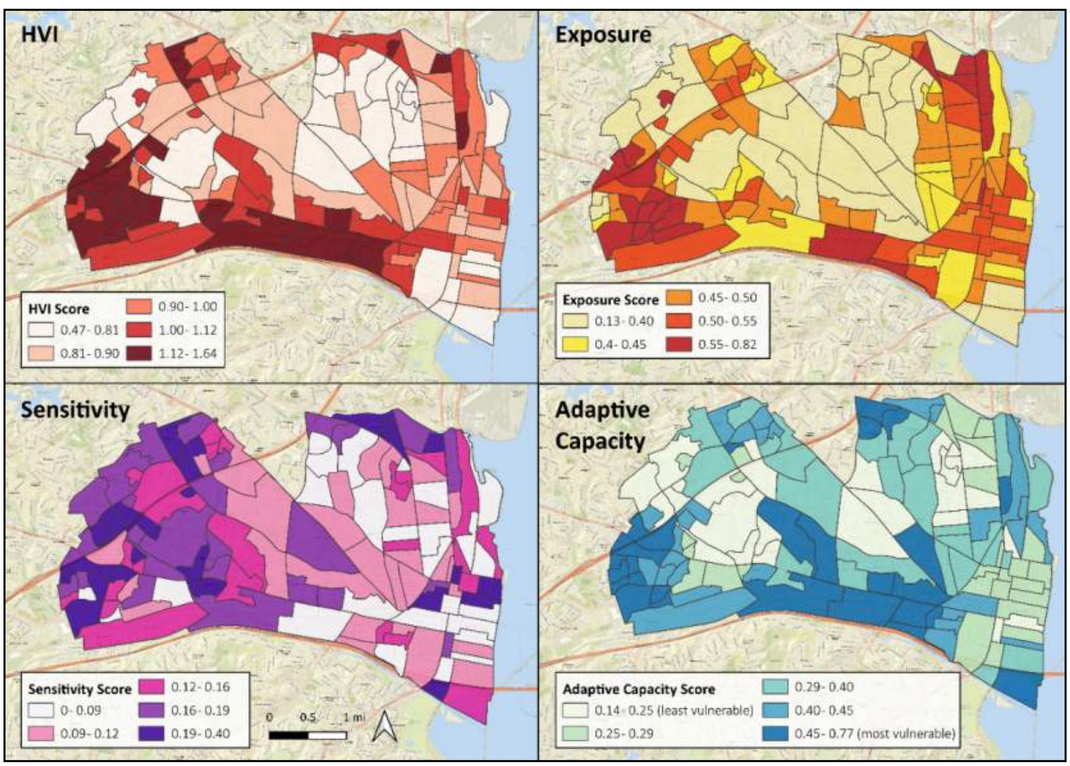
Relative Land Surface Temperatures in Alexandria

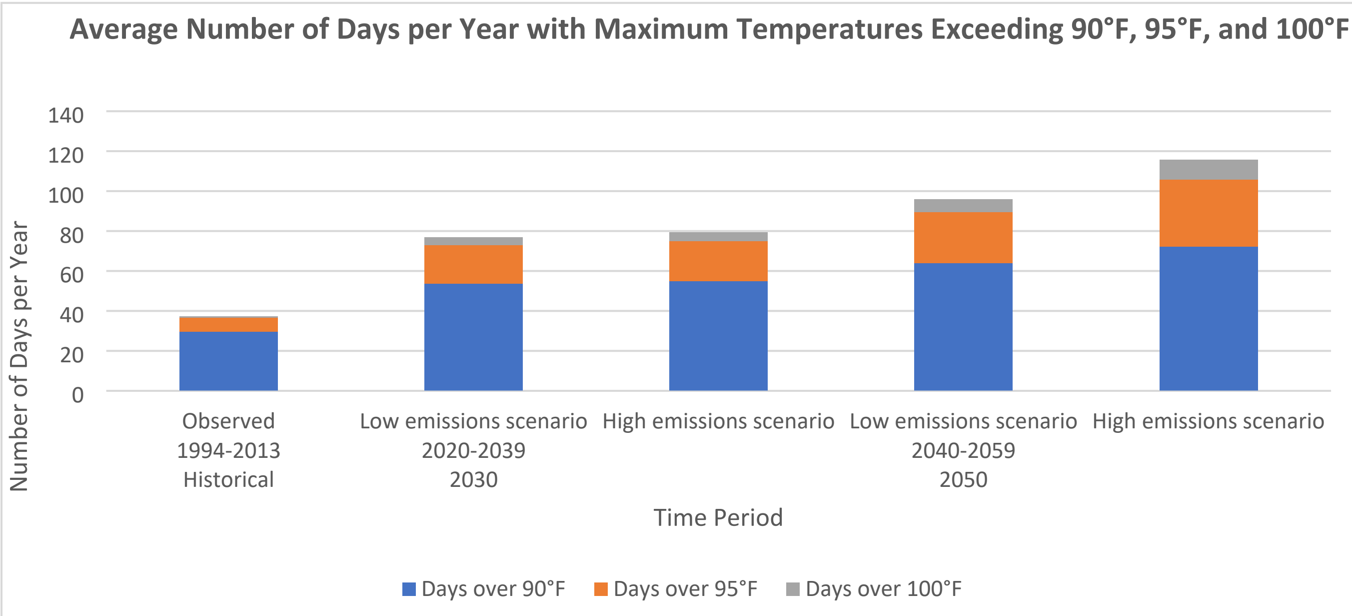


Heat Vulnerability Index Scores for Alexandria Block Groups, Overall (Top Left) and by Component



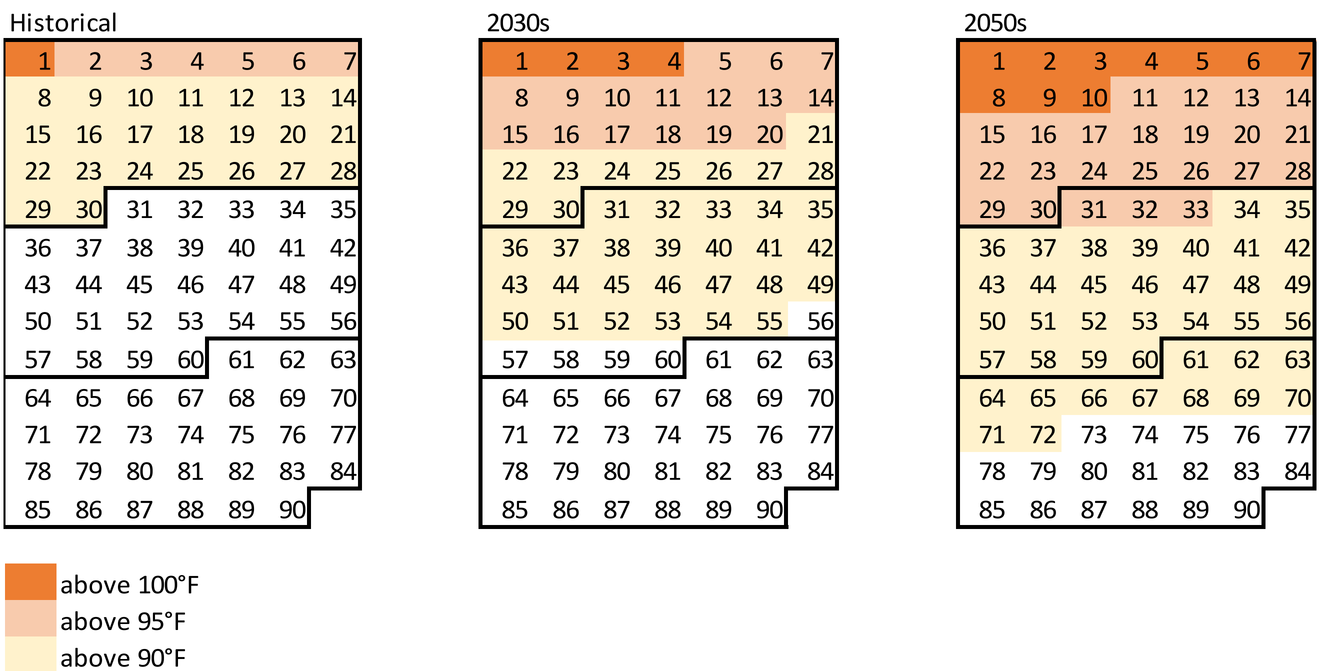
Heat Vulnerability Indices for Separate Vulnerable Population Groups

Number of Days per Year with Maximum Temperatures Exceeding 90 °F, 95°F, and 100°F (under high emissions scenario RCP 8.5 and low emissions scenario RCP 4.5)

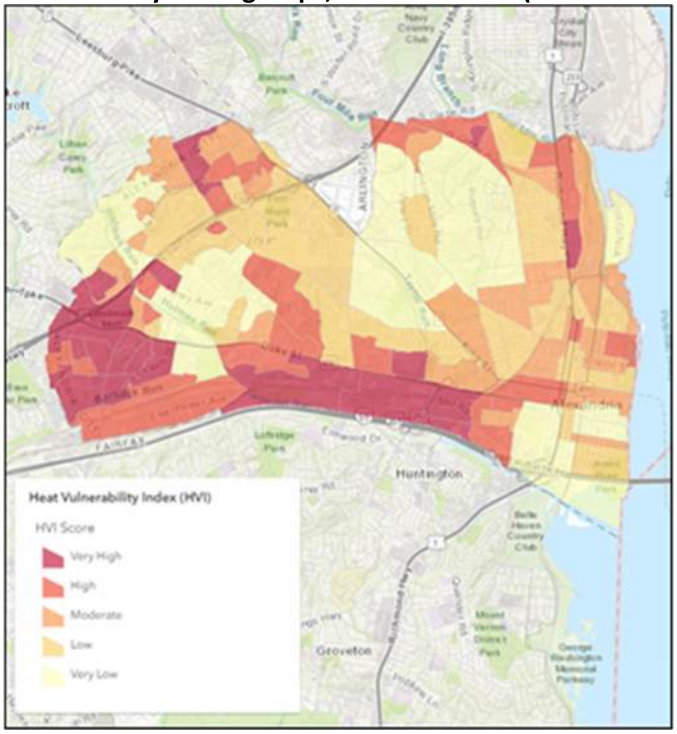


Number of Days per Year with Maximum Temperatures Exceeding 90 °F, 95°F, and 100°F (under high emissions scenario RCP 8.5)

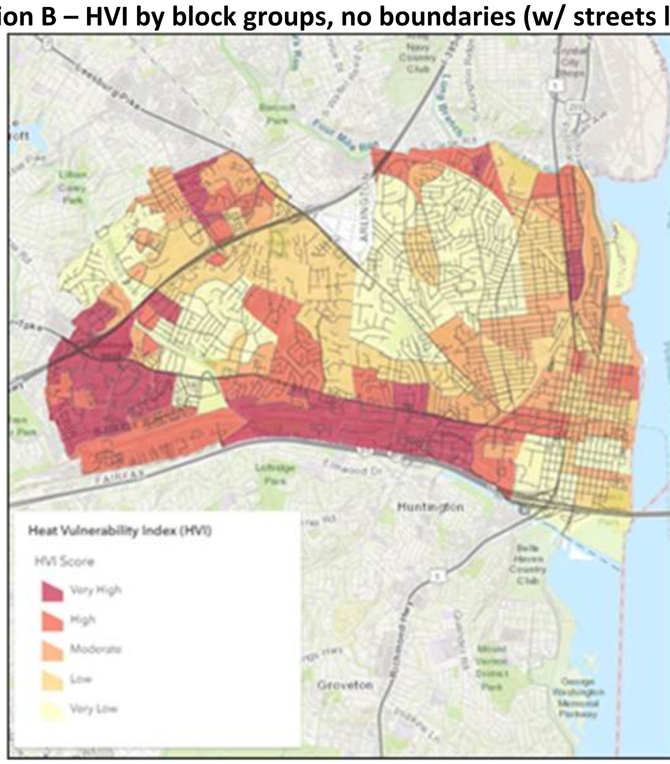
Average Annual Number of Hot Days



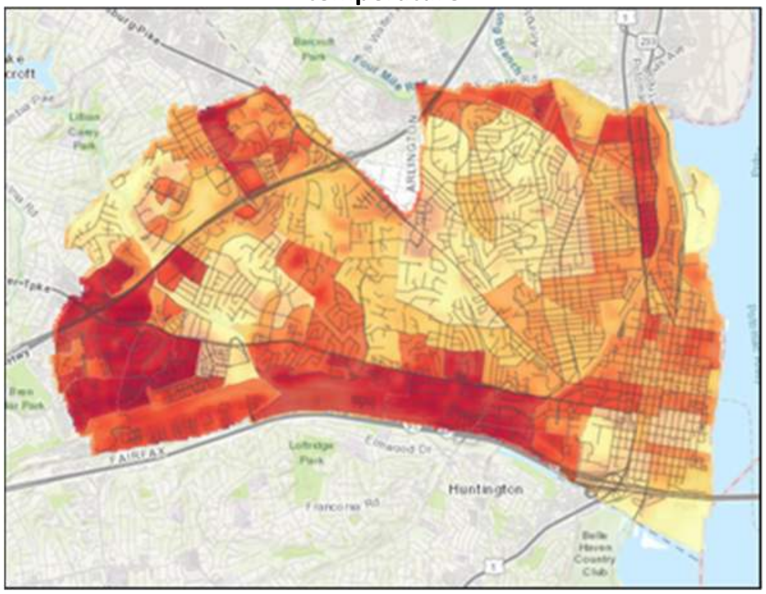
Option A – HVI by block groups, no boundaries (no streets layer)



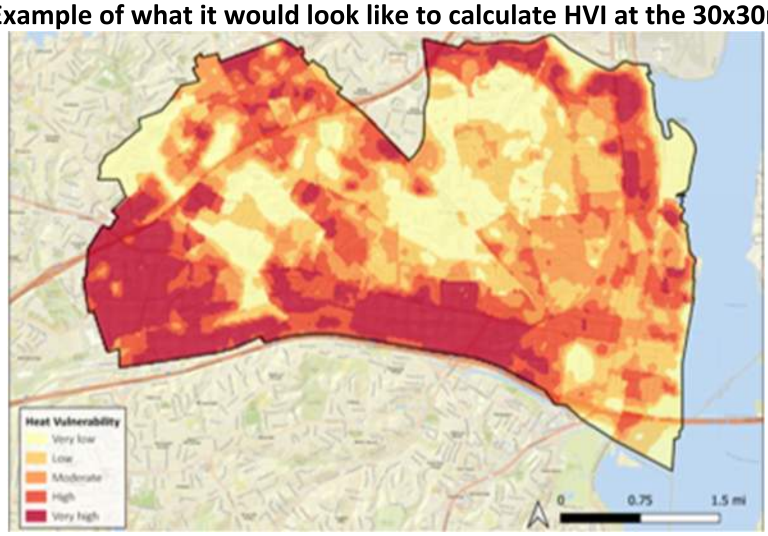
Option B – HVI by block groups, no boundaries (w/ streets layer)



Option C – HVI by block groups, no boundaries (w/ streets layer), overlaid on land surface temperature



Option D – Example of what it would look like to calculate HVI at the 30x30m resolution



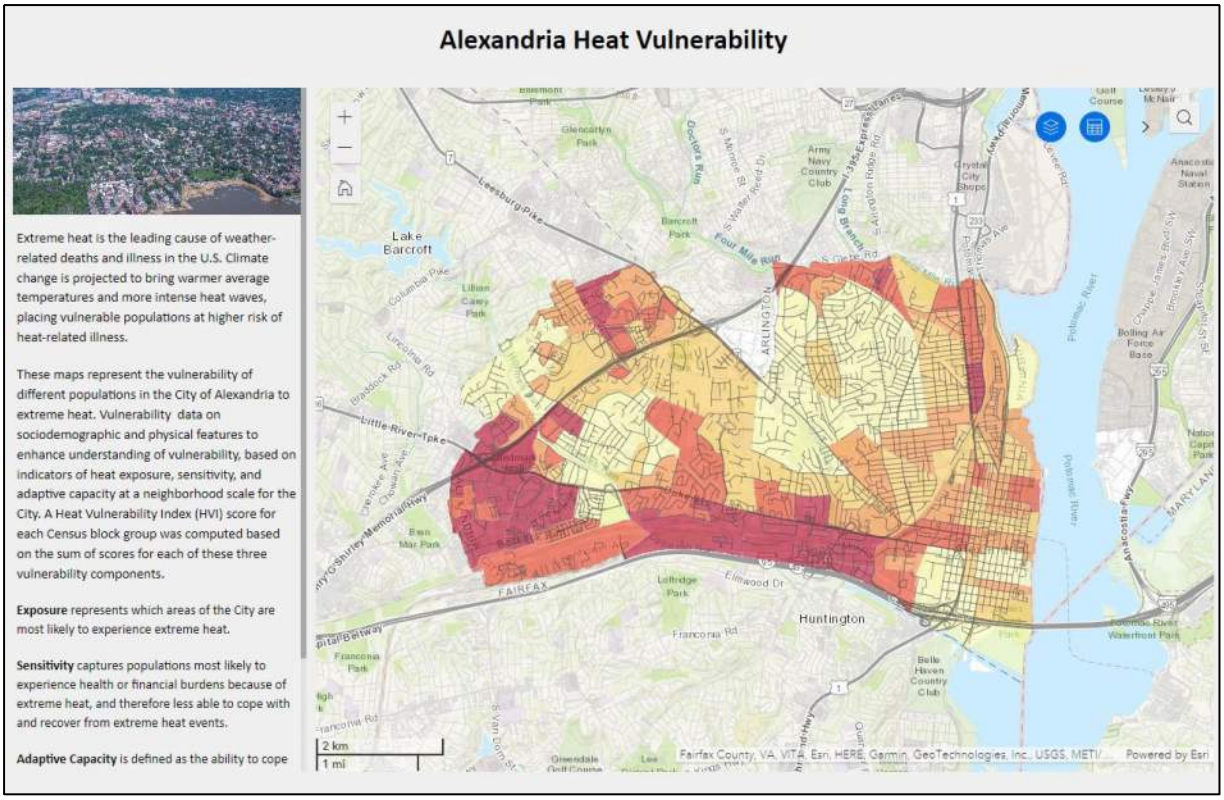


Figure 1. HVI

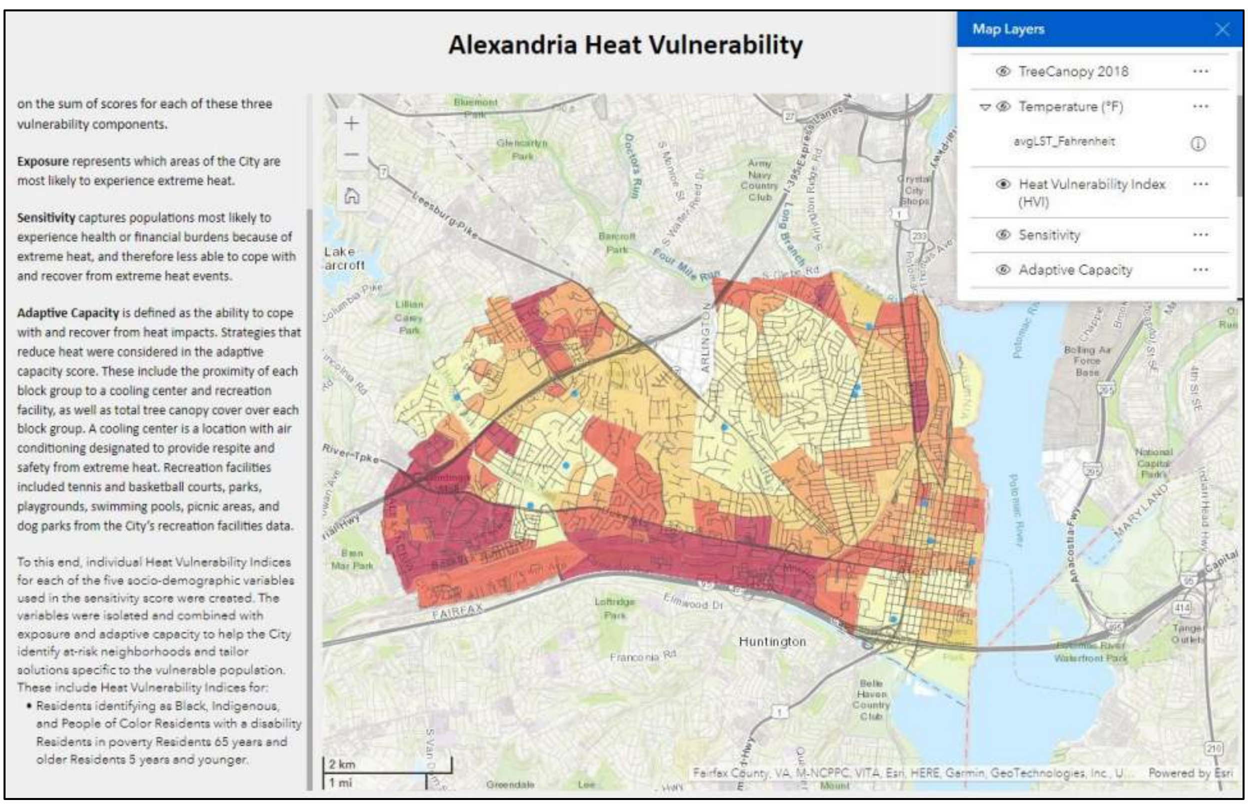


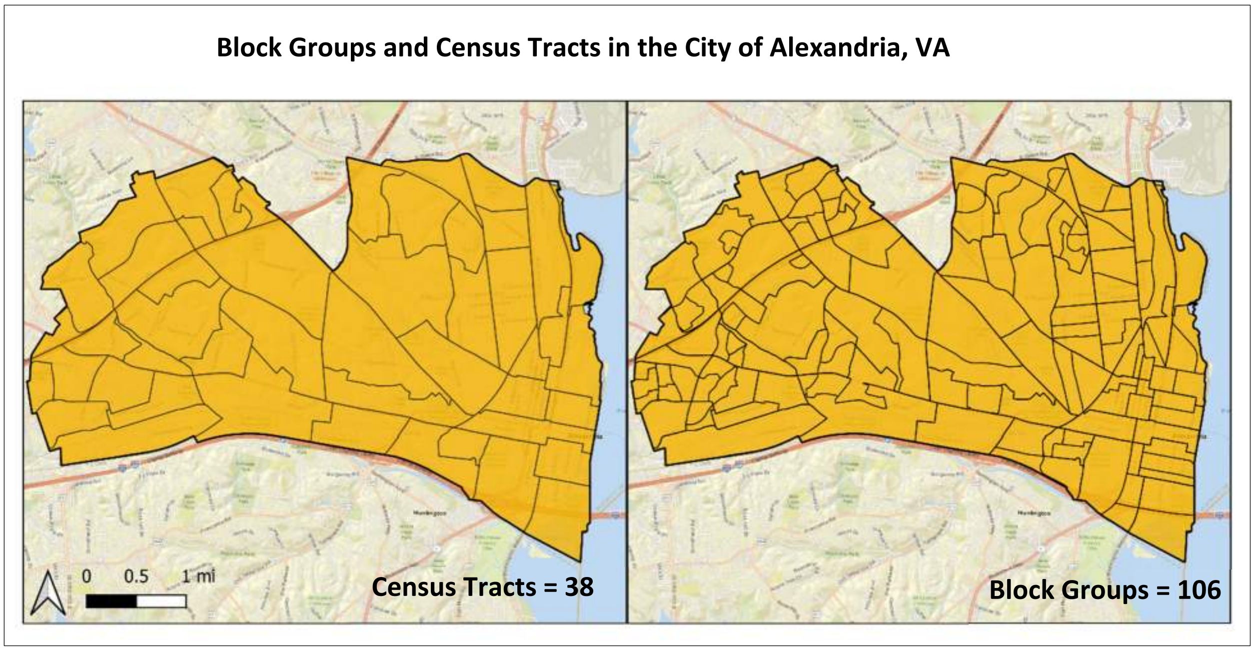
Figure 2. HVI & Cooling Centers

Heat Vulnerability Assessment Methodology

The City of Alexandria conducted a heat vulnerability assessment to identify areas with greatest vulnerabilities and opportunities for adaptation. A Heat Vulnerability Index was calculated for each Census block group in the City.

The vulnerability assessment was conducted at the block group level, as opposed to larger census tracts to analyze heat vulnerability at a smaller geographic granularity (see Figure 16). The higher resolution will enable the city to make more targeted adaptations based on identified vulnerabilities.

Figure 16: Census Tracts and Block Groups in Alexandria



The Heat Vulnerability Index included variables representing the three components of vulnerability, based on the following formula:

$$Heat\ Vulnerability\ Index\ (HVI) = Exposure\ (E) + Sensitivity\ (S) + Adaptive\ Capacity\ (AC)$$ [42]

Where:

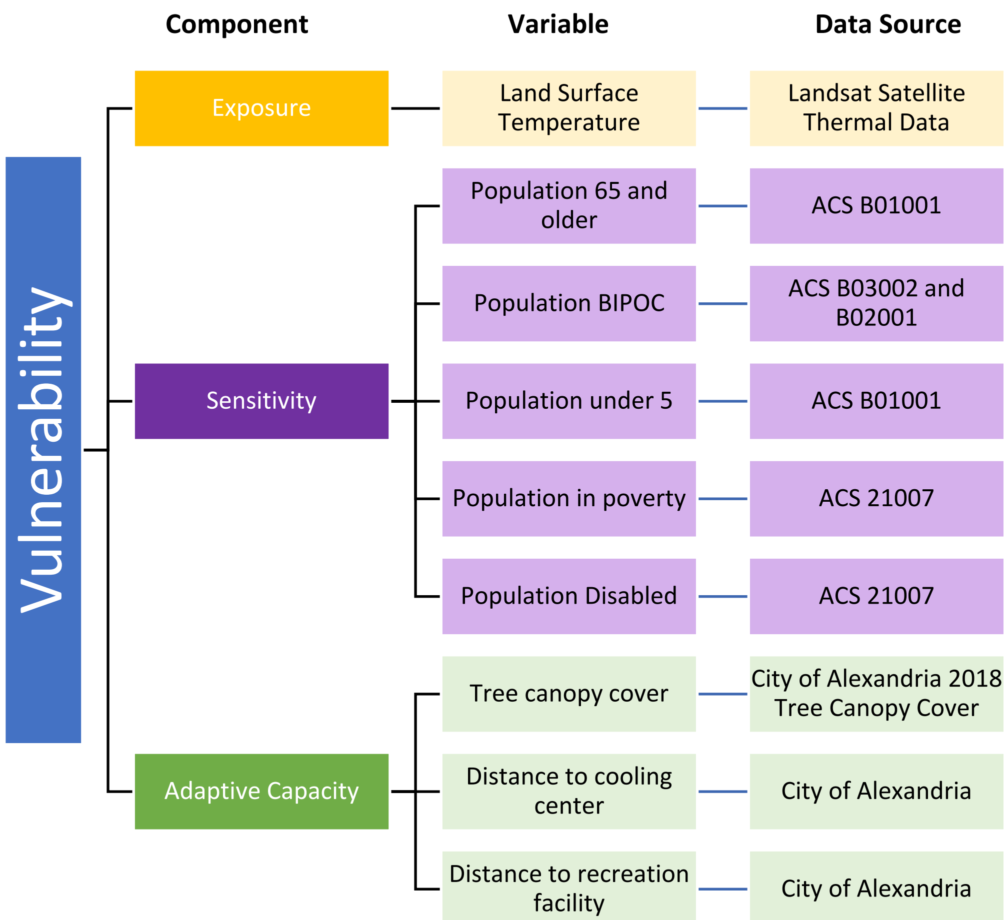
- **Heat Vulnerability Index** for each block group was scored on a scale of 0 (least vulnerable) to 3 (most vulnerable), which effectively ranked HVI's among block groups within the City of Alexandria
- **Exposure** was determined by the block group's relative land surface temperature, compared to regional maximum and minimum temperatures, from two extreme heat events.
- **Sensitivity** included an aggregated average of social variables which increase vulnerability to urban heat risk (Adults Aged 65 and Older, Minority Status, Poverty, Disability Status, and Children Aged 5 and Younger)

[42] 8. HHVA Methodology 4.5.2021.pdf (harriscountytx.gov)

- **Adaptive Capacity** included an aggregated average of physical characteristics of block groups which increase adaptive capacity and decrease overall vulnerability. In this assessment, we will assess tree canopy cover, proximity of block groups to cooling centers, and proximity of block groups to recreation amenities and green space.

The overall methodology is summarized in Figure 17. Each component type and its associated variables are described in greater detail below. Each component was scored on a scale of 0 to 1, where 0 represents lowest vulnerability and 1 is highest vulnerability. This resulted in a possible HVI range of 0 to 3.

Figure 17: Heat Vulnerability Index Components



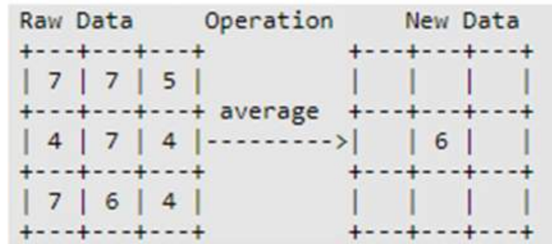
Exposure

Exposure was calculated using the average relative land surface temperature in each block group for two summer days.[43] This produced a value between 0 and 1 for each block group's temperature and was assessed within percentile ranges above minimum temperature and up to the maximum temperature during a given extreme heat event.

[43] Land surface temperatures are generated utilizing LANDSAT 8 Thermal Infrared Sensor (TIRS) taken on July 29, 2020 and September 2, 2021. These images were selected as the least cloudy Landsat images from summer months (June through September) 2020 to 2022.

The City extracted land surface temperature from two Landsat images using Google Earth Engine. A methodology developed by Ermida et al. was utilized to transform top of atmosphere values into land surface temperature values.[44] Two Landsat 8 images from summer months (May through September) from 2020 to 2021 were selected using optimization techniques that selected the images with the least amount of cloud cover over the city of Alexandria. Minimal cloud cover is desired because clouds prevent the satellite sensor from taking measurements, leaving a blank area without data. Landsat does not capture temperature directly, but rather the top of atmosphere (TOA) brightness temperature. The TOA temperature was converted into land surface temperature by combining TOA measurements with the Normalized Vegetation Index (NDVI), atmospheric data, and surface emissivity. After land surface temperature was calculated, the two images were uploaded to QGIS and clipped to the city's boundary. From there, the average pixel value was calculated on a cell by cell basis following NVRC Urban Heat Islands methodology.[45] The r.neighbors[46] tool was used to calculate the mean statistics for each cell in the surrounding [area] (see Figure 18).

Figure 18: Sample of the r.neighbors Tool in QGIS. This method was used to smooth the average land surface temperature layer.



The land surface temperature was normalized on a scale of 0 to 1 using the equation for exposure. The minimum temperature was subtracted from the average land surface temperature value from the r.neighbors output for each cell and divided by the difference between the maximum and minimum temperature. This resulted in a scaled value ranging from 0 to 1 for each 30m-by-30m cell. Zonal statistics were calculated to find the average scaled value variation for each block group.

$$Exposure^{47} = \frac{Block\ Group\ Average\ Temperature - Minimum\ Temperature}{Maximum\ Temperature - Minimum\ Temperature}$$

Inputs for Sensitivity

Sensitivity captures which populations may be most likely to experience health or financial burdens because of extreme heat. Five socio-economic variables were identified from existing literature discussing vulnerable demographics and indicators that contribute to heat vulnerability.

[44] Ermida, S.L., Soares, P., Mantas, V.M., Göttsche, F., & Trigo, I.F. (2020). Google Earth Engine Open-Source Code for Land Surface Temperature Estimation from the Landsat Series. Remote. Sens., 12, 1471.
[45] https://www.novaregion.org/1509/Urban-Heat-Islands
[46] This makes each cell category value a function of the category values assigned to the cells around it, and stores new cell values in an output raster map layer.
[47] The input for this equation is the smoothed average of the two Landsat images.

Previous studies (Reid et al., 2009[48]; Conlon et al. 2020[49]; Nayak et al. 2018[50]) used principal component analysis (PCA) to distill various vulnerability factors to determine a heat vulnerability index. The City drew on these analyses to identify variables for use in the heat vulnerability assessment, limiting the number of variables to five in order to focus the assessment and its outcomes. The variables and justification for including them are described below.

- **Percentage of Population 65 and Older;**
  - People who are 65 years and older are more prone to heat-related health problems, according to the CDC[51]
  - Data source: Census Bureau ACS 2020 5-Year Estimates Table B01001
    - Added population estimates for males and females 65 years and older
- **Percentage of Population 5 and Younger;**
  - Young children are more susceptible to heat illness than adults, due to greater surface area to body mass ratio, lower rates of sweating, and slower rates of acclimatization[52]
  - Data source: Census Bureau ACS 2020 5-Year Estimates Table B01001
    - Added population estimates for males and females 5 years and younger
- **Percentage of Population Designated as Black, Indigenous, or Persons of Color (BIPOC)**
  - Minority groups are more likely to experience heat risk due to comorbidities associated with higher rates of asthma in youth and COPD in adults.[53]
  - Data source: Census Bureau ACS 2020 5-Year Estimates, Table B03002 and Table B02001
    - This variable is the percentage of the population that identifies as non-white.
- **Percentage of Population with Poverty Status**
  - Individuals in poverty are less likely to be able to afford air conditioning, leaving them susceptible during extreme heat events.
  - Data source: Census Bureau ACS 2020 5-Year Estimates, Table C21007, "Age by Veteran Status by Poverty Status by Disability Status for the Civilian Population 18 Years and older"
    - Estimates for the number of nonveteran and veterans below the poverty line were added together for populations under 64 and 65 and older to get total estimates for the population below the poverty line for residents 18 years and older
- **Percentage of Population with Disability Status;[54]**

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[48] Reid CE, O'Neill MS, Gronlung CJ, Brines SJ, Brown DG, Diez-Roux AV, et al. (2009). Mapping community determinants of heat vulnerability. *Environmental Health Perspectives,* 117(11):1730-1736, PMID: 20049125, 10.1289/ehp.0900683

[49] Conlon KC, Mallen E, Gronlund CJ, Berrocal VJ, Larsen L, and O'Neill MS. (2020). Mapping Human Vulnerability to Extreme Heat: A Critical Assessment of Heat Vulnerability Indices Created Using Principal Components Analysis. *Environmental Health Perspectives,* Vol. 128, No. 9.

[50] Nayak SG, Shrestha S, Kinney PL, Ross Z, Sheridan SC, Pantea CI, Hsu WH, Muscateillo N, Hwang SA. (2018). Development of a heat vulnerability index for New York State, Public Health, Volume 161, Pages 127-137, ISSN 0033-3506, https://doi.org/10.1016/j.puhe.2017.09.006

[51] Heat Stress in Older Adults | Natural Disasters and Severe Weather | CDC

[52] Heat illness in children - PubMed (nih.gov)

[53] Johns Hopkins University - Health Effects of Extreme Heat among Vulnerable Populations with Asthma and COPD (nih.gov)

[54] Based on the census block group dataset "Poverty Status in the Past 12 Months by Disability Status"

- Individuals with disabilities are more likely to be unemployed and earn less income compared to those without disabilities. Additionally, disabilities create mobility issues which reduces access to cooling centers and other resources.[55]
    - Data source: Census Bureau ACS 2020 5-Year Estimates, Table C21007
        - Estimates for the number of nonveteran and veterans with disabilities were added together for populations under 64 and 65 and older to get total estimates for the population disabled and population below the poverty line for residents 18 years and older
- *Additional Variables for Consideration that were not included in the sensitivity score: Income by Household, Immigration Status, Housing Density, Adults with Asthma and/or COPD, Adults with Diabetes, Percentage of Population without Health Insurance, Percentage of Population Working Outdoors, Educational Attainment*

The overall sensitivity score for each block group were quantified as an aggregated percentage of total block group populations vulnerable to heat, out of the overall total population of each block group.

$$Sensitivity\ Per\ Variable = \frac{\text{Vulnerable Population}}{\text{Total Population}}$$

$$Sensitivity = \frac{Sensitivity\ Per\ Variable\ (S1 \ldots S5)}{5\ Social\ Variables}$$

Inputs for Adaptive Capacity

Adaptive capacity captures physical characteristics of surface conditions and cooling resources at the block group level. Adaptive capacity is primarily achieved through higher degrees of tree canopy cover and the presence of cooling centers within reasonable walking or commuting distance.[56]

The methodology accounted for the following physical attributes of each block group:

- **Percentage of tree canopy cover**
    - This variable was scored on the inverse of the percentage of the block group with tree canopy cover, whereby a score of 1 represents no tree canopy (and higher vulnerability), and 0 represents lower vulnerability.
    - Data source: City of Alexandria Tree Canopy Cover
- **Distance from locations of cooling centers**
    - Block groups were scored based on the distance to the closest cooling center from the block group centroid, as shown in the table below.

Distance to closest cooling center	Score (1 = higher vuln)
≤ 0.5 miles	0
0.5 – 1 mile	0.5
> 1 mile	1

    - Data source: City of Alexandria

[55] Climate Change and the Health of People with Disabilities (epa.gov)
[56] 8. HHVA Methodology 4.5.2021.pdf (harriscountytx.gov)

- Cooling center locations[57]:
    - Charles Houston Recreation Center (901 Wythe St.)
    - Leonard "Chick" Armstrong Recreation Center (25 West Reed Ave.)
    - Lee Center (1108 Jefferson St.)
    - Mount Vernon Recreation Center (2701 Commonwealth Ave.)
    - Nannie J. Lee Recreation Center (1108 Jefferson St.)
    - Patrick Henry Recreation Center (4653 Taney Ave.)
    - William Ramsay Recreation Center (5650 Sanger Ave.)
    - Libraries (Branch hours vary, check the links below for hours)
    - Charles E. Beatley, Jr. Central Library (5005 Duke St.)
    - Kate Waller Barrett Branch Library (717 Queen Street)
    - Ellen Coolidge Burke Branch Library (4701 Seminary Road)
    - James M. Duncan Branch Library (2501 Commonwealth Ave.)
- **Distance from recreation amenities (sports fields/courts, swimming pools, public gardens, playgrounds, picnic shelters, and dog parks)**
  - Block groups were scored based on the distance to the closest open or green space from the block group centroid, as shown in the table below.

Distance to recreation amenities	Score (1 = higher vuln)
≤ 0.5 miles	0
0.5 – 1 mile	0.5
> 1 mile	1

  - Data source: City of Alexandria

The overall adaptive capacity score for each block group was quantified as a portion or number of resources over a given block group. For example, for tree canopy over, adaptive capacity will be calculated as follows:

$$Tree\ Canopy\ Cover\ variable = 1 - \ Proportion\ Tree\ Canopy\ Cover\ of\ Block\ Group$$

$$\text{Adaptive Capacity} = \frac{Cooling\ Center\ Score + Adaptive\ Capacity\ Score + Proportion\ nontree\ canopy\ cover}{3}$$

The overall adaptive capacity score is an average of each of the three variable scores. A higher score corresponds to lower adaptive capacity. This is the opposite of the exposure and sensitivity variables where higher scores correspond to higher exposure or sensitivity. Scores for all three variables were arranged so that higher scores correspond to higher vulnerability.

Output Assessment of Priority Areas (Census Tracts or Block Groups) of Heat Vulnerability

An aggregated Heat Vulnerability Index across block groups for the entirety of Alexandria was developed by adding the exposure, sensitivity, and adaptive capacity scores together. Additionally, the Heat Vulnerability Indices were broken down by each of the five social variables into separate, viewable, layers. The separate sensitivity HVIs were created by adding the sensitivity variable (as proportion of the population from each block group) with the exposure and adaptive capacity scores.

[57] Summer Cooling Options for Alexandria Residents and Seniors | City of Alexandria, VA (alexandriava.gov)

The Heat Vulnerability Index scores by census tract or block group will help the City identify and assess priority areas for targeted adaptation interventions.