Addressing the Urban Heat Island Effect in Alexandria, Virginia

December 16th, 2022

Authors

Nicholas Culkin

Lexi Dahlquist

Gabriel Garbes

Jonathan Martin

Dreivone Townsend

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An interactive qualifying report proposal submitted to the faculty of
Worcester Polytechnic Institute
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the degree of Bachelor of Science.

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Authors
Nicholas Culkin
Lexi Dahlquist
Gabriel Garbes
Jonathan Martin
Dreivone Townsend

Report Submitted to
Bill Eger
Energy Manager, City of Alexandria, Virginia
Steve Waltz
Member of Alexandria Energy and Climate Change Task Force

Advisors
Professor Fred J. Looft
Professor Linda C. Looft
Worcester Polytechnic Institute

Abstract

The project goal was to provide recommendations to help the City of Alexandria mitigate the effects of Urban Heat Islands (UHI). The team compiled individual, existing geospatial, demographic, and temperature maps of Alexandria into a database. We documented the impact of extreme heat events on City infrastructure and vulnerable groups using the acquired geospatial, demographic, and temperature maps. We determined the best UHI mitigation strategies and improvements for affected regions of Alexandria based on their physical, and socioeconomic attributes. Finally, we recommended improvements for current practices to mitigate the effects of urban heat islands. Resulting recommendations including outreach, tangible techniques, and future research.

Acknowledgements

Our team has learned a significant amount of information on Urban Heat Islands and City policy. The best part of our project was learning about the City of Alexandria and Washington DC. The insight gained from this helped us understand the communities we were helping and inspired us to find creative ways to help the City.

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    - The Alexandria Health Department
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    - The Race and Social Equity Office
    - The Office of Housing
    - The Department of Planning and Zoning
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Addressing the Urban Heat Island Effect in Alexandria, VA

Executive Summary

December 16th, 2022

Introduction

Urban heat islands (UHI) in cities like Alexandria, Virginia are exacerbated by condensed populations, dense construction materials, and compact building distributions, and can have a direct impact on residents' quality of life (*Heat safety*. n.d.). For example, Alexandria officials describe in their heat safety summary that dangerous and even fatal health hazards such as heat stroke, exhaustion, and cramps can occur as a result of extreme heat events (Heat safety, 2022).

These increased temperatures have also resulted in more greenhouse gas emissions as they encourage the use of cooling appliances that rely on mostly nonrenewable energy sources (Renewable energy policies in a time of transition: Heating and cooling, 2020).

UHIs also place additional socioeconomic pressures on disadvantaged populations by increasing the cost of living and financial inequality (Miner, 2016). For example, the energy cost in low-income housing is often greater because those buildings lack efficient cooling as a result of inadequate building maintenance, "poor structural conditions and energy inefficiencies" (Hernández, 2015) ("Low-Income Household Energy Burden Varies Among States — Efficiency Can Help in All of Them," 2018).

To improve the quality of life for its citizens and its overall climate health, the City of Alexandria and the Metropolitan Washington Council of Governments (MWCOG) have started to tackle the problem of UHIs in the City, but their preliminary strategies needed to be improved upon with expanding approaches to the problem.

Methods

The goal of this project was to provide recommendations to help the City of Alexandria in their efforts to mitigate the effects of urban heat islands. To achieve this goal, we identified the following four objectives to accomplish this goal:

1. Compile individual existing geospatial, demographic, and temperature maps of Alexandria into a database.
2. Document the impact of extreme heat events on critical City infrastructure and vulnerable groups using the acquired geospatial, demographic, and temperature maps.
3. Determine the best UHI mitigation strategies and improvements for affected regions of Alexandria based on their physical and socioeconomic attributes.
4. Develop a report that recommends improvements for current City practices to mitigate the effects of urban heat islands.

The first objective was completed by obtaining topographical, temperature, and demographic data from NASA Satellites, the City of Alexandria's GIS depository, the City of Alexandria's website, census logs, and geographic data from ArcGIS online. The website was wrapped up by compiling and organizing the results.

For the second objective, the team analyzed the individual geospatial maps compiled in the first objective and used this analysis to create new viewpoints of the existing data by overlaying key demographic, City operational, and other pertinent data with temperature maps.

To complete the third objective, the team organized the City's resources and previous research and used it to determine whether the general practices have already been implemented in Alexandria. Also in this objective, the team conducted interviews with experts who specialize in urban heat islands as well as community members in Alexandria to gather more information about the impact of UHIs.

Finally, for the fourth objective, the results of the previous objectives were compiled into a report that detailed the team's research and recommendations for improvements on Alexandria's UHI mitigation and adaptation tactics.

Results

This section describes key findings of the project. From the database created for our first objective, gaps in the City of Alexandria's research were identified, which allowed the team to select critical topics for the new map views to be created. After compiling the database and conducting initial background research, the team developed some additional maps through ArcGIS to add to the City's database. These maps help fill the gaps in the City's research and include maps describing different factors, such as park and cooling center location, versus the average temperatures in Alexandria.

To address these gaps, a series of interviews were completed with experts, local department heads, and community groups. Departments interviewed included the Department of Community and Human Services, the Alexandria Health Department, the Race and Social Equity Office, the Office of Housing, the Department of Planning and Zoning, the Office of Energy Management, and a specialist from the National Oceanic and Atmospheric Administration (NOAA). Overall, the team learned through these interviews that the City of Alexandria does not have many policies in place to directly mitigate the UHI problem, but the departments were open to improvements on how to proceed forward. The team also took the information to help guide several tables to discern which strategies would be the most appropriate for the City of Alexandria to pursue. More information about this process is detailed in the full report.

Recommendations

Below are the recommendations the team has provided for the City of Alexandria divided into two groups: strategies and further research.

Strategies

Through the collected research and the results, the team selected the following strategies as the best recommendations for the City of Alexandria. These mitigation strategies are followed by a small paragraph that contains a of the strategy and outlines their strengths and limitations.

1) **The City of Alexandria should implement outreach programs to inform the population.**

Strategies like the use of pamphlets (like the one shown in figure 32 in Appendix E), newspaper PSAs, social media posts and community workshops could be used to inform the population about the signs, risks, and possible solutions to UHIs and EHEs.

2) **The City of Alexandria should gather data and expand their cooling centers strategy.**

As seen in the Cooling Centers vs Temperature map in Appendix A, there are 15 cooling centers in Alexandria, but they tend to be clumped together in hot areas, which brings about access and transportation concerns. The City should begin to establish more cooling centers throughout the City and disperse them evenly for more widespread access.

3) **The City should update their vegetation policy to include other green alternatives.**

The City of Alexandria has begun to expand vegetation throughout the city, but their efforts could be improved by implementing more tree canopies, green roofs, rooftop gardens and vegetation walls.

4) **Alexandria should utilize cool surfaces to help reflect sunlight and reduce pavement temperatures.**

We recommend the City of Alexandria implements reflective coatings on roofs and pavements to reduce the amount of energy these surfaces typically absorb and amplify.

5) **The City of Alexandria should use careful urban planning and design to encourage airflow.**

It is recommended that the City of Alexandria begin using alternative construction materials. These materials such as retro reflector materials and thermal insulated materials could help prevent the absorption and retention of heat from the conventional dense materials. The City should also begin to emphasize the importance of building arrangements that allow proper airflow and ventilation to avoid heat.

6) **The City of Alexandria should expand and advertise their cooling assistance programs.**

The City of Alexandria has sanctioned in two main cooling assistance programs that help cover the cost of cooling appliances for vulnerable populations. This program can use some improved advertising by updating the graphic designs of posters and advertising in newspapers

to appeal to this populations' traditional source of news and information.

Further Research

This section discusses possible future projects and research endeavors that the City of Alexandria should pursue to better address the problems of UHIs and EHEs in the City.

1) **The City of Alexandria should apply for the NOAA mapping campaign.**

The City of Alexandria should apply for the 2023 UHI Mapping Campaign hosted by the National Oceanic and Atmospheric Administration or NOAA. A description of this campaign, the need for community support of the campaign, and how the City can use the data that results from the campaign is provided in Appendix D.

2) **The City of Alexandria should identify vulnerable populations to implement directed strategies.**

Our research covered some of the major vulnerable populations such as adults over 60, children under 6, people with disabilities, and low-income housing. However, the City would benefit from additional geospatial data, population density numbers, and health information on some of the smaller vulnerable populations.

3) **The City of Alexandria should conduct a heat analysis on its power and water systems**

The City should conduct a heat analysis on power and water systems to see how these critical infrastructure systems are affected by extreme heat since the team did not have access to this sensitive information.

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Section	Primary Authors	Primary Editors
Paragraph 1	Lexi	Gabe
Paragraph 2	Lexi	All Members
Paragraph 3	All Members	All Members
Paragraph 4	All Members	All Members
Appendices and References Sections	All Members	All Members

Background Authorship Table:

Section	Primary Authors	Primary Editors
2.1	Lexi	Lexi
What are they?	Gabe	All Members
What Causes UHIs?	Gabe	All Members
How to recognize UHI effects	Lexi	All Members
What are the impacts of UHIs?	Gabe	All Members
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Voluntary Efforts	Gabe	All Members
Policy	Jon	All Members
2.2.2	Lexi	All Members
Trees and Vegetation	Jon	All Members
Cool Pavements	Lexi	All Members
Roofing Technologies	Nic	All Members
2.3	Jon	All Members
The Problem of UHIs in the City	Gabe	All Members
Local Action to Mitigate UHIs	Dre	All Members
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Methodology Authorship Table:

Section	Primary Authors	Primary Editors
3	Lexi	Lexi, Dre
3.1	All Members	Jon
3.2	All Members	Dre
3.3	All Members	Nic, Lexi
3.4	All Members	Dre, Jon, Lexi
Appendices and References Sections	All Members	All Members

Results and Key Findings Authorship Table:

Section	Primary Authors	Primary Editors
4	Gabe	All Members
4.1	Gabe	Lexi
4.2	Lexi,	All Members
4.3	Gabe, Nic, Jon, Dre	All Members
4.3.1	Gabe, Nic, Jon, Dre	All Members
4.3.2	Jon	All Members
4.4	Lexi	Gabe, Jon, Dre

Recommendations and Conclusions Authorship Table

Section	Primary Authors	Primary Editors
5.1	Gabe	Lexi
5.1.1	All Members	All Members
5.1.2	Gabe, Dre	Jon
5.2	Nic	All Members

1.0 Introduction

Although human-induced climate change has been recognized for over 80 years (Callendar, 1938), relatively recent efforts of scientists, policymakers, and activists have encouraged City governments to evaluate the local and global impacts of climate change (The White House, 2022). This increased focus on climate health has consequently generated research that theorizes a given modern metropolis is, during the day, expected to sustain an average surface temperature of 1-7°F greater than the surrounding rural areas, a phenomenon known as the Urban Heat Island (UHI) Effect (Wang, 2021) (Learn About Heat Islands | US EPA, 2022).

Urban heat islands in cities like in the City of Alexandria, Virginia are exacerbated by large population densities, compact building distributions, and dense construction materials like steel or concrete. This urban phenomenon can have a direct impact on residents' quality of life (Heat safety. n.d.). For example, Alexandria officials describe in their heat safety summary webpage that dangerous and even fatal health hazards such as heat stroke, exhaustion, and cramps can occur as a result of extreme heat events (Heat safety, 2022).

Increased temperatures have also resulted in more greenhouse gas emissions as they encourage additional use of cooling appliances that rely on mostly nonrenewable energy sources (Renewable energy policies in a time of transition: Heating and cooling, 2020).

UHIs also place additional socioeconomic pressures on disadvantaged populations by increasing the cost of living and financial inequality (Miner, 2016). For example, the energy cost in low-income housing is often greater because those buildings lack efficient cooling retention as a result of inadequate building maintenance, "poor structural conditions and energy inefficiencies" (Hernández, 2015) ("Low-Income Household Energy Burden Varies Among States — Efficiency Can Help in All of Them," 2018).

To improve quality of life for its citizens and overall climate health, the City of Alexandria and the Metropolitan Washington Council of Governments (MWCOG) have begun to implement policies and expand programs to mitigate the effects of UHIs. Alexandria is adopting new and improved strategies that focus on financial cooling assistance, cooling centers, extended hours of operation for public pools, increased plant preservation, and local tree canopy expansion. Alexandria's government agencies have also begun to advocate for more shaded surface parking lots and expand open spaces in the City (Energy and Climate Change Action Plan, 2022). However, to achieve an impactful change, Alexandria is seeking to improve their current UHI response strategies and to implement new best practices for UHI mitigation.

The goal of this project was to provide recommendations to the City of Alexandria that will help in their efforts to mitigate urban heat islands. To develop these recommendations, the team proposed the creation of a database containing existing heat and City related maps, an analysis of the gaps in the City's resources and data, and an evaluation of the City's current mitigation and adaptation strategies.

2.0 Background

The effects of urban heat islands on a community can be harmful if left unresolved, especially in cities with large populations and varying demographics. In this chapter, the team explored the causes and effects of UHIs as well as common mitigation and adaptation strategies that many cities pursue.

2.1 Urban Heat Islands

UHIs are defined by the United States Environmental Protection Agency as "urbanized areas that experience higher temperatures than outlying areas" (Heat Island Effect, 2022). According to other research studies, urban regions tend to exhibit greater temperatures as a result of factors such as greater population density, more greenhouse gas emissions, more complex urban planning, and less vegetation. In fact, in terms of greenhouse gas emissions, experts estimate that urban areas, "account for ~70% of global carbon emissions," significantly impacting the temperatures in cities (Wang, 2021, Page 1). The UHIs are illustrated in Figure 1 for the City of Alexandria some regions of Alexandria are hotter than others.

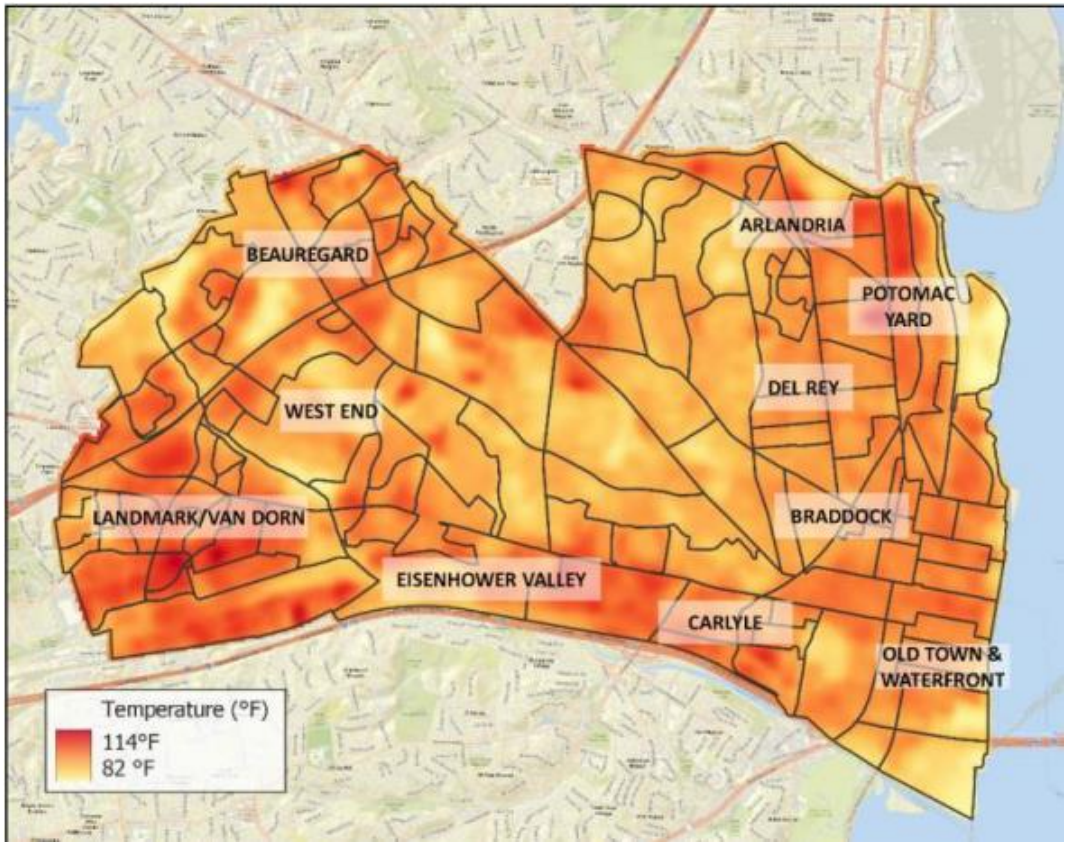


Figure 1. Map of relative surface temperatures in the City of Alexandria. The temperatures range from 82ºF to 114ºF.
(City of Alexandria Energy and Climate Change Task Force, 2022)

According to NASA, the difference in suburban and urban temperatures is likely a result of the differences in the corresponding surface and structural heat absorption abilities. Although

UHI effects are only experienced in urban areas, the nature and composition of rural areas can be used to identify possible mitigation practices for cities. While some of the common ways of mitigating extreme heat have been effective, a more focused approach on addressing Urban heat islands is necessary to mitigate the increasing severity of UHI effects.

What Causes UHIs?

UHIs are caused by several factors, but the effect is most often attributed to a rise in temperature from reduced natural landscapes, increased human activity, and expanded urbanization (Heat Islands, 2022). By reducing the natural landscape of a region through urbanization, the vegetative cooling properties typically perpetuated by evapotranspiration[1] are reduced, thus contributing to an increase in local temperatures. The overall inverse correlation between temperature and vegetation can be seen in Figure 2 where, as tree canopy increases, surface temperature decreases.

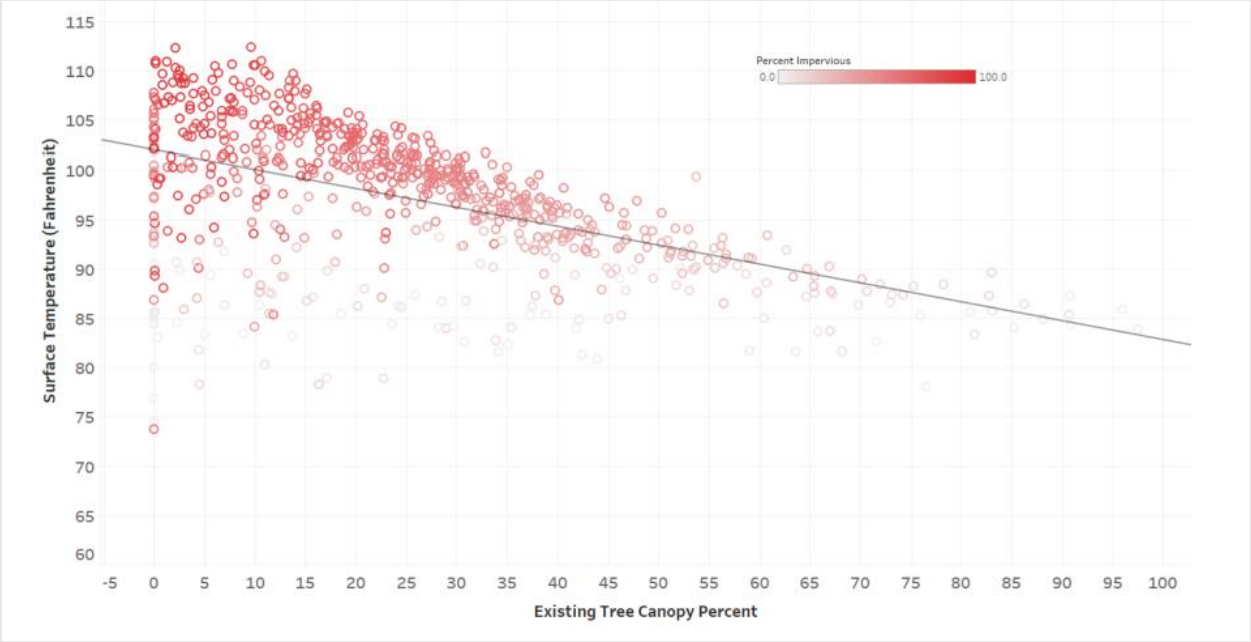


Figure 2. A plot of the surface temperature in degrees Fahrenheit vs. the tree canopy percentage in Boston, MA. (O'Neil-Dunne, 2017)

When vegetation is replaced by urban development, the temperature of a region also increases as the dense construction materials used in most City buildings tend to absorb and amplify incoming solar heat in a way that raises the overall ambient temperature of the City (Urban Heat Island, 2022). A material's ability to reflect or absorb heat is typically measured by

[1] Evapotranspiration is defined as "the sum of all processes by which water moves from the land surface to the atmosphere via evaporation and transpiration" (*Evapotranspiration and the Water Cycle, 2019).*

its albedo[2], where materials with lower albedos absorb more heat, thus increasing local temperatures and materials with higher albedos reflect more heat, thus lowering local temperatures. This relationship between albedo and local temperature can be observed by comparing Figures 3 and 4. In Figure 3, all the plotted materials have the same albedo and also generate very similar air temperatures. However, in Figure 4 where the albedos of each material differ, the air temperatures are also noticeably different. Granite which has an albedo of around 0.3 tends to generate greater air temperatures than limestone which has a greater albedo of around 0.4 (Tufail, 2016).

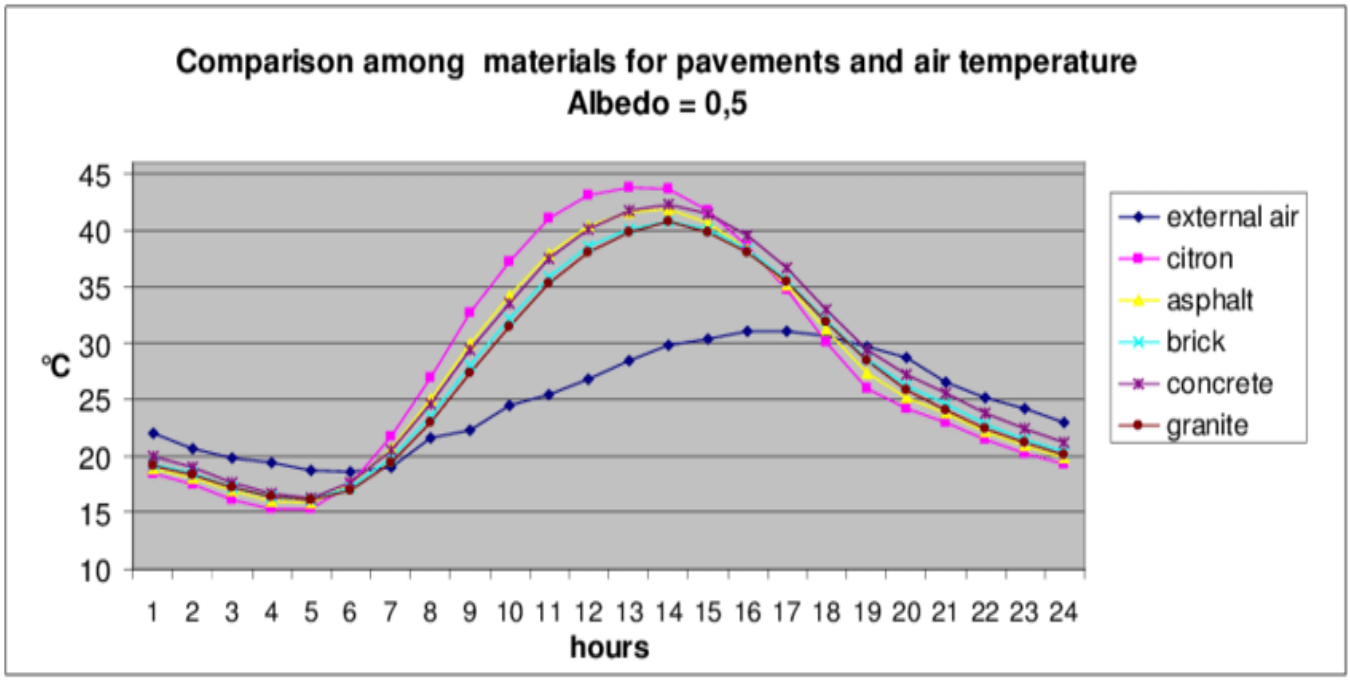


Figure 3. Air temperatures at different times of the day for materials with the same albedo.
(Dessì, 2011)

[2] Albedo is defined as "the ratio of the reflected solar radiation to the incident solar radiation at the surface" (Li, H, 2016a).

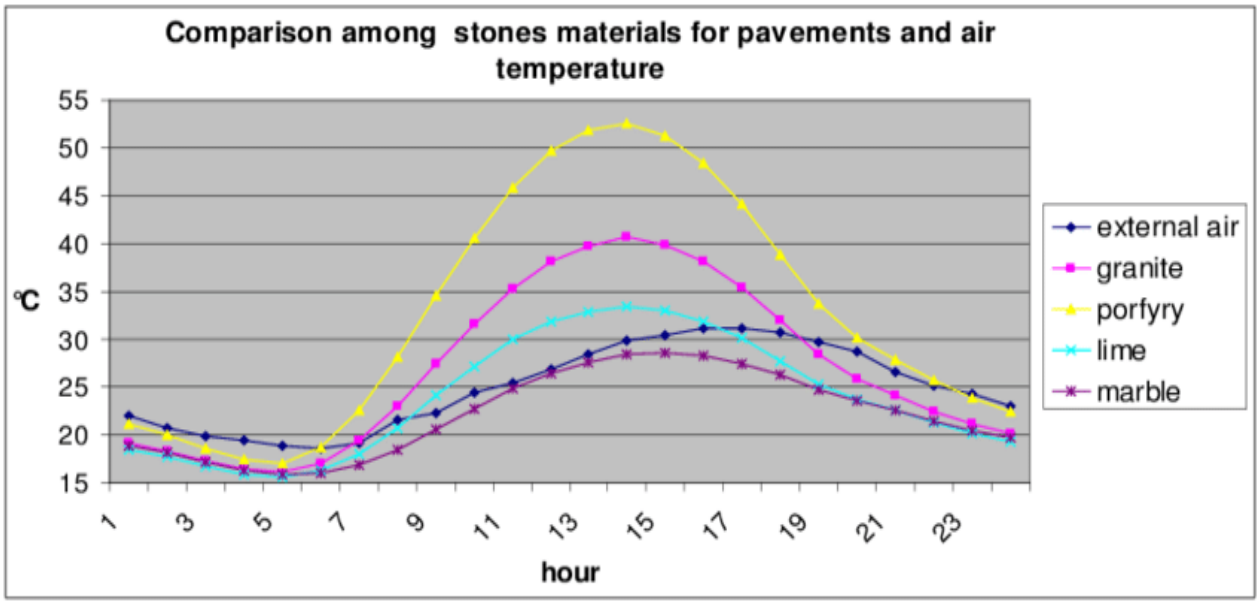


Figure 4. Air temperatures at different times of the day for materials with different albedos.
(Dessì, 2011)

The non-aerodynamic and vertical arrangement of major cities traps heat on lower levels and reduces the amount of air flow present (Keith, 2022), thus further increasing City temperatures (Figure 5). In rural and suburban areas, the lack of tall buildings allow heat to disperse over the area, preventing it from creating pockets of extreme heat. However, in cities, the tall buildings trap the heat and do create these pockets of extreme heat as proper airflow and ventilation do not allow for heat dispersion.

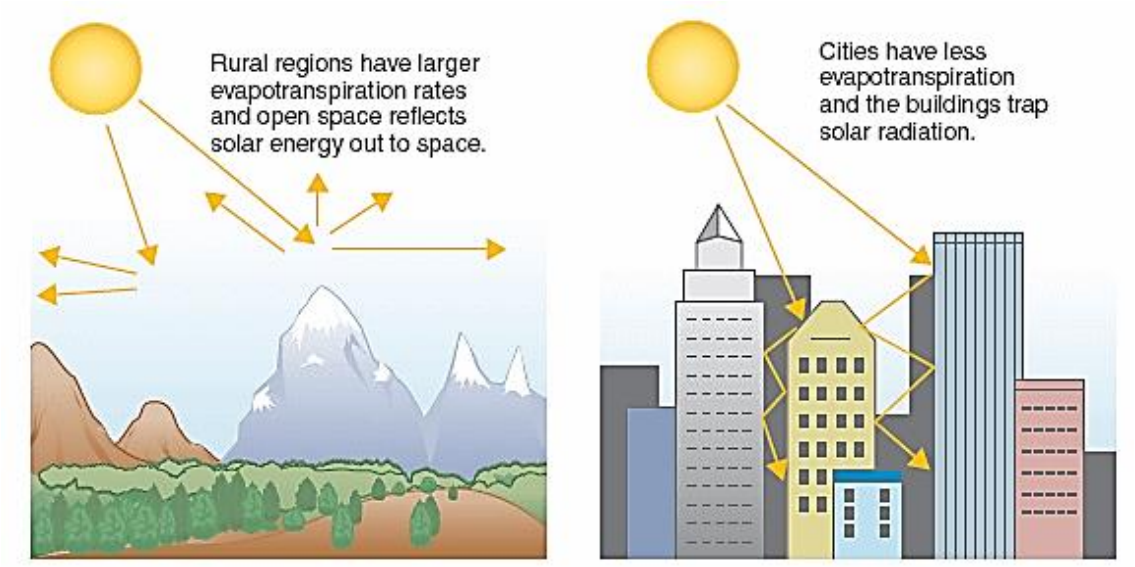


Figure 5. Diagram comparing the heat retention and evapotranspiration capabilities of rural landscapes with abundant vegetation and urban landscapes with dense construction materials.
(Wagle, K, 2018)

There are also factors to consider when analyzing the relationship between population density, which tends to be greater in urban areas, and surface temperatures. Because an increase in population density requires an increase in living spaces, large cities tend to build vertically to accommodate more people. By using dense building materials like concrete for these types of vertical structures, the air and surface temperature will likely increase (Wonorahardjo, 2019).

In a case study of increased urban temperatures in Lagos, Nigeria, researchers concluded that "urbanization and global climate change contributed averagely 60.97% and 39.03% of the urban warming in Lagos, respectively" (Liying, 2022), indicating that urban expansion plays a crucial role in the generation of UHIs. As shown in Figure 6, this differs from rural and coastal areas, where the open and green spaces reduce the heat absorbed by streets and other dark surfaces (Warren, 2004). Another study, in Hangzhou, China, confirmed that "cooling efficiency increased with blue–green landscape density in general" (Xingyu, 2022). In this case, blue landscapes indicate the existence of waterways such as rivers. Green landscapes indicate the strong presence of vegetation. These factors are especially valuable in determining the temperature disparity between urban, suburban, and rural areas. This difference in urban, suburban, and rural temperatures can be seen in Figure 6.

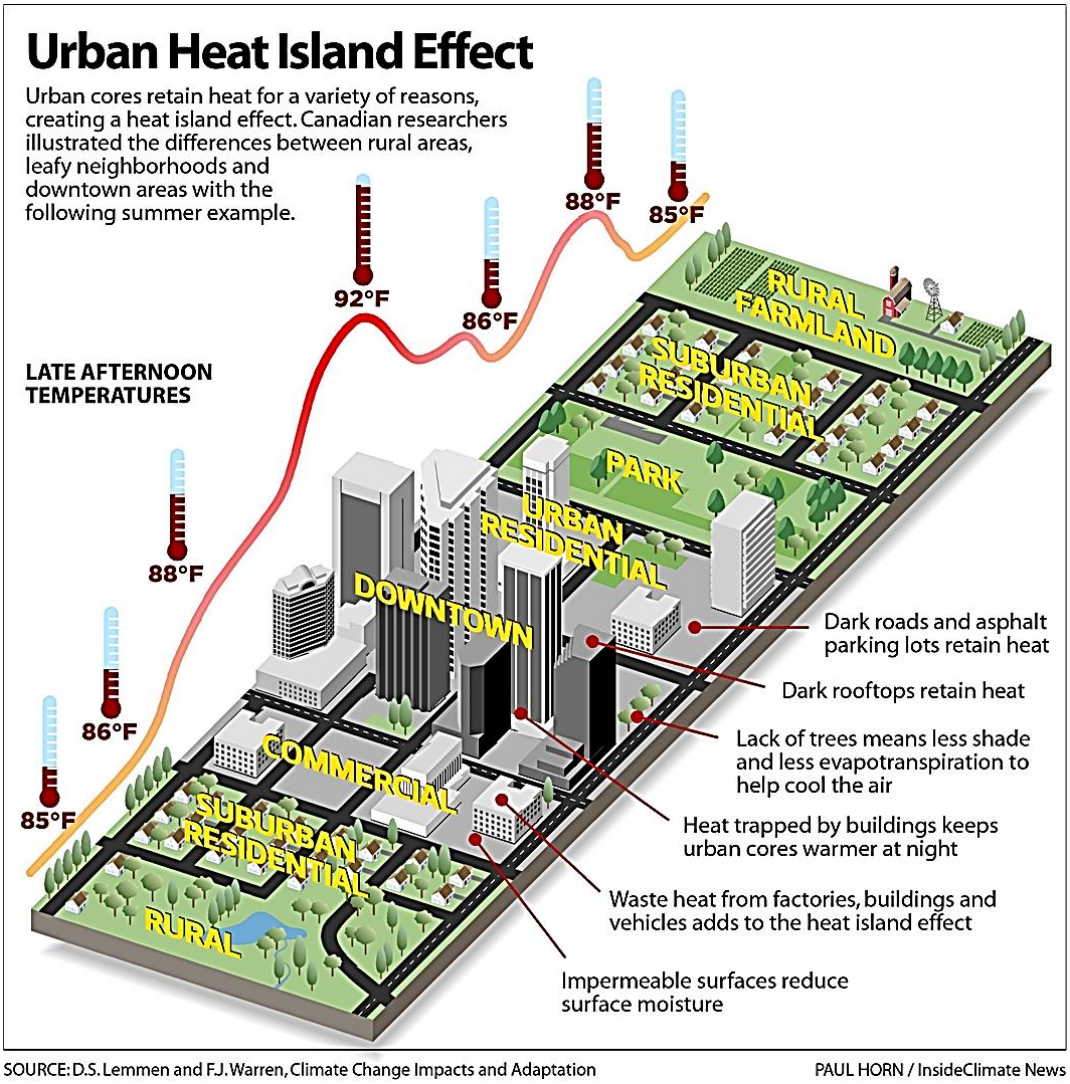


Figure 6. Diagram of the difference in temperatures between urban, rural, and suburban areas based on their vegetation levels.
(Warren, 2004)

How to recognize UHI effects

For a microclimate[3] to meet the criteria of being an urban heat island, some additional conditions other than experiencing extreme heat events need to be met. As outlined in an 1800's report on UHIs, British researcher Luke Howard found that the temperatures within cities are not the natural climate, rather these are artificial climates exacerbated by internal structures, large population, and local greenhouse gas emissions. He claimed, "the temperature of the City is not to be considered as that of the climate; it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and the consumption of great quantities of fuel in fires" (Luke Howard, 2007).

[3] Microclimate is defined as "the statistical state of the atmosphere in the layer being affected directly by the characteristics of the underlying surface." (Rotach, M, 2003)

To identify whether an area is classified as an urban heat island, a comparison must be made with the temperatures of the surrounding areas to determine if the region's temperature aligns with or exceeds the natural local climate. This comparison can be reached by collecting temperature data in the City of interest and comparing it to the temperature data from the surrounding regions. If the readings in the City are the same as those in the surrounding areas, then it is likely just to experience the natural temperature of the day. However, if the difference in temperature readings between the two regions is significantly different, with the temperature of the urban area being greater, then the City is likely experiencing a UHI.

What are the impacts of UHIs?

Two of the most significant impacts of UHIs are heat-related health illnesses, like heat stroke or dehydration, and additional costs among residents of different income levels.

A case study about the extreme heat events in Lagos, Nigeria summarizes the importance of understanding how UHIs impact City residents: "The increasing urban-induced heat…could cause urban residents to suffer more heat-based health risks and increase the extreme events. Therefore, quantifying the impact of urbanization on UHI is of great value for future research on how to mitigate the UHI effect and enhance the comfort of tropical dwellers living in cities" (Liying, 2022). This claim is supported by other researchers like Wang who stated that people can experience several adverse health effects, many of which may be life-threatening, not only on the global scale but also within smaller communities (Wang, 2021).

The most common heat related illness is dehydration, but other more serious problems such as heat stroke, cramps, and exhaustion can occur if people are exposed to high temperatures for an extended period of time (Warning Signs and Symptoms of Heat-Related Illness, 2022). These illnesses are especially dangerous among vulnerable populations such as individuals over 65 or under 6 years old. In addition, during days where extreme heat is present, pre-existing health conditions like asthma can be severely exacerbated (*Summer Asthma and Warm Weather*, n.d.).

During extreme heat events, the demand for energy from cooling appliances increases, and, aside from the rise in greenhouse gas emissions this produces, the energy demand also increases the overall cost of living in the City. Therefore, people of lower income levels may not be able to afford the necessary appliances to remain cool in times of extreme heat. Even when resources such as cooling centers are provided by City governments, these establishments often require paid transportation or are not located near these disadvantaged communities (Jacob, 2020).

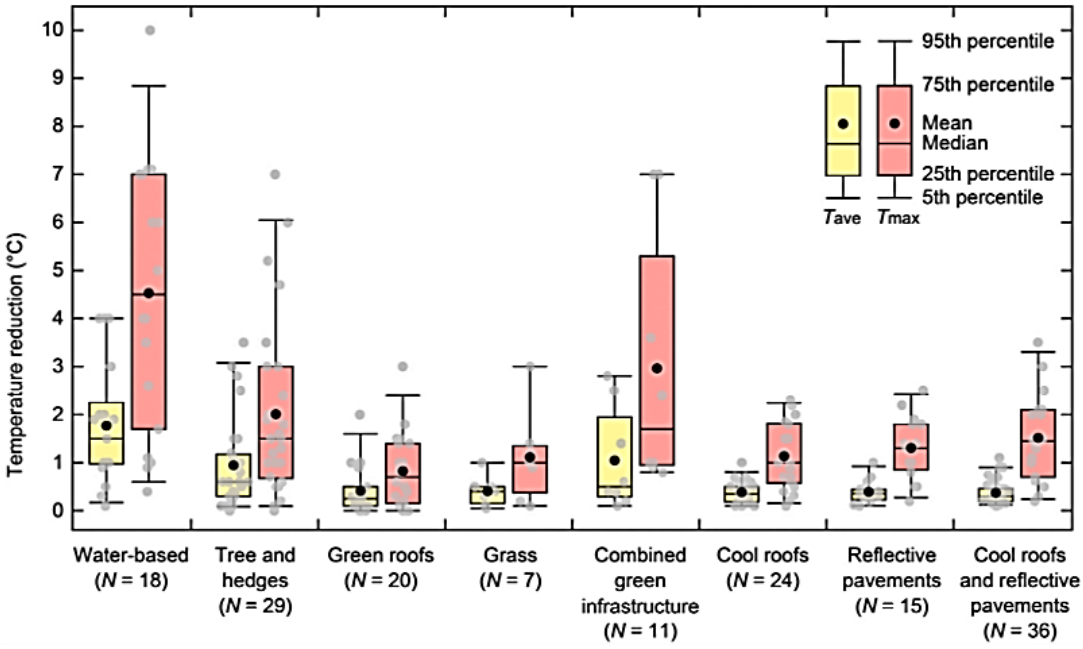
2.2 Mitigating Urban Heat Islands

Cities traditionally use two primary approaches to address UHIs in their communities: societal adaptations and tangible strategies to mitigate extreme heat. Societal adaptations can include changing public policy; providing information to the public; and utilizing firefighter, police, and healthcare resources. Cities can also develop tangible mitigation strategies that

reduce the impact of UHIs on the community. Some strategies that have been implemented with varying effectiveness in communities include building green roofs, incorporating cool pavements, and expanding open space vegetation, as shown in Figure 7 (Wang, 2021).

Figure 7 highlights the effectiveness of the different strategies in lowering the temperature of their surroundings. For example, the plot shows that when water based UHI mitigation strategies are implemented, the average daily temperature, depicted by the yellow box plot, will likely be reduced by about 1.5 degrees Celsius with a maximum reduction of 4 degrees Celsius and a minimum reduction of around 0.2 degrees Celsius. When it comes to the maximum daily temperature, the red box plot shows that water-based strategies are likely to reduce these values by about 4.5 degrees Celsius with a maximum reduction of 9 degrees Celsius and a minimum reduction of about 0.5 degrees Celsius. Ultimately, the combined adaptation and mitigation efforts of all strategies is necessary to substantially reduce the effects of UHIs and improve the quality of life in a City.

Figure 7. A distribution of box plots to describe the effectiveness of different UHI



mitigation strategies through a comparison of maximum and average temperatures. The yellow boxes represent the cooling effects of different strategies on the average daily temperature. The red boxes represent the cooling effects of different strategies on the maximum daily temperature.

(Wang, C, 2021)

2.2.1 Reducing Risk in Communities

Cities can minimize the impacts of UHIs through societal adaptation initiatives that fall under the categories of voluntary citizen efforts or local policy enactment and improvement.

Voluntary Efforts

While the cohesiveness and urban layout differences in communities require varying mitigation efforts, some widely implemented volunteer strategies have been proven to be effective. For example, neighborhood groups can be established to check in on vulnerable populations like the elderly, young children, and those who cannot afford the energy costs of cooling. Developing groups like this will ensure that vulnerable members of the community are adjusting well in times of extreme heat.

One common societal adaptation strategy is expanding City public services and outreach initiatives to increase awareness about extreme heat events and their impacts. Such services and initiatives could help residents identify the early warning signs of dangerous heat-related illnesses sooner, thus allowing for more immediate medical intervention. City outreach can include informational pamphlets, newspaper ads, public service announcements, and social media posts. These outreach initiatives could provide information on UHIs and their potential health threats and help citizens remain mindful of their actions that contribute to UHI propagation.

Individuals can help reduce the impact of UHIs in their communities by remaining mindful of their actions like driving cars in heavy traffic and using excess amounts of energy in their home. Both actions require "Increased use of fossil-fuel-powered plants" and thus "emissions of greenhouse gases, such as carbon dioxide, which contribute to global climate change"(U.S. Global Change Research Program, 2018) and increased local temperatures. Citizens can choose to take public transportation and to maintain just one cool room in their household as opposed to cooling every room. According to one study, "electriCity demand for air conditioning increased approximately 1-9% for each 2°F (1°C) increase in temperature" (U.S. Global Change Research Program, 2018). These individual actions can contribute to a reduction of the overall UHI effects.

Policy

Every region incorporates slightly different policies to mitigate and adapt to UHIs, but most tend to include mandates that expand public parks and open spaces; protect local forestation; and change zoning codes to incorporate the use of new, eco-friendly green roofs. One example of a City's legislation to limit the impacts of UHIs is in Beijing where they passed ordinances to reduce traffic with the assumption that temperatures would also decrease. These assumptions were based on data collected about increased traffic and temperatures during the 2008 Olympic Games (Yang, 2022). As another example, in 2001, the City of Portland, Oregon enacted the Central City Plan District Zoning Code, which modified the zoning codes of the City to include green roofs, providing an incentive bonus for projects that install green roofs into new buildings ("Heat Island Community Actions Database | US EPA", 2020). Major cities in the United States have begun enacting various UHI mitigation and adaptation strategies, some of which can be seen in an EPA database here.

2.2.2 Physical mitigation techniques

Whereas policy and voluntary actions are common ways to drive the implementation of the City's chosen adaptation tactics, the following strategies present some tangible options to mitigate urban heat islands. Figure 8 shows the number of mitigation strategies implemented by cities around the United States to reduce the impact of UHIs in their communities.

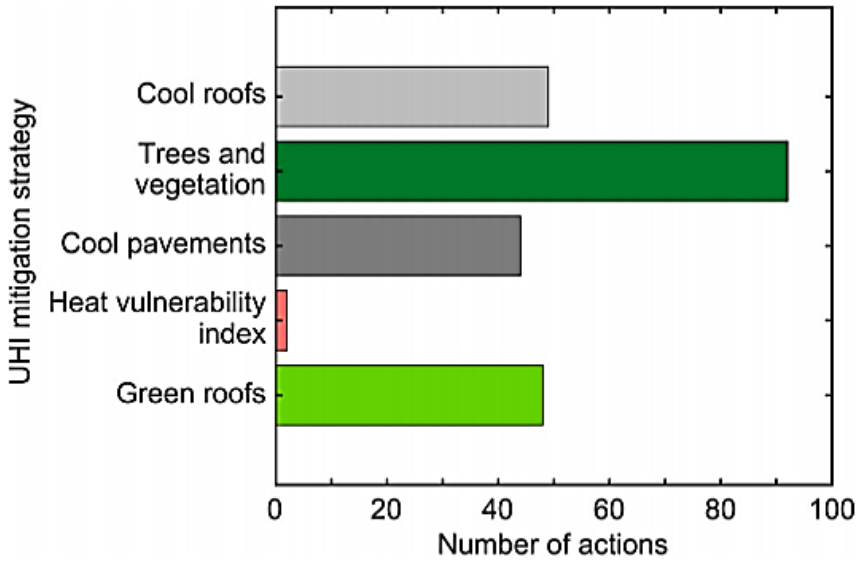


Figure 8. A bar chart of the of UHI mitigation strategies employed by cities through the US.
(Wang, C, 2021)

Trees and Vegetation

Through urbanization, regions are losing the existing natural vegetation that helps regulate surface temperatures through evapotranspiration (Liying, 2022). Increasing the amount of vegetation in cities has been proven to reduce extreme temperatures in urban heat islands and can be implemented in many ways including, but not limited to expanding vegetation on the ground, creating green roofs, and adding climbing plants on the sides of buildings ("Using Trees and Vegetation to Reduce Heat Islands | US EPA", 2022). One example of this strategy is planting tree canopies, which provide shade and limit sunlight exposure on asphalt, a material which readily absorbs, amplifies, and re-emits energy from the sun due to its coarse, black surface (Chaston, 2022). With the use of natural vegetation and tree canopies, the amount of sunlight reflected off buildings and absorbed by asphalt is reduced, thus lowering the temperatures of the City ("Using Trees and Vegetation to Reduce Heat Islands | US EPA", 2022).

Another way plants help reduce heat is through evapotranspiration, or the cooling of an area through evaporation of water off plants, as shown in Figure 9. Public parks and other open spaces have also been created and expanded to increase the green spaces in cities, which also

reduce temperatures through both evapotranspiration and shade (Using Trees and Vegetation to Reduce Heat Islands, 2022).

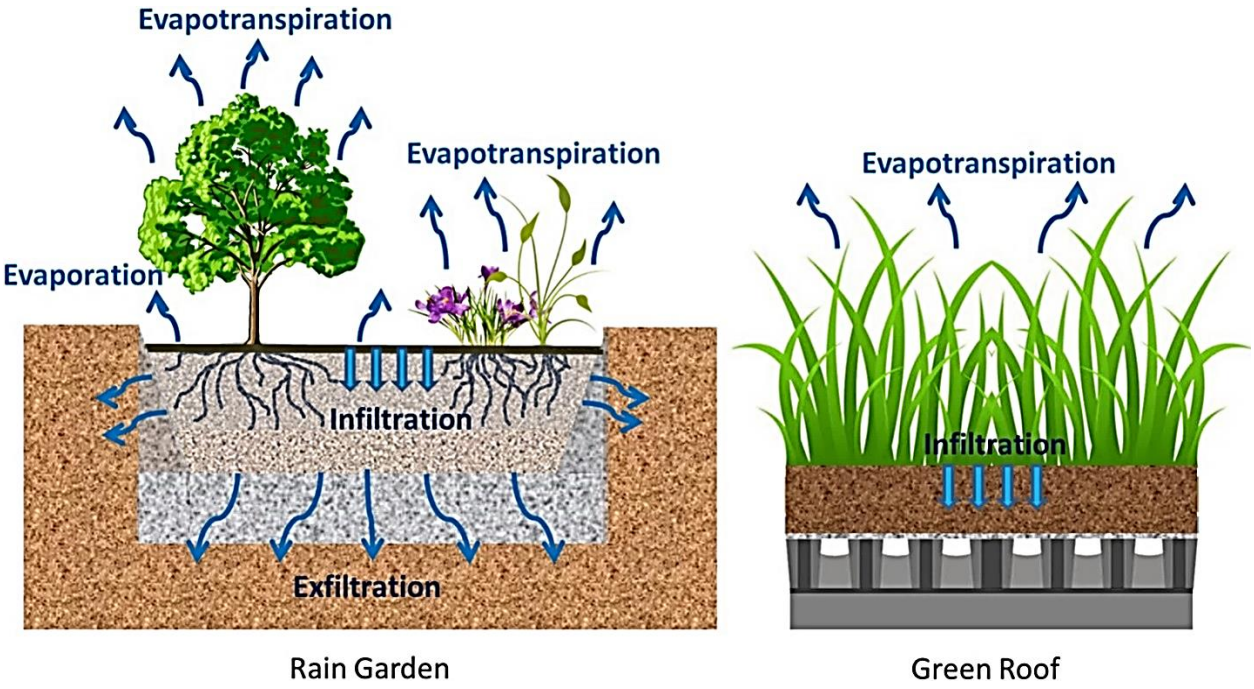


Figure 9. A diagram of plant evapotranspiration and a green roof showing how it produces an overall cooling effect. The blue arrows indicate the flow of water either as a liquid or vapor.
(*Ebrahimian, 2019*)

Cool Pavements

Some cities, like Los Angeles, California (Freedman, 2022), have begun to implement alternative pavements known as "cool pavements" which alter a surface's albedo (light reflection capabilities) or water retention levels to produce an overall cooling effect. Some types of cool pavements that have been researched include reflective pavements or coatings and permeable pavements (Wang, 2021). A comparison of these types of pavements with typical asphalt pavements is shown in Figure 10.

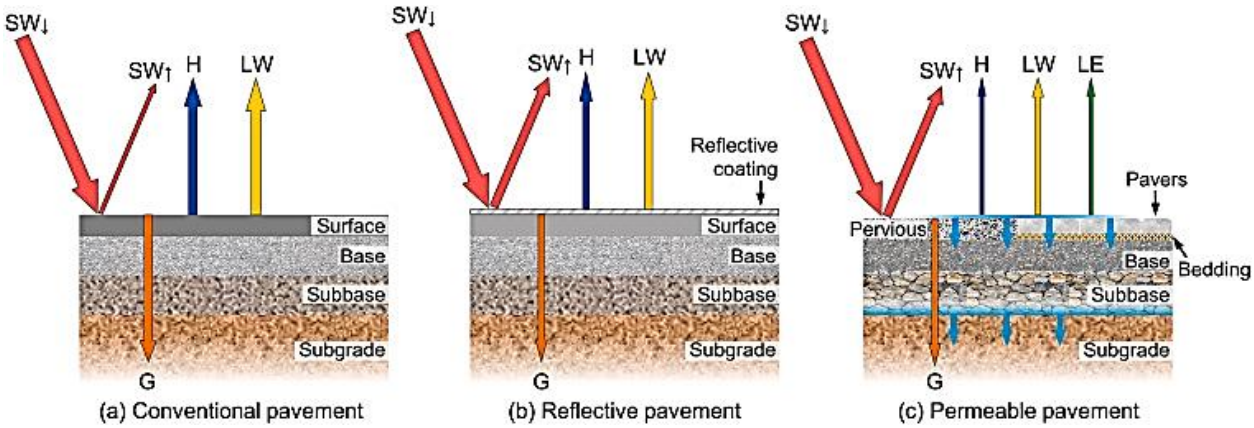


Figure 10. These diagrams depict the heat retention and reflection capabilities of (a) conventional pavements, (b) reflective pavements, and (c) permeable pavements. SW refers to the shortwave radiation or reflection, LW refers to net long wave radiation, G refers to heat conduction, H refers to sensible heat flux, and LE refers to latent heat flux. (Wang, C, 2021)

As shown in Figure 10.b, reflective pavements reduce the overall surface and air temperatures to mitigate urban heat island effects by increasing the shortwave solar reflectance and decreasing both the sensible and latent heat fluxes (Wang, 2021). However, the reflective pavements can also result in both increased glare and radiation, which decreases the quality of life for citizens (Wang, 2021). Increasing the albedo of existing pavements with reflective coatings or constructing new pavements with this attribute have been proven to reduce surface temperatures where an "increase of 0.1 in the pavement albedo can reduce the maximum surface temperature by ~6 ◦C and ~3 ◦C in summer and winter, respectively" (Wang, 2021). The use of reflective pavements is more effective in lowering maximum than average temperatures, which can also "reduce urban energy consumption and carbon emissions, especially during hot seasons" (Wang, 2021, Page 3).

In addition to the increased glare, "the reflectance of pavements can change over time due to weathering and dirt accumulation" (Wang, 2022, Page 3), thus negating the intended effects over long periods of time. Reflective coating technologies are also being developed to raise the albedo of existing surfaces without having to reconstruct entire roads.

As shown in Figure 10.c, permeable pavements reduce temperatures through evaporation of captured water off their surfaces (Wang, 2021), in a similar manner as evapotranspiration. One research team "compared surface temperatures of impervious and permeable pavements and observed strong cooling effects of 15–35◦C over permeable surfaces with watering in the early afternoon in summer" (Wang, 2021, Page 5). In addition to this temperature reduction, permeable pavements do not interfere with pedestrian traffic as there is minimal glare off the surface to increase pedestrians' radiation exposure. Some additional benefits of this type of cool pavement include the ability to refill ground water supply, decrease tire noise and hydroplaning, and improve the transfer of water and oxygen to plant roots (Wang, 2021).

Roofing Technologies

Common, dense building materials are also responsible for exacerbating the urban heat island effect by absorbing and retaining heat in a way that increases the overall City temperature. There are several research studies with evidence to promote the idea that green and cool roofs are a viable strategy to mitigate the effects of urban heat islands with the added benefit that they have the least negative impacts on pedestrians due to their vertical locations (Fjendbo, 2017). According to "both scientific and non-scientific literature, vegetated rooftops, commonly known as 'green roofs,' are often said to deliver a range of environmental, economic, and social benefits, or 'ecosystem services' (Fjendbo, 2017, Page 167) as well. The structure of green roofs is shown in Figure 11.

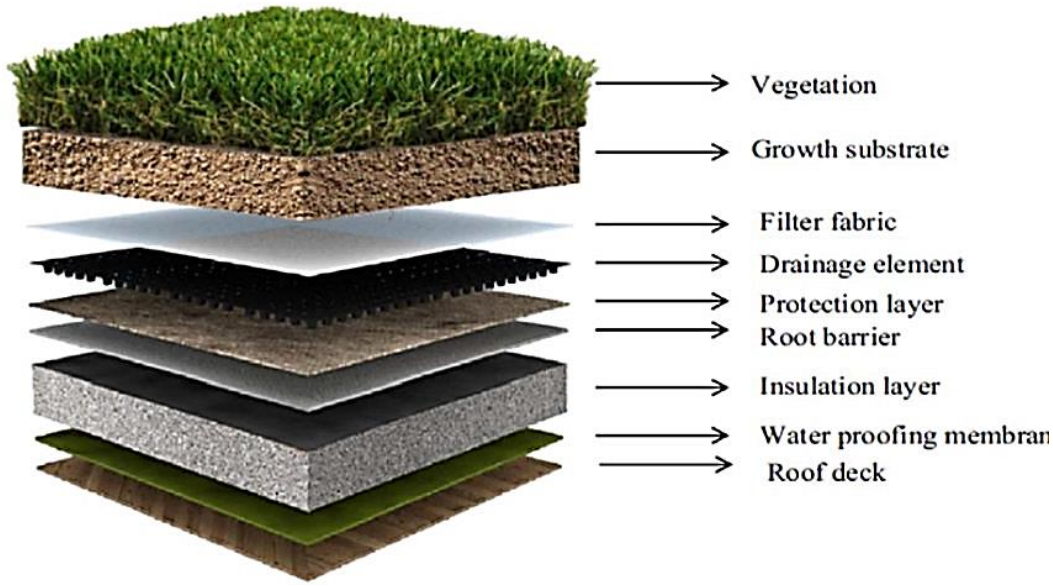


Figure 11. An exploded cross section of a green roof depicting the different layers involved in this mitigation strategy.
(Components of Green Roofs, n.d.)

Cool roofs are made of materials that reflect the sunlight away from the City so that heat does not get trapped in the lower levels, thus reducing the ambient temperatures felt specifically by pedestrians. As reported by a literary review, "The maximum cooling at street level ranges from 0.03 to 3 °C…according to the 17 studies providing original data on UHI reduction" (Fjendbo, L., 2017, Page 170). Green roofs can also reduce energy consumption by preventing excessive heat transfer into the buildings, thus encouraging less energy usage from cooling appliances (Overbey, 2019).

The process by which green roofs reduce the air temperature and limit heat transfer into the buildings can be seen in Figure 12. In addition to decreasing City temperatures and building energy consumptions through evapotranspiration, green roofs also reduce air pollution by using

the high surface area and roughness provided by the branches, twigs, and foliage to make vegetation an effective sink for air pollutants (Fjendbo, 2017) (Yang et al., 2008).

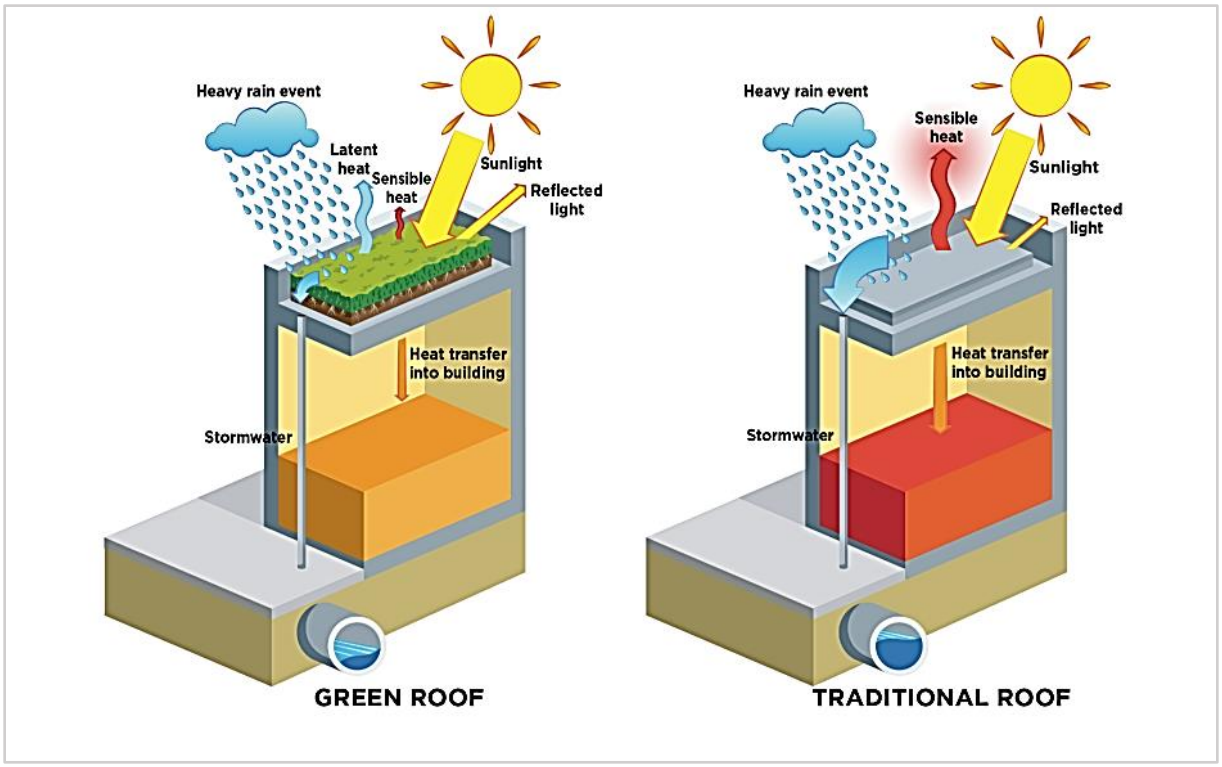


Figure 12. A diagram of the green roof cooling process.
(Estimating the Environmental Effects of Green Roofs,
A Case Study in Kansas City, Missouri, 2018)

2.3 Alexandria's Urban Heat Islands

The City of Alexandria has been experiencing rapid growth in the past century because of its proximity to the nation's capital (World Population Review, 2022), and one of the problems that plagues the City are Urban heat islands (City of Alexandria Energy and Climate Change Task Force, 2022). Alexandria and the surrounding areas have been known for warm weather in the summer, but in recent years, the demand for industrialization to compensate vertically for the increasing population has exacerbated this warm weather into urban heat islands (City of Alexandria Energy and Climate Change Task Force, 2022).

In 2019, the City of Alexandria adopted the Energy and Climate Action Plan and have recently been updating it in order to improve their response to natural challenges like urban heat islands (City of Alexandria Energy and Climate Change Task Force, 2022). The City's energy and climate task force mission is to keep its citizens and visitors well informed about the local heat crisis by implementing public announcements about extreme heat conditions and providing resources to limit their effects (City of Alexandria Energy and Climate Change Task Force, 2022).

Alexandria's recent efforts to mitigate UHIs involve incorporating more sustainable solutions to the problems at hand such as planting more local vegetation throughout the City to create more shaded areas and encouraging green roof implementation (City of Alexandria Energy and Climate Change Task Force, 2022).

Local Action to Mitigate UHI

The City of Alexandria has begun to improve its UHI mitigation and adaptation practices to minimize heat-related health risks like stroke and dehydration and to improve citizen's quality of life. It is addressing this by creating a task force to specialize in climate health, instituting cooling centers, extending public pool hours, and offering cooling assistance programs. The Climate Change and Energy Program focuses on City emissions and their effects on the local and global climate. In recent years, they have begun to address UHIs in the City through the Energy and Climate Change Task Force which at one of its meetings discussed the need to develop heat-related climate vulnerability assessments. The Alexandria Environmental Policy Commission, which focuses on the environmental impacts of urban life, has addressed the growing problem of UHIs by submitting recommendations to the City Council for mitigation strategies like updating building codes and establishing cooling centers (City of Alexandria Energy and Climate Change Task Force, 2022).

This will build on existing efforts. There are 15 cooling centers set up around the City of Alexandria where residents can go when they do not have access to cooling appliances like air conditioners or fans at home. The City also offers a Senior Cooling Care Program for adults over the age of 65 who qualify to receive fans and other aid. The Virginia Energy Assistance Cooling Program offers financial assistance to qualifying households with elderly, children, or people with disabilities for purchasing cooling systems. The City has also advocated for additional resources in their communities such as extended pool hours and expanded vegetation. The City of Alexandria is seeking to make additional improvements on their UHI mitigation practices.

3.0 Methodology

The goal of this project was to provide recommendations to help the City of Alexandria in their efforts to mitigate the effects of urban heat islands. We identified the following four objectives to accomplish this goal:

1. Compile individual existing geospatial, demographic, and temperature maps of Alexandria into a database.
2. Document the impact of extreme heat events on critical City infrastructure and vulnerable groups using the acquired geospatial, demographic, and temperature maps.
3. Determine the best UHI mitigation strategies and improvements for affected regions of Alexandria based on their physical and socioeconomic attributes.
4. Develop a report that recommends improvements for current City practices to mitigate the effects of urban heat islands.

In the following sections, the methods associated with each objective are detailed.

3.1 Compile individual existing geospatial, demographic, and temperature maps of Alexandria into a database.

A database containing existing maps was compiled to centralize the geospatial, demographic, and temperature maps previously created by the City of Alexandria and other organizations. To compile this database, the team:

1. Obtained topographical data from NASA satellites and GIS depository
2. Identified and downloaded heat maps and temperature data located on City of Alexandria's website.
3. Gathered relevant demographic data from Alexandria's census logs and geographic data from ArcGIS Online.
4. Obtained relevant weather measurements from weather satellites or ArcGIS online.
5. Organized the data into a website database.

The topographical data described in the third step included information about surface elevations, roads, waterways, land cover, and other information pertaining to the natural landscape and critical infrastructure of Alexandria and the surrounding regions. The demographic data included information such as community averages for age, gender, economic status, or any other information that helped describe the demographics of the communities. The political boundary data included City borders, zoning areas, borough or neighborhood edges, congressional districts, and other political, and governmental borders.

3.2 Document the impact of extreme heat events on critical City infrastructure and vulnerable groups using the acquired geospatial, demographic, and temperature maps.

The team analyzed the individual geospatial maps compiled in Objective 1 to create new viewpoints of the existing data by overlaying key demographic, City operational, and other

pertinent data with temperature maps. This allowed the team to identify the communities and infrastructure that are most severely affected by the urban heat islands in Alexandria and which existing practices may impact the UHIs.

To create these new views, the team first used the spatial analytics software ArcGIS and its database to generate a base layer of the region as well as a border around Alexandria. The base layers were selected according to the desired display information so that the underlying spatial data did not overshadow the data conveyed by the base layer. To selectively analyze different demographics, the US census data as well as the population information from the City of Alexandria's website were used to highlight metrics of interest in different communities such as race, income, and age. The layers and the temperature maps from Objective 1 were overlaid in ArcGIS with different types of demographic information and critical infrastructure to create a map showing communities and critical infrastructure systems located in areas of extreme heat. The maps the team created to accomplish this objective are listed in Appendix A.

3.3 Determine the best UHI mitigation strategies and improvements for affected regions of Alexandria based on their physical and socioeconomic attributes.

To determine the best UHI mitigation strategies and improvements for Alexandria, an Excel flow chart was created for organizational purposes. A list of general practices were compiled from sources such as Scopus and Compendex to highlight potential improvements on and expansions of the City's efforts.

The team organized the City's resources and previous research completed by the Energy and Climate Change Task Force and used it to determine whether the general practices have already been implemented in Alexandria. If the general mitigation strategies have been implemented, details on how they can be improved were then provided. With additional research, a description of the benefits, detriments, areas of effectiveness, and the cost for each general practice was also included. This provided the City with the information needed to decide whether to execute each general practice, as it helps highlight the different aspects of consideration to achieve the best result for the City.

Next, the team conducted a series of interviews with experts and City department heads who specialize in urban heat islands and related topics to gather more information about the impact of UHIs and extreme heat events as well as about the City's specific mitigation practices. This interview data was used to confirm past research that describes how communities are affected by extreme heat events and to highlight the City's gaps in mitigation strategies or research. The questions that were asked in these interviews are listed in Appendix B along with a brief description of each interview's importance and purpose. Interviewees were provided with the consent form found in Appendix C.

In addition to interviewing subject matter experts, the team also interviewed members of the local community that represent specific neighborhood groups. This data was used to

determine how the City can improve their efforts to better inform the citizens in these communities. The questions asked in these interviews are listed in Appendix B along with a brief description of each interview's importance and purpose. The interviewees were all provided with the consent form found in Appendix C.

3.4 Develop a report that recommends improvements for current City practices to mitigate the effects of urban heat islands.

The results of the previous objectives were compiled into a report that detailed the team's research and recommendations for improvements on Alexandria's UHI mitigation and adaptation strategies, particularly in the most impacted and vulnerable areas.

4.0 Results and Key Findings

This chapter presents the results and key findings of the project based on the information gathered from the team's map compilation, interviews, and research. This information allowed the team to identify knowledge gaps within Alexandria's current research and develop suggestions on how the City can attempt to close these gaps by improving their current mitigation and adaptation practices.

4.1 Site Database

As outlined in Chapter 3, our first objective focused on compiling Alexandria's heat-related maps into a central database. The team used Google Sites to create this database, as it provided simplicity, flexibility, function, and form. A critical review and analysis of the website's data was used to identify gaps in the City of Alexandria's research and allowed the team to select critical topics for the new map views created in objective two. The website database can be accessed by following this link.

4.2 Gaps

After compiling the database and conducting initial background research, the team noticed several gaps[4] in the City of Alexandria's mitigation and adaptation practices and research. These gaps involved missing UHI-related data as well as communication disparities between the government and its citizens.

The City was missing maps that may be helpful when analyzing the impacts of UHIs and extreme heat events on different populations. For example, they were lacking maps that overlaid collected data, like the locations of cooling centers, with temperature measurements to visualize the effectiveness of current UHI mitigation practices, the locations of vulnerable regions, factors that contribute to UHIs in communities, and areas for mitigation improvement. The City does have several heat vulnerability maps, but detailed overlays of other aspects of the City's inner workings would be helpful in improving the City's current strategies. Consequently, the team developed additional maps through ArcGIS to add to the City's database and improve the scope of their research.

The team identified a series of gaps in the City's map database as well as research topics. The location of large pavements such as parking lots were individually mapped in the City's database, however, they do not have a combined temperature and pavement map. The analysis involved in creating these maps would be helpful as it could be used to identify areas where cool pavements or similar strategies may be useful to implement. The City has access to individual traffic and transportation systems information; however, the City would benefit from a map that combines all these systems into one view to compare to the UHI effects. These views would help

[4] We do not use the word "gaps" with the intention of implying a negative connotation. We use the word to highlight the research or data that the City of Alexandria does not currently have but would benefit from obtaining.

the City identify which systems are predominately located in UHIs and require more attention in terms of heat impacts on City infrastructure.

The database was also missing geospatial information which could help researchers identify aspects of the City's natural landscape that either perpetuate or mitigate UHIs so that accommodations can be made in these regions and the information gathered can be applied to mitigation strategies.

It would be helpful for the City to have maps with the locations of their currently implemented UHI mitigation strategies to see how effective they appear to be in altering the climate of the affected regions.

Finally, access to water and power systems as well as heat-related health incidents like ambulance calls or reported asthma attacks are limited as a result of national and personal security. This data compared against land heat data from satellites or ground data would be crucial to identifying affected and vulnerable areas of the City. Although the City does have access to a large selection of general demographic, greenery, transportation, and other information pertaining to Alexandria, they are missing the key maps that compare raw data with the temperatures of the region, which would allow the City to identify vulnerable groups and infrastructure.

To compensate for some of the missing information in the City's map database and UHI research, the team created a series of new view maps. The purpose of these maps was to foster a better understanding of the problem and help the City move forward in their attempt to address UHIs. The maps created by the team are in Appendix A and are listed as follows along with the benefits they will provide to the City:

Table 1: Summary of each of the views created to fill gaps in the City of Alexandria's research along with the benefits of creating these views.

Maps	Ways the City Can Use the Map
Transportation and Temperature	• Highlight transportation systems located in UHIs to identify which systems may be affected by extreme heat • Identify how transportation systems might contribute to regional temperature changes by comparing thermal readings at rush hour and non-rush hour times • Promote the use of transportation systems that do not travel through UHIs for better passenger comfort along the routes and to limit the usage of systems that might be affected by extreme heat
Traffic and Temperature	• Identify the need for additional roadways to better disperse traffic and hopefully reduce temperature • Identify how traffic might contribute to regional temperature changes by comparing thermal readings at rush hour and non-rush hour times • Promote public transportation as a means to limit additional emissions that have the capacity to increase temperatures in the city
Shopping Centers and Temperature	• Visualize impact of large centers with dense construction materials on a region's temperature
Pavements and Parking lots and Temperature	• Identify potential locations for cool surface implementation to minimize the impact of heat in regions with large pavement surface areas • Understand the connection between large areas of pavement and local temperatures
Topography and Temperature	• Display the connection between a physical land feature and temperature • Identify features that seem to mitigate UHIs, so that these aspects can be incorporated or considered for new or improved UHI mitigation and adaptation strategies
Zoning and Temperature	• Highlight vulnerable types of zones in the city • Identify types of urban development projects (residential, commercial, industrial…) that might benefit from additional attention to detail when it comes to incorporating UHI mitigation strategies into the design of the area
Potential Green Roofs and Temperature	• Identify potential locations of green roofs to improve the city's UHI mitigation strategies by eliminating unfeasible locations for this strategy's implementation. • Highlights regions that could be doing more to mitigate UHIs, so that incentives or policies can be applied here in the hopes of improving regional temperatures
Cooling Centers and Temperature	• Begin analysis on effectiveness of UHI mitigation strategies by highlighting the distances between cooling centers as well as areas that would benefit from more cooling centers

Population Density and Temperature	• Begin the research on the connection between population density and city temperatures to highlight additional vulnerable communities in the city and focus UHI mitigation and adaptation strategies on
Parks and Temperature	• Visualize the cooling effect of vegetation and open space especially in warmer areas • Highlight areas that can benefit from parks as a result of their extreme temperatures when compared to the other regions of the city
Open Space Density	• Show areas with more open space and greenery • Highlight areas where more open space and parks can be implemented • When overlapped with temperature readings, this map can display the connection between vegetation and heat in the city as support for expanding green spaces in the city
Female Resident Distribution	• Start to fill in gaps on other vulnerable populations

Figure 13 is an example of one of the new maps shown in Appendix A. These maps help fill the gaps in the City's research and are listed along with a brief description, a highlight of the map's key features, an explanation as to why it could be useful to the City, and the data sources and processes used to create said map. In each map that incorporated land temperature data from a satellite, the darker red regions are the hotter sections of the City while the lighter red regions are the cooler sections of the City. In this map, concentrated groups of dark red regions can be considered UHIs.

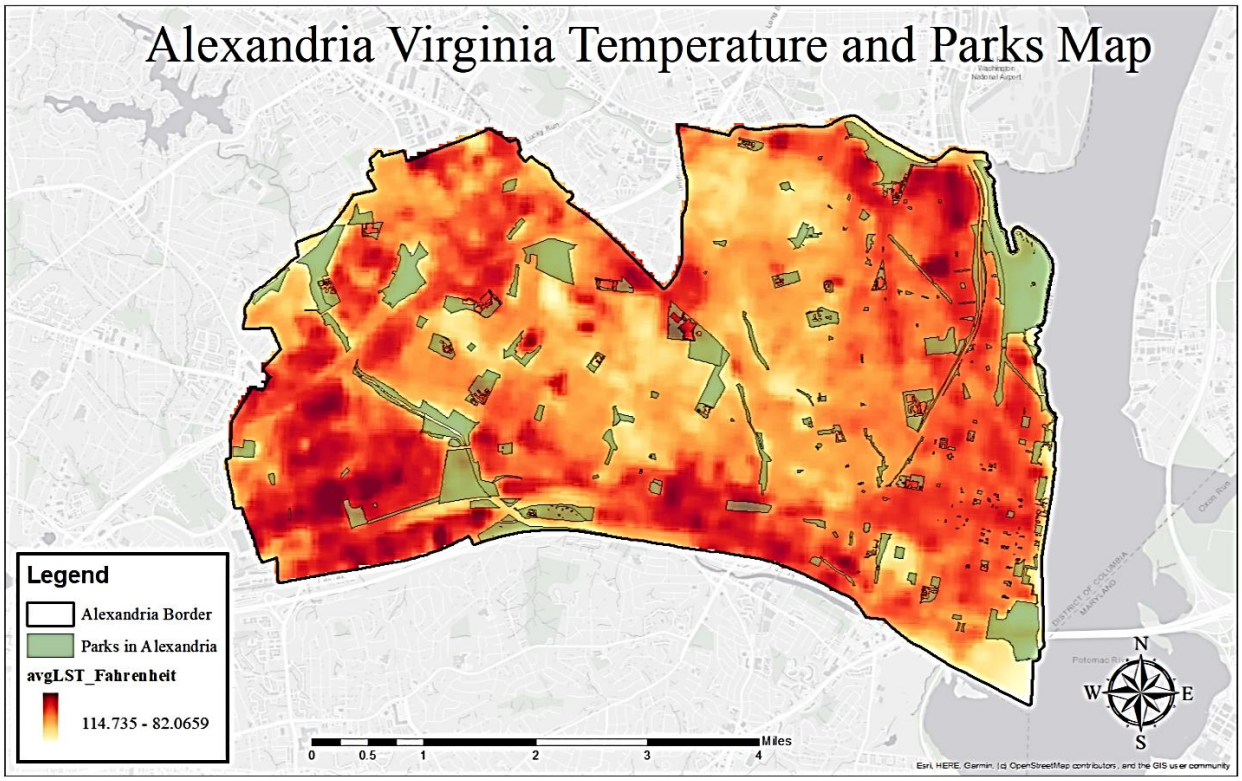


Figure 13. Map of the parks in Alexandria compared to land heat satellite data. See Appendix A for details on the description summary of this map.

Although these maps can create new perspectives of UHIs in the City of Alexandria, there are more types of maps that may be helpful for the City but could not be produced due to time or access restrictions. This information includes air quality data; water systems data; and health related maps involving information like ambulance calls, asthma attacks, or emergency service data. There is also a lack of integrated heat maps[5], which may highlight the people and areas most severely affected by heat. Ultimately, the database allowed the team to analyze the gaps in research and knowledge so that new maps and viewpoints could be constructed for use during the City's development and improvement of mitigation and adaptation practices.

4.3 Interviews

To provide recommendations to the City of Alexandria on how best to improve their current UHI mitigation and adaptation practices, the team conducted a series of interviews with local departments, experts, and community groups. The department interviews were conducted to gather information about the City's current mitigation and adaptation strategies and to visualize how each area of the City is commonly affected by extreme heat events. The expert interviews were intended to gather background data on UHIs and extreme heat events in general, highlight

[5] Integrated heat maps refer to maps that overlay City data with temperature readings with the purpose of analyzing the correlation between the two variables.

the effective and ineffective strategies utilized by other cities, and verify the team's research. The interviews with the local community leaders were aimed at gauging how helpful the people feel the government has been in reducing the impacts of UHIs and extreme heat events.

4.3.1 Department Interviews

The interviews with City departments were divided into three groups; the first round of department interviews focused on human services, the second focused on departments pertaining to urban planning, and the third focused on other Subject Matter Experts (SME). The departments who were interviewed in each round are listed below:

Group 1: Members from the Department of Community and Human Services, the Alexandria Health Department, the Race and Social Equity Office, and the Office of Housing.

Group 2: Members from the Department of Planning and Zoning, the Department of Code Administration, the Department of Recreational Parks and Cultural Activities, and the Department of Transportation and Environmental Services.

Group 3: A distinguished member of the Office of Energy Management and a representative from National Oceanic and Atmospheric Association

From these interviews, the team obtained the following information:

Group 1: Human Services

Department of Community and Human Services

Through the interview process, the Department of Community and Human Services informed the team that their department offers financial assistance for utilities regarding inclement weather. These financial assistance programs address both the cold and warm temperatures, are funded at the state and local level, and fund fan and cooling system purchases for seniors, low-income housing, families with young children, etc.

Not only does the department support this financial assistance program, but they also have the capacity to track critical data, like cooling center usage, but due to privacy limitations they have held off in doing so. If data like this can be collected, then the other departments in the City of Alexandria can use the internally generated data to guide their policies and correctly address the UHI and EHE problems in the City.

Alexandria Health Department

The interview with the Alexandria Health Department revealed that they do not have any programs to address UHIs or EHEs. The Health Department showed interest in using UHI related data to protect the vulnerable populations of the City of Alexandria, but the lack of data has stopped them from taking a more proactive approach. Their preliminary research revealed that they would like to address this problem by creating more shaded structures, by supporting people in their homes, and by taking a more proactive approach to preventing risks in their communities.

Race and Social Equity Office

The interview with the Race and Social Equity Office informed us that they do not have any specific programs and normally delegate UHI concerns to other departments. This means that the office is not equipped to directly handle these issues and must coordinate with different departments as they have limited data. They do, however, have an interest in climate change and could be an effective way to provide outreach to the population.

Office of Housing

The department is aware that there are disparities in different income houses, but their main mission does not emphasize UHI concerns. The Department of Housing did mention that there is data related to unequal utility bills with low-income housing and other types of housing, but this inconsistency is not one of the department's current concerns.

Group 2: Urban Planning

The Department of Planning and Zoning, represented by the City Architect and Principal Planner, informed us of the various concerns they had for the relationship between the City's landscape and infrastructure and the urban heat island effect. The department discussed how the City and vegetation are affected by heat damage. They noted that the reflective materials used on buildings to mitigate UHIs are reflecting heat onto the surrounding trees and vegetation, causing damage to the plants. The Department of Planning and Zoning also explained that there are neighborhoods in the City with poor infrastructure quality and discussed the need to update the infrastructure in Alexandria.

During the interview, the members stated that the cost of desired programs and developments have been the major limitation preventing their ultimate implementation. The department explained many of their urban planning related to UHI mitigation ideas such as the development of shade structures and engineered water walls, however, most of them were rejected due to budgeting concerns. The department also discussed the limitations and inflexibility associated with building codes and the implementation of UHI strategies because the building codes are state-mandated codes rather than City codes. Lastly, the department representatives discussed their hope for spreading awareness to residents, so the people of Alexandria can express their concerns on the urban heat island effect, push the City to offer more assistance programs, and encourage officials to invest in new urban development mitigation strategies.

Group 3: Experts

Office of Energy Management

The Office of Energy Management staff highlighted the potential impacts of extreme heat on different City infrastructure systems. For example, they declared that there is a 10-25% increase in residential energy usage during extreme heat events. Additionally, they emphasized that as more energy is pushed through power lines and substations, the temperature of these

systems increases, thus requiring more energy to cool the infrastructure. They also declared that as the temperature increases, more irrigation and drinking water is used by residents. In terms of water management systems, the representative stated that there is minimal direct impact on sewers or water systems from extreme heat. However, they did indicate that there should be more research done regarding the effects of heat on the chemical treatment of water to ensure the best quality for residents. Additionally, it was emphasized that if energy systems are overloaded, then water may not be accessible, which poses a great threat to the communities.

The representative discussed cooling centers and programs offered to help residents as well as UHI mitigation policies pertaining to open spaces and tree canopies. Emphasis was placed on green building codes which can also help reduce energy consumption. The representative revealed that the City has no other active mitigation techniques implemented and is interested in implementing new strategies. The representative recommended that the City track UHI mitigation program usage to determine effectiveness and more efficiently use City energy.

Finally, the representative also talked about the creation of the Alexandria Climate Action Office. This office will involve positions that focus on climate action, communications, sustainability coordination, energy management, EV planning, and green building program management. They will be responsible for enacting the City's climate action plan and providing advice to the community. The office will also be responsible for communicating with the other departments to advocate for the minimization of greenhouse gas emissions. This will be the primary office to look at heat vulnerability and track updates on UHI and other green policy changes.

National Oceanic and Atmospheric Administration

The main organization that monitors UHIs in the United States is the National Oceanic and Atmospheric Association (NOAA), and this organization has started a program, the Urban Heat Island (UHI) mapping campaign program, to map UHIs and EHEs in cities across the US. The City of Alexandria hopes to partner with NOAA in this program and receive more fine grain UHI data; updated maps; and a better, more systematic approach to addressing UHIs. In order to get more information about this program and understand the requirements, the team talked with a NOAA researcher. Through this discussion, many points were raised in terms of responses for UHI mitigation in Alexandria and other cities. Discussion points included the questionable effectiveness of Cooling Centers, missing health data, the generalized use of vegetation, and the importance of community buy-in.

The effectiveness of cooling centers was discussed as there is a lack of data surrounding their use, which puts into question the scientific benefits of implementing cooling centers. Without tracking data about the people using cooling centers there is no way to understand the impact this strategy has on the community. The second point that was discussed related to the lack of health data available for the public. This limits the scope of the project as it becomes harder to understand the vulnerable populations in Alexandria and how extreme heat events or urban heat islands directly affect them.

The next discussion topic highlights the importance of evapotranspiration and how it is important for the City to improve its vegetation policy to allow more natural shade. Ideally, the vegetation would be natural to the region, but simply planting trees is a good first step. NOAA's researcher stated that introducing new water features to the City could help with temperature management and lower the overall temperature of the area. The last point of discussion related to the importance of community buy-in, which revolves around the idea of a City-wide push to address the UHI problem and continue the City of Alexandria's support with the interest of the different communities in mind. This community aspect of the program can be addressed with a bigger emphasis on outreach and teaching communities about the effects of UHI and on what to do during EHEs.

4.3.2 Neighborhood Organization

As part of the team's research, a questionnaire was developed and sent out to members of six City neighborhood organizations[6]. The questionnaire asked the community members about their knowledge of Alexandria's UHI mitigation strategies or on new mitigation strategies that would better suit their needs. Other questions also asked if the community members knew what causes UHIs (the full questionnaire can be reviewed in Appendix B). From the six responses received, the group was able to understand how the community in Alexandria understands the problems of urban heat islands and how well the government has been interacting with the community on this topic (A table showing a summary of the gathered results is located in Appendix F).

First, it was noted that not all community members feel the effects of urban heat islands. In fact, only half of the communities responded that they feel the effects of heat on a regular basis, which could be due to the City's mid-Atlantic geographical location or several other factors. It was also found through the questionnaire that many of the community members recognize that large areas of pavement are a main contributor to urban heat and that a way to reduce this heat would be to increase green space and tree canopies. It is also important to note that a smaller but still significant number of members believe that other features causing heat related problems include areas that have many buildings but little green space, the fact that people may not be able to afford cooling appliances in extreme heat, and that there are many members of sensitive populations, such as those over 65 years old, living in these communities. Surprisingly, no members mentioned that the lack of air conditioners was a significant problem, which could be the case due to the living arrangements in the communities. On the other hand, many members mentioned that having an air conditioning unit or having a nearby cooling center could be effective in reducing heat effects.

When asked about what the City of Alexandria has been doing for the mitigation of urban heat islands, most community group respondents had either heard of or were familiar with some of the ways the City has worked to mitigate UHIs. However, five out of the six community

[6] Because of the small sample size of our survey and the generalized location of these communities, these data may be accurately extended to the whole city.

representatives said that within their respective communities, many of the members have no knowledge of what Alexandria has done to mitigate urban heat islands. In other words, little outreach to the general population has been done.

On another note, none of the communities stated that the City's prevention programs have been effective: the programs were either partially effective or not effective at all. It was also found that most of the communities did not know about any of the City's response programs, and if the members did know about them, they said that the programs were either not effective or were partially effective. Finally, only one of the six neighborhood groups was found to aid its members through programs such as cooling assistance.

4.4 UHI Mitigation Strategy Assessment

The team summarizes the benefits of each of the researched strategies in the tables below along with a priority rating for each, which the City should use to determine which strategy to focus their efforts on. The higher the score, the higher the priority. As indicated in this table, the City should focus on strategies that are physically, cost-wise, timewise, and resource-wise feasible; are effective in mitigating or encouraging the mitigation of UHIs; and have not yet been implemented in Alexandria. The team asked four questions for each strategy and summed the resulting scores:

Feasibility: (a) Can the strategy be physically implemented (if no, do not move on to question 2).
Yes=5 No=1

Feasibility: (b) Can the strategy be otherwise implemented based on cost, time, resources, etc.
1 (not feasible) to 5 (very feasible)

Effectiveness: How well does the strategy reduce or encourage the reduction of temperatures
1 (does not) to 5 (does)

Implementation: Has the City of Alexandria already implemented this strategy (when a strategy has not been implemented, the City should look more into it, therefore it should have higher priority)?
Yes=1 No=5

Table 2: Summary of recommended UHI mitigation strategies along with their priority ratings (higher numbers correspond to more important strategies), their benefits, and their detriments.

Strategy Summary			
Strategy	Priority Rating	Benefits	Detriments
Outreach – All Advertising	16	Informs public about UHIs	Costs money to print
		Prepares public for heat	People to design and distribute
		Brings awareness to heat related illness	Constant updating
Outreach - Community Group Partnerships	18	Builds community-government trust	People to network
		Event networking	
Outreach - Workshops	17	Can reach vulnerable population	People to organize and host
		Engages entire community	Supplies to promote
		Highlights City heat resources	
Outreach - Fundraising	14	Will raise money to implement more strategies	Requires volunteers and supplies
Cooling centers	10	Informs public about UHIs	Money to maintain
		Residents don't need to leave for food	Workers to run
		Better City-wide access	Energy to run
Vegetation - Tree Canopies	11	Reduces City temperatures through evapotranspiration	Not comprehensively useful alone
		Provides shade	Costs money to plant and maintain
		Improves air quality	
Vegetation - Green Roofs	11	Reduces ambient temperatures	Need to be incorporated in construction plans
		Don't interfere with pedestrians	Requires maintenance
		Roof insulation	
		Promotes less energy usage	
		Reduces air pollution	
Vegetation - Garden Rooftops	14	Reduces ambient ground temperatures	Requires maintenance
		Don't interfere with pedestrian	May be on personal property, so might be hard to encourage
		Reduces air pollution	
Vegetation - Vegetation walls	16	Reduces air pollution	Can be expensive
		Reduces both surface and air temperatures	Requires certain construction materials

Table 2 (Cont.)

Strategy Summary			
Strategy	Priority Rating	Benefits	Detriments
Cool Surfaces - reflective coatings (ground)	8	Reduces City temperatures	Difficult driving conditions from street glare
		Easy and cheap to apply	Pedestrian uncomfort from street glare
Cool Surfaces - Permeable Pavements	1	Reduces City temperatures	Requires road reconstruction
		Decreases tire noise	Weathering and erosion concerns
		Limits hydroplaning	
		Helps Groundwater resupply and flow	
Cool Surfaces - White Rooftops	9	Easy and cheap to apply	Buildings can be under City or personal jurisdiction, so may be hard to encourage
Urban Planning and Design - Alternative construction materials	17	Absorbs less heat to reduce temperatures	Requires reconstruction to fix existing structures
		Promotes more sustainable materials	Materials require more research
Urban Planning and Design - City Arrangement	17	Better airflow through City	Requires reconstruction to fix existing structures
		Heat is less likely to get trapped in lower levels	
Urban Planning and Design - Shade Structures	18	Reduces surface temperatures	Can be intrusive
		Spaces to get out of heat	Can be hard to incentivize
Cooling Assistance	10	Encourages City-wide utilization	Money to advertise
		Helps a vulnerable population	People to serve on committee
Senior Cool Care Program	11	Uses Seniors' main sources of information	Money and people to advertise
		Helps a vulnerable population	Money for more fans

Table 3: The division of priority scores for each of the strategies listed in Table 1

Strategy	Physical Feasibility	Other Feasibility	Effectiveness	Implementation
Outreach – All Advertising	5	3	3	5
Outreach - Community Group Partnerships	5	5	3	5
Outreach - Workshops	5	4	3	5
Outreach - Fundraising	5	2	2	5
Cooling centers	5	3	1*	1
Vegetation - Tree Canopies	5*	2	3	1
Vegetation - Green Roofs	5	2	3	1
Vegetation - Garden Rooftops	5	2	2	5
Vegetation - Vegetation walls	5	2	4	5
Cool Surfaces - reflective coatings	5	1	1	1
Cool Surfaces - Permeable Pavements	1	N/A	N/A	N/A
Cool Surfaces - White Rooftops	5*	1	2	1
Urban Planning and Design - Alternative construction materials	5	3	4	5
Urban Planning and Design - City Arrangement	5	3	4	5
Urban Planning and Design - Shade Structures	5	4	4	5
Cooling Assistance	5	3	1*	1
Senior Cool Care Program	5	4	1*	1

*The astricts represent limitation or constraint that will be discussed in the following sections

The team also rated the importance of certain further research opportunities, as show in the following table:

Table 4: Recommended UHI related research opportunities along with their order of priority (higher numbers correspond to more important strategies), their benefits, and their detriments.

Research Opportunities			
Topic	Priority Rating	Benefits	Detriments
NOAA Mapping Campaign	21	➢ More fine-grained maps. ➢ Expand community engagement on UHIs.	➢ Need people and community group resources and efforts. ➢ Need to contribute funds to campaign.
Heat-Related Health Information	20	➢ Will help identify vulnerable groups and areas of the City.	➢ Resources, data collection, and record keeping methods. ➢ Requires post processing. ➢ Might not be available to the public because of HIPPA.
Vulnerable Populations	18	➢ Expand the City's research database to better help vulnerable populations. ➢ Ensures equality of government resources.	➢ Requires more research and people to work on the information gathering.
Water Treatment	17	➢ Ensures residents are still receiving healthy water in EHEs and UHIs.	➢ Requires research, experiments, and scientists.

5.0 Recommendations and Conclusions

This chapter summarizes the team's recommendations on how to improve the City of Alexandria's current UHI mitigation and adaptation practices based on the collected maps, interviews, and research. It also discusses the research opportunities for future project groups working on UHI mitigation in Alexandria. These practices are to be considered based on the information from the preliminary research and the information given in the group interviews.

5.1 Recommendations

5.1.1 Strategies

Through the collected research and the results, the team selected the following strategies as the best recommendations for the City of Alexandria. These mitigation strategies are followed by a small paragraph that contains a description of the strategy and outlines their strengths and limitations.

1) **The City of Alexandria should implement outreach programs to inform the population.**

As the City of Alexandria seeks to mitigate the effects of urban heat islands, an area of improvement would be to their approach to public outreach. Strategies like the use of pamphlets (like the one shown in Figure 33 in Appendix E), newspaper PSAs, social media posts and community workshops could be used to inform the population about the signs, risks, and possible solutions to UHIs and EHEs. This information campaign is the first step in bringing the community together for a cause, a crucial starting point for any extensive City effort.

2) **The City of Alexandria should gather data and expand their cooling centers strategy.**

Cooling centers have been the City of Alexandria's primary UHI adaptation strategy in recent years, but there are many areas for improvement within the framework of this strategy. As seen in the Cooling Centers vs Temperature map in Appendix A, there are 15 cooling centers in Alexandria, but they tend to be clumped together in hot areas, which brings about access and transportation concerns. The City should begin to establish more cooling centers throughout the City and disperse them evenly for more widespread access. They should also provide free public transportation to the centers to address the transportation concerns. These cooling centers do offer water to users but adding access to food would encourage people to stay in these cooled areas and not venture out in the heat. The team also recommends that the City track information such as the number of people utilizing each center to determine if their maintenance is worth the City's efforts and to determine which locations are most often used. However, they must be careful not to take or release any personal information about the people using the cooling centers to not discourage people from taking advantage of the City's resources out of fear of identification or discrimination for any reason.

3) The City should update their vegetation policy to include other green alternatives.

The City of Alexandria has begun to expand vegetation throughout the City, but their efforts could be improved by implementing more tree canopies, green roofs, rooftop gardens and vegetation walls. Although there are some limitations with this strategy when related to research and their true effectiveness, these would be good steps for the City of Alexandria to take.

4) Alexandria should utilize cool surfaces to help reflect sunlight and reduce pavement temperatures.

We recommend the City of Alexandria implements reflective coatings on roofs and pavements to reduce the amount of energy these surfaces typically absorb and amplify. The City could also collaborate with businesses and property owners to realistically implement cool surfaces in large parking lots and on roofs. The major limitation with cool surfaces and reflective pavements is the reflection of light. This could impair the vision of drivers, pedestrians, and pilots landing near Alexandria.

5) The City of Alexandria should use careful urban planning and design to encourage airflow.

It is recommended that the City of Alexandria begin encourage the use of alternative construction materials. These materials such as retro reflector materials and thermal insulated materials could help prevent the absorption and retention of heat from the conventional dense materials. The City should also begin to emphasize the importance of building arrangements that allow proper airflow and ventilation to avoid heat pockets. While the overall arrangement of the City cannot reasonably be changed, more attention can be placed on building arrangement that limits UHI effects during future urban development projects. Lastly, the City should consider the use of shade structures to assist with reducing surface temperatures and improving the thermal comfort of residents.

6) The City of Alexandria should expand and advertise their cooling assistance programs.

The City of Alexandria has sanctioned two main cooling assistance programs that help cover the cost of cooling appliances for vulnerable populations. The first cooling assistance program covers the cost of new or repaired cooling appliances for households with at least one person from of the following group vulnerable populations: individuals 60 years of age or older, children under 6, or individuals with a disability. This program should be improved by establishing a committee to focus on the smooth functionality of this program, spreading information about the program, and destigmatizing the need for financial help by emphasizing the dangers of not having cooling appliances in extreme heat. The senior cool care program provides fans and even air conditioning units for qualifying senior citizens in Alexandria, Virginia. This program can use some improved advertising by updating the graphic designs of

posters and advertising in newspapers to appeal to this populations' traditional source of news and information.

5.1.2 Further Research

This section discusses possible future projects and research endeavors that the City of Alexandria should pursue to better address the problems of UHIs and EHEs in the City. These projects could be done independently or with the help of other organizations.

1) **The City of Alexandria should apply for the NOAA mapping campaign.**

The City of Alexandria should apply for the 2023 UHI Mapping Campaign hosted by the National Oceanic and Atmospheric Administration or NOAA. This campaign will produce more fine-grained temperature data for the City and will expand community engagement in the City's efforts to mitigate and adapt to UHIs. Officials will need to find citizen scientists to take ground measurements with their cars and bikes and community organizations to provide monetary and in-kind donations. A description of this campaign, the need for community support of the campaign, and how the City can use the data that results from the campaign is provided in Appendix D.

2) **The City of Alexandria should identify vulnerable populations to implement directed strategies.**

More research should be done on how heat specifically affects other, less prominent, populations such as pregnant women. Our research covered some of the major vulnerable populations such as adults over 60, children under 6, people with disabilities, and low-income housing. However, the City would benefit from additional geospatial data, population density numbers, and health information on some of the smaller vulnerable populations. The City should also track heat-related asthma attacks to identify areas of emergency during extreme heat events where mitigation practices are in dire need.

3) **The City of Alexandria should conduct a heat analysis on its power and water systems**

The City should conduct a heat analysis on power and water systems to see how these critical infrastructure systems are affected by extreme heat since the team did not have access to this sensitive information. In addition, the City's departments should work with local scientists and universities to analyze the effectiveness of water treatment chemicals during extreme heat events and in urban heat islands to ensure the best quality of water for the residents

5.2 Conclusion

With the results of this project, the City of Alexandria will be able to improve their current UHI mitigation and adaptation practices as well as implement new strategies to accomplish this goal.

The City would benefit from future projects that include tracking cooling center usage in terms of who uses them, and which neighborhoods would benefit from an additional center. This would greatly improve the effectiveness of the cooling centers and would allow the City to figure out which neighborhoods need the most assistance. Another future project recommendation is to assess air quality in Alexandria. The current air quality data is very limited and is not in a very fine grain. Having a finer grain data set would allow the City to more effectively assess health risks and allocate resources to help those affected by poor air quality.

In developing these recommendations for the City, a few general limitations were faced. The most pressing issue faced in this project was a lack of data due to national security and privacy reasons. Some examples of the types of data we were unable to get were data such as electrical systems, water system locations, and heat-related health data.

Ultimately, the team recommends that the City conduct additional research on the highest priority topics identified in tables 2 and 4: community group partnerships, workshops, alternative construction materials, alternative City arrangement plans, shade structures, NOAA's mapping campaign, heat-related health information, vulnerable populations, and water treatment.

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Appendix A

Maps addressing Vulnerable Areas or Groups
to document their strategic feasibility

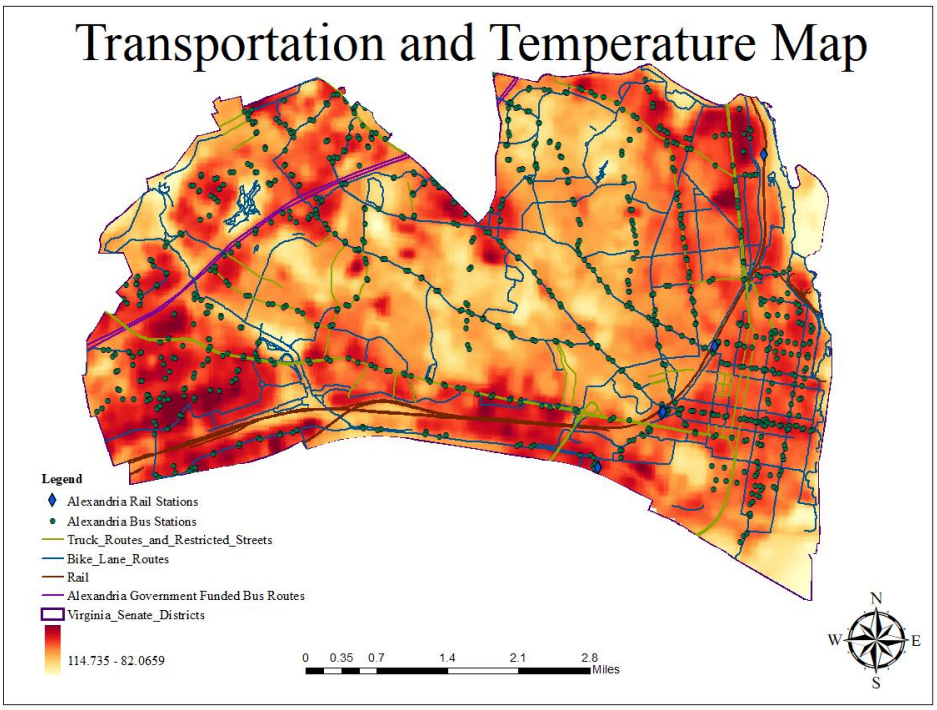

Figure 15. Map of the transportation systems through Alexandria including roads, rail stations, bus stations, bike lanes, and bus routes compared to land heat satellite data.

Description: Figure 15 above compares the different transportation systems through Alexandria with the temperature readings from a satellite. The map key indicates transportation systems or routes.

Results: Notice that areas where there are more transportation systems tend to be much hotter than areas with less transportation systems. This may be because there are more people in those regions that require more transportation. All the rail stations are in relatively hot areas, meaning there is a greater chance of these systems being affected by the extreme heat.

Benefit: A map like this could be helpful to the City of Alexandria as it highlights the transportation systems that are in UHIs to both identify topics for future travel policies or laws and understand how different types of transportation might affect the temperature and climate of a region. This information can also be used to promote specific means of transportation both to avoid extreme heat and to limit its propagation.

Data Sources:

<u>Temperature Layer:</u>

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Bus Stops and rail stations:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Alexandria Funded Bus Routes:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Truck Routes and Restricted Areas:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

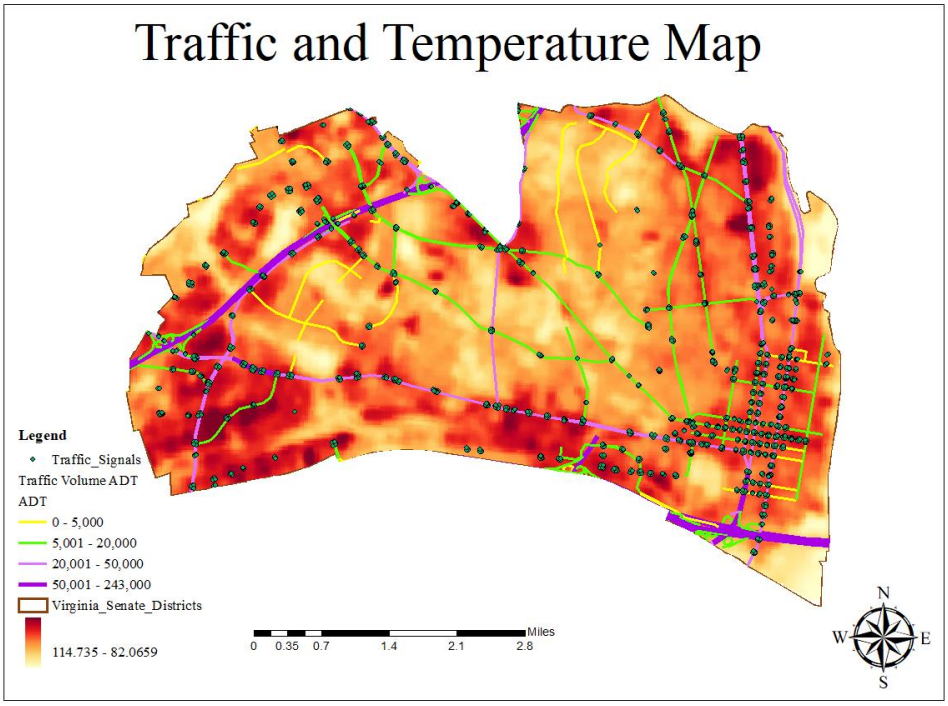

Figure 16. Map of the traffic volume along major roadways in Alexandria compared to land heat satellite data.

Description: Figure 16 above compares the traffic volume through Alexandria with the temperature readings from a satellite. The traffic density for this map is measured by average daily traffic (ADT), or the average number of vehicles that travel on a given roadway in one day. In this map, the green circles represent the traffic signals, the yellow lines represent the main roads with the least amount of traffic by volume, the green lines represent main roads with an ADT of 5,001 to 20,000 vehicles, the pink lines represent main roads with an ADT of 20,001 to 50,000 vehicles, and the thick purple line represents the main roads with the most amount of traffic by volume.

Results: Notice that the roads with a greater ADT tend to be in the outer rim of the City where the regions are hotter. This could indicate that a greater traffic volume generates more emissions and therefore increases the local and regional temperatures of the City.

Benefits: Similarly, to Figure 15, a map like this could be useful for the City of Alexandria as it helps to visually understand the effects of traffic volume on the temperature and climate of a region. With a map and information like this, the City can pass traffic ordinances or alter road planning to try and spread-out traffic and limit the heating effects of dense traffic. This information can also be helpful to promote public transportation as a means of de-densifying the roadways in the hopes of reducing local temperatures raised by increased traffic emissions. The map also shows which areas of the City people tend to travel through more heavily.

Data Sources:

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Traffic Volume:

VDOT Spatial Intelligence Group

Traffic Signals:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

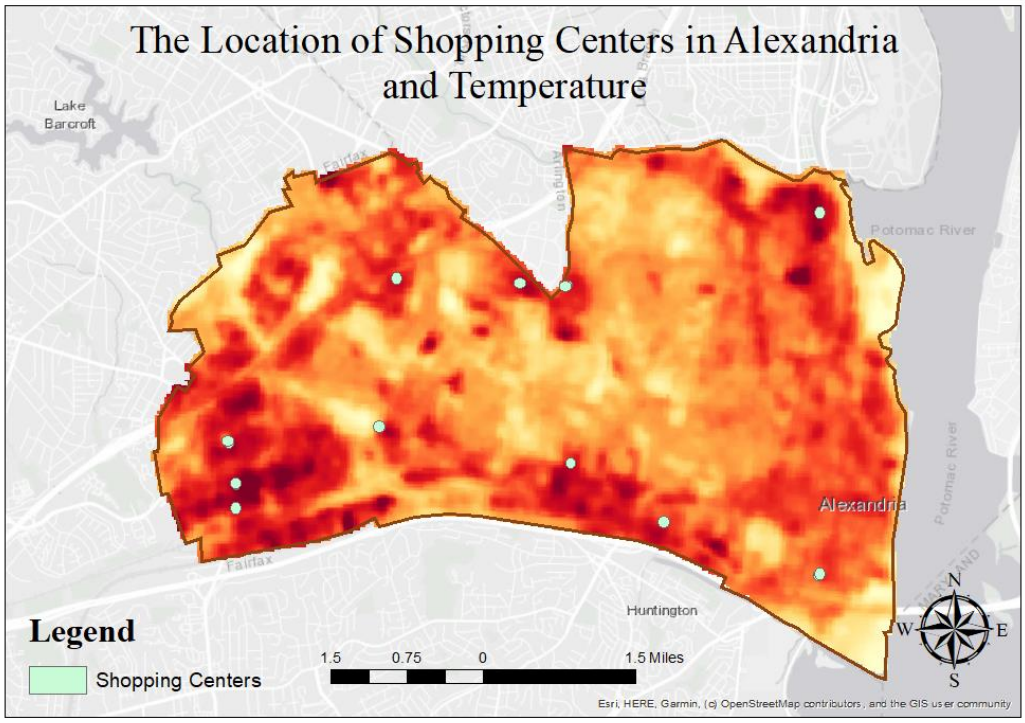

Figure 17. Map of the shopping center's locations in Alexandria compared to land heat satellite data.

Description: Figure 17 above compares the locations of large shopping centers in Alexandria with the temperature readings from a satellite. In this map, the light green circles represent the location of a shopping center.

Results: Notice that every one of the large shopping centers depicted in this map is in extreme heat. This may be due to one of two reasons: shopping centers are typically located where there are more people meaning there is likely a combination of other aspects that increase the local temperature or the extensive asphalt and concrete in and around shopping centers has a significant impact on local temperatures.

Benefits: A map like this can help the City analyze the potential impact of large centers of dense construction materials on the local temperatures and climate of a region.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Shopping Center Locations:

ArcGIS Editor with google maps

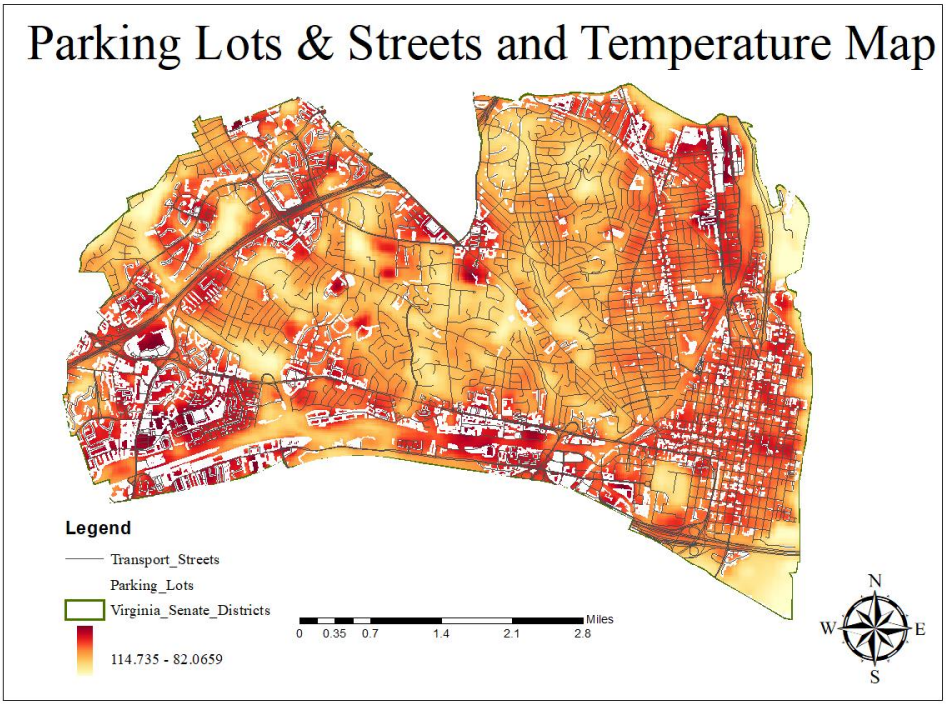

Figure 18. Map of the major parking lots and streets in Alexandria compared to land heat satellite data.

Description: Figure 18 above compares the parking lots and streets with the temperature readings from a satellite. In this map, the dark grey lines represent roads, and the white areas represent parking lots in the City.

Results: Notice that most of the major parking lots and large areas of asphalt are in the extremely hot regions of the City. This likely indicates a connection between the use of dense construction materials and UHIs.

Benefits: A map like this would be useful to the City of Alexandria as it identifies possible locations for cool surface or vegetation implementation and serves as a visual representation of the connection between large areas of dense construction material and extreme heat.

Data Sources:

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Transportatio Streets:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Parking Lots:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

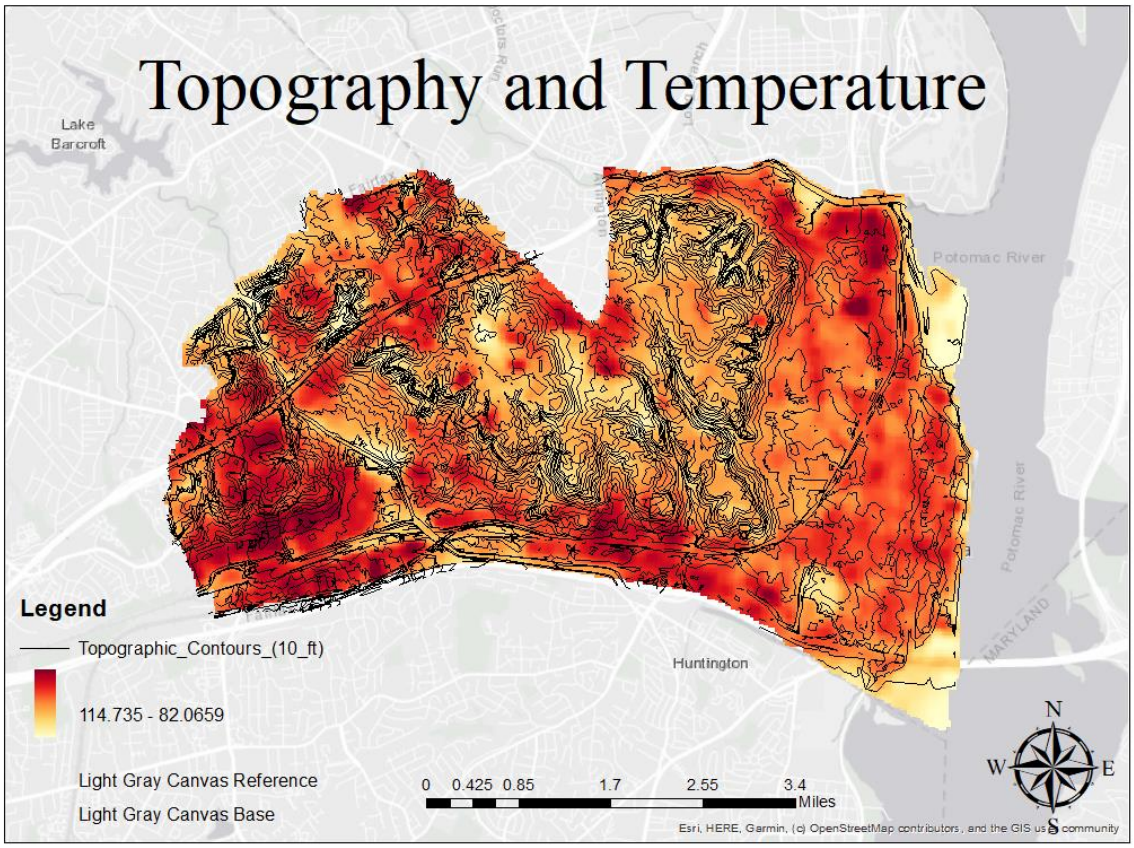

Figure 19. Map of the topography of Alexandria compared to the land heat satellite data.

Description: Figure 19 above compares the topography of Alexandria with the temperature readings from a satellite. In this map, the black lines represent the contour lines of the topography. Contour lines indicate a given elevation level, and the closer consecutive lines are to each other, the steeper the change in elevation.

Results: Notice that the areas of steeper elevation in the center of Alexandria are much cooler than the areas with less steep elevation changes are in areas of extreme heat. The edge of the center steep elevation areas almost exactly follows the edge of the differences in heat levels.

Benefits: A map like this would be helpful to the City of Alexandria as it visually demonstrated a commonly overlooked land feature that may impact UHIs, and the themes highlighted by this map may be applied to mitigation strategies to improve their impacts.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Topography

Developed by the City of Alexandria, Information Technology Services, GIS Division

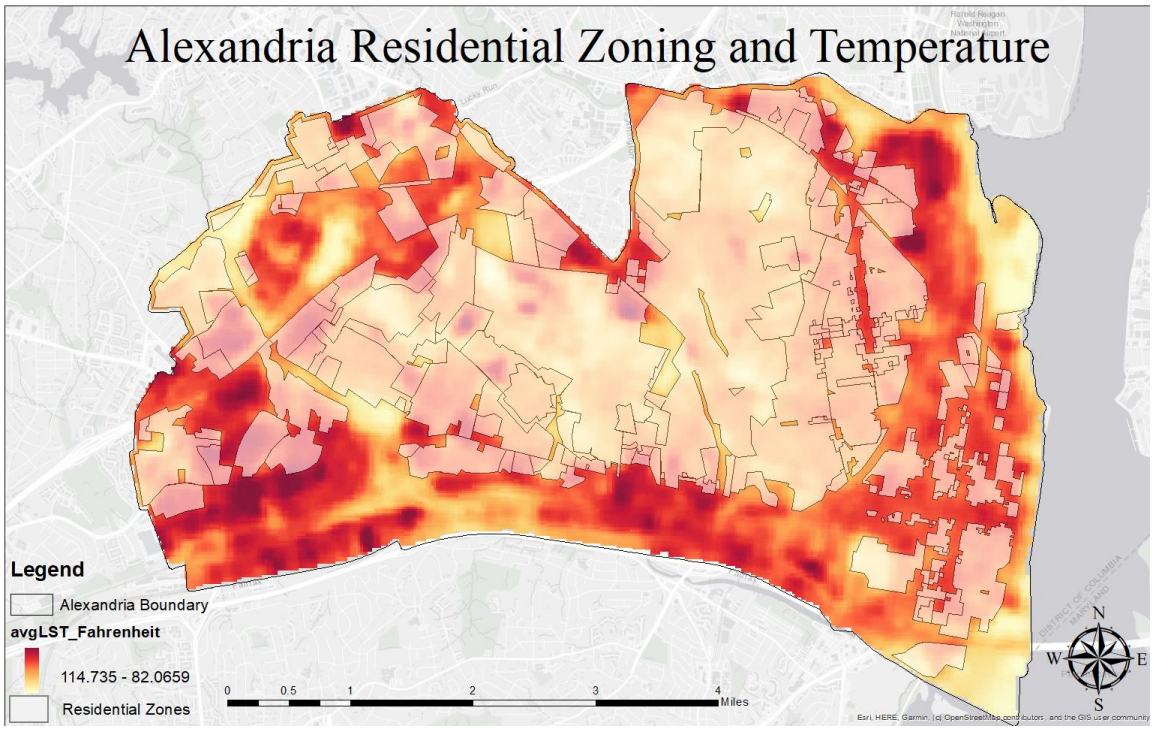

Figure 20. Map of the residential zoning regions of Alexandria compared to the land heat satellite data.

Description: Figure 20 above compares the residential zoning districts of Alexandria with the temperature readings from a satellite. In this map, the white sections outlined in black represent the residential zoning districts. A region is a residential zone if the number of housing units predominates over businesses, offices, factories, parks, and transportation or utility systems.

Results: This map highlights the residential zoning of Alexandria with the temperature map, which highlights the fact that the areas with the worst temperatures are found in the residential areas.

Benefits: A map like this would be useful to the City as it highlights the residential zones that are in UHIs so that when implementing mitigation and adaptation policies, officials understand which residential areas are most affected. As seen in Figure 20, the center residential region is in a region that is much cooler than the residential areas located on the outskirts of the City. Therefore, the City should focus their mitigation as adaptation practices in the outskirts of the City to improve the overall temperature comfort in Alexandria.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

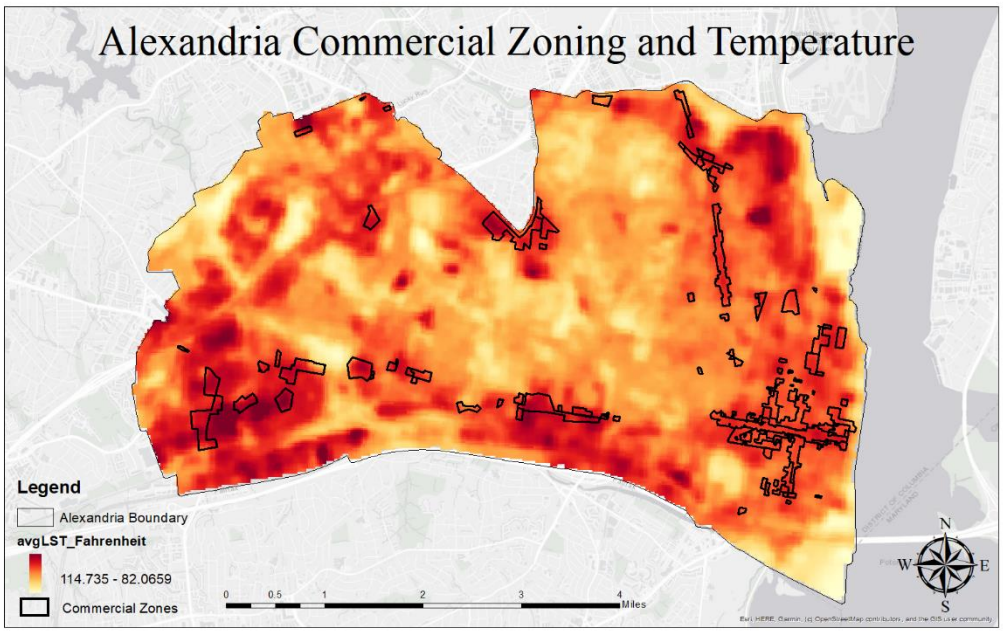

Figure 21. Map of the Commercial zoning regions of Alexandria compared to the land heat satellite data.

Description: Figure 21 above compares the commercial zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the commercial zoning districts. A region is a commercial zone if the number of businesses predominates over houses, offices, factories, parks, and transportation or utility systems.

Results: Notice that almost all the commercial zones are in the hotter areas of this City, which indicates that businesses tend to exhibit the lack of mindfulness when it comes to limiting their actions that may contribute to the perpetuation of UHIs and the development of these regions may also incorporate aspects of urban planning that further this perpetuation.

Benefits: A map like this would help the City identify the types of zones that most contribute to UHIs but also may be most affected by extreme heat.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

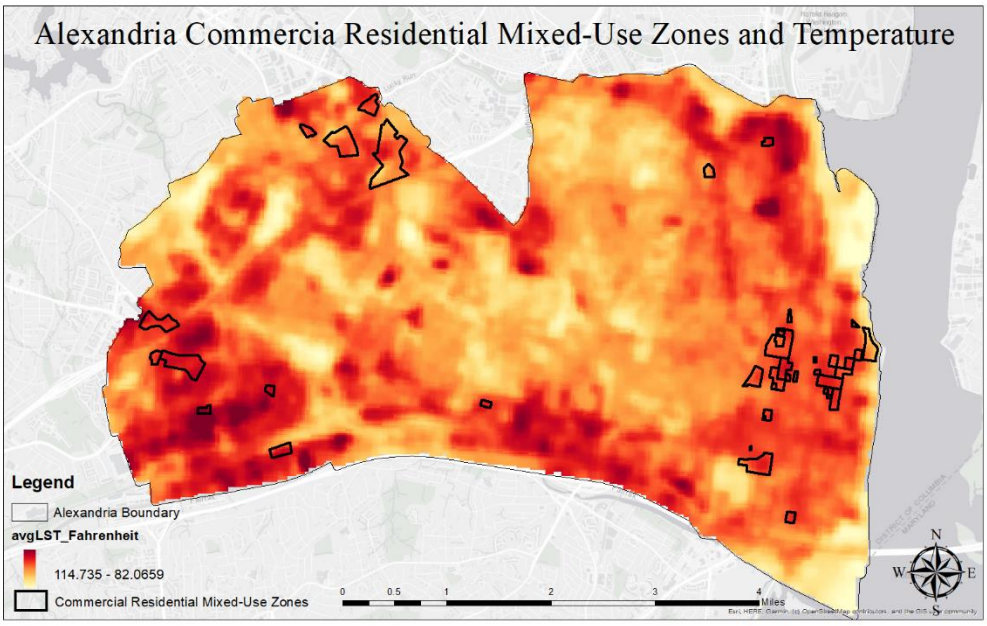

Figure 22. Map of the mixed-use commercial and residential districts of Alexandria compared to land heat satellite data.

Description: Figure 22 above compares the mixed-use commercial residential zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the mixed-use commercial residential zoning districts. A region is a mixed use commercial residential zone if the number of businesses and houses predominates over offices, factories, parks, and transportation or utility systems.

Results: Notice that almost all the mixed-used commercial residential zones are in the hotter areas of this City, which similarly to Figure 21 indicates that these types of zones might not focus on their actions that contribute to UHIs and their urban development plans may not take into considerations the design's impact on UHIs as much.

Benefits: A map like this would help the City identify the types of zones that most contribute to UHIs but also may be most affected by extreme heat.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

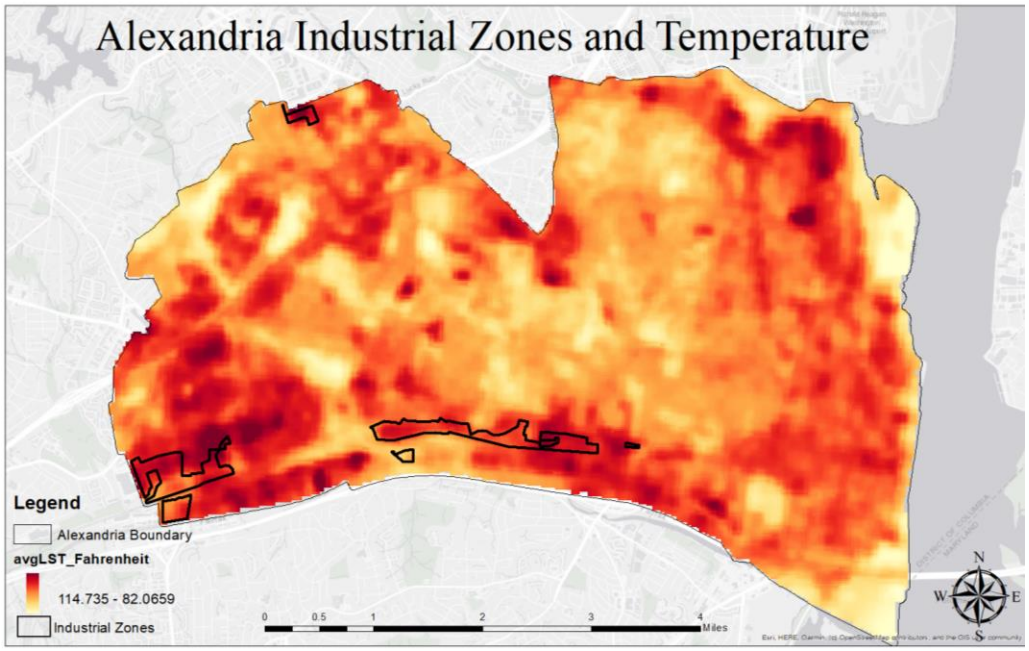

Figure 23. Map of Industrial zones of Alexandria compared to land heat satellite data

Description: Figure 23 above compares the industrial zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the industrial zoning districts. A region is an industrial zone if the number of factories and industrial facilities predominates over houses, businesses, offices, factories, parks, and transportation or utility systems.

Results: Notice that all the industrial zones are in UHIs meaning their processes and use of dense building materials that are typically incorporated in these types of structures likely contribute heavily to increased temperatures.

Benefits: Like Figures 20 and 21, this map would be helpful to the City of Alexandria as it would help identify types of City systems that contribute to UHIs and might be severely affected by them.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

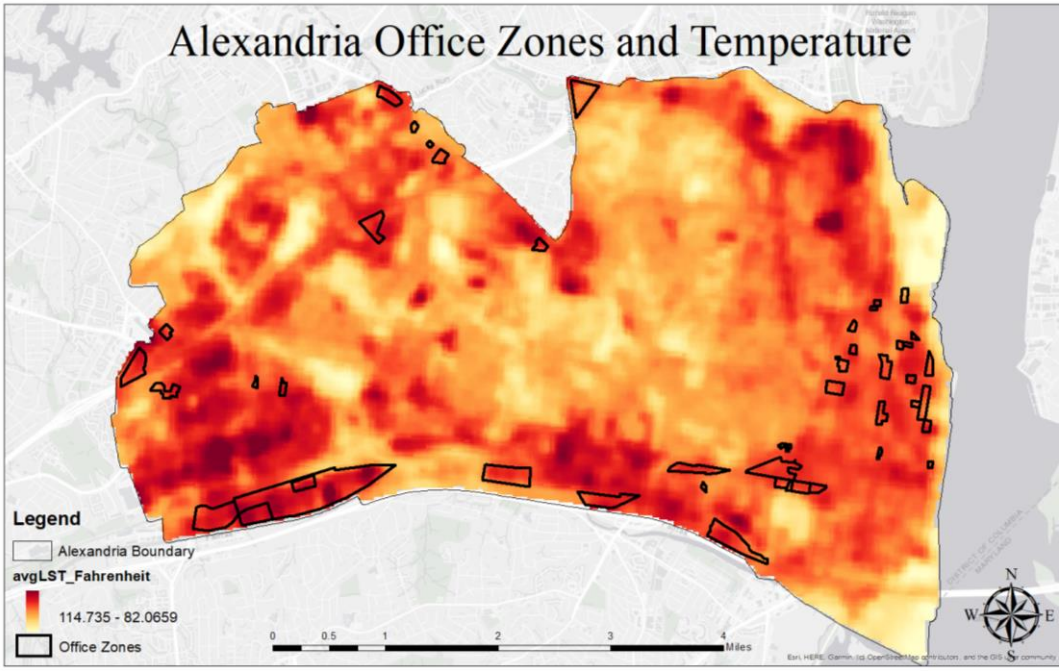

Figure 24. Map of Office Zones of Alexandria compared to land heat satellite data

Description: Figure 24 above compares the office zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the office zoning districts. A region is an office zone if the number of offices and professional facilities predominate over houses, businesses, factories, parks, and transportation or utility systems.

Results: Notice that all the industrial zones are in UHIs, meaning these types of buildings are likely to be affected by extreme heat and will require more energy to cool off the buildings. The airflow around large office buildings and dense building materials typically involved in their construction are further contributing to the problem of UHIs in the City.

Benefits: A map like this would be helpful for the City of Alexandria as it identifies additional structures that may need additional mitigation and adaptation strategies.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

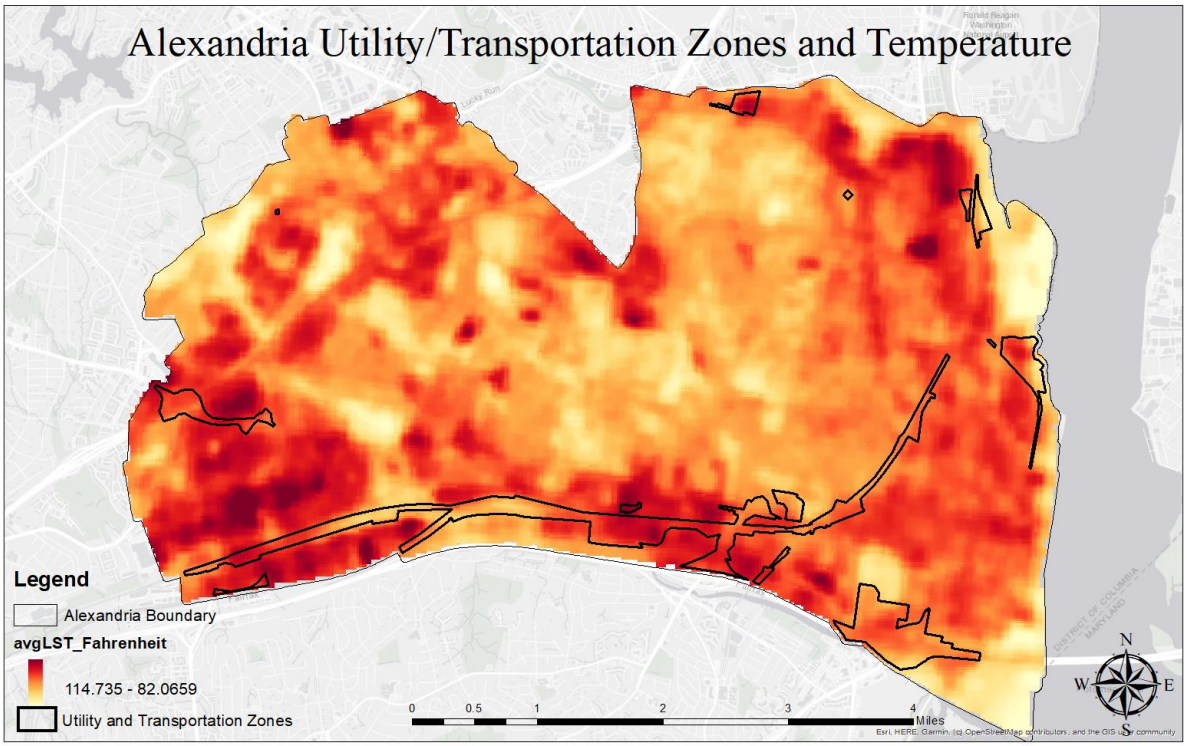

Figure 25. Map of Utility and Transportation Zones of Alexandria compared to land heat satellite data.

Description: Figure 25 above compares the utility and transportation zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the utility and transportation districts. A region is a utility and transportation zone if the number of land, sea, or air transportation systems and critical City infrastructure like power lines and water systems predominate over houses, businesses, offices, factories, and parks.

Results: Because these zones are not located in the hottest regions, it is likely that they are not the biggest contributor to UHIs although they still have some contribution, and they may be affected by extreme heat but not as severely. However, because transportation and utility systems are crucial to the City's workings, attention should still be placed in these regions.

Benefits: A map like this would be helpful to the City of Alexandria as it shows the relationship between areas of predominantly transportation or utility systems and temperature.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

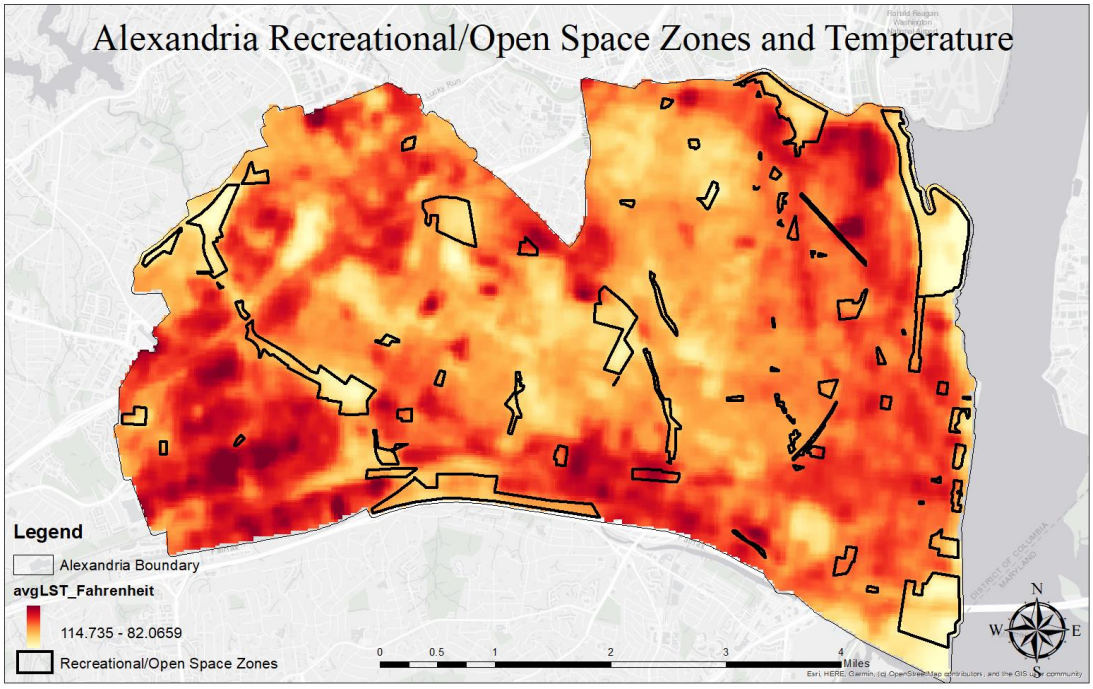

Figure 26. Map of recreational and open space zones of Alexandria compared to land heat satellite data.

Description: Figure 26 above compares the recreational and open space zoning districts of Alexandria with the temperature readings from a satellite. In this map, the sections outlined in black represent the recreational and open space zoning districts. A region is a recreational and open space zone if the number of open spaces used for recreational activities predominate over houses, businesses, offices, factories, and parks.

Results: Notice most of these zones are in regions of cooler temperatures indicating a likely connection between the cooling effects of greenery or open spaces and lower temperatures.

Benefits: A map like this would be helpful for the City as it identifies areas that may not need to be focused on in the new mitigation and adaptation strategies and can provide them with potential evidence for the cooling effect of vegetation.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Zoning

Sdegari.ALEXGIS.Planning_Zoning_y,Alexandria, VA

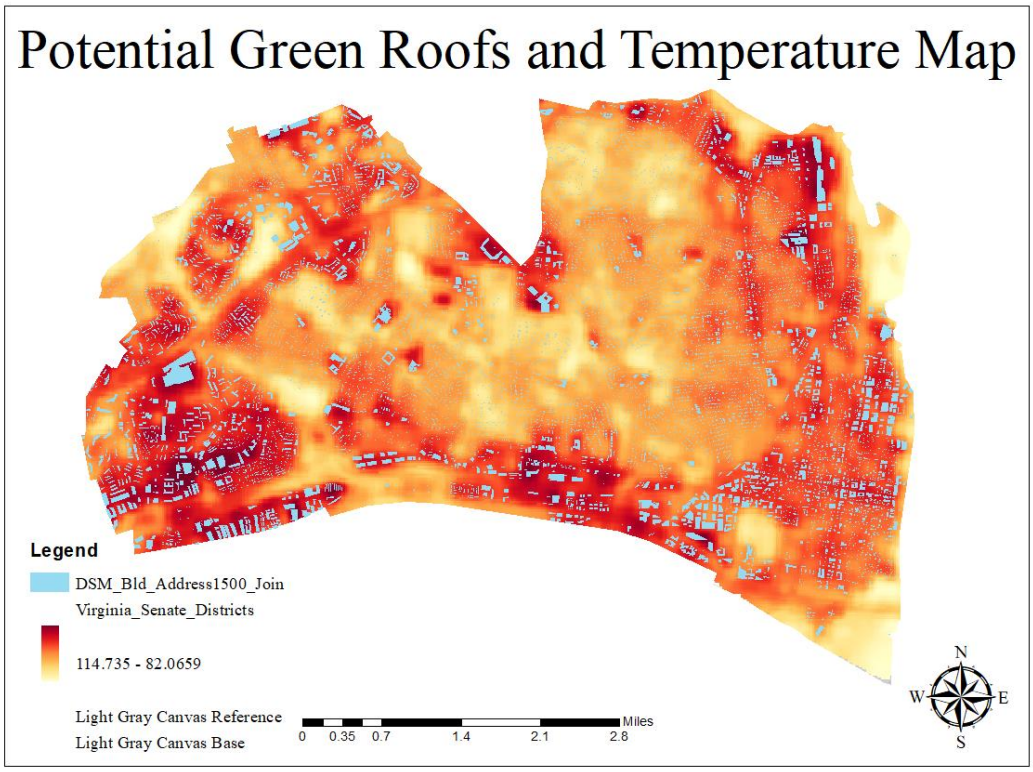

Figure 27. Map of buildings with potential green roofs compared to land heat satellite data

Description: Figure 27 above compares the locations for green roofs in Alexandria with the temperature readings from a satellite. In this map, the blue regions represent the possible locations for green roofs.

Results: Notice this map highlights mostly locations for green roofs in the extremely hot areas of the City as this mitigation practice will likely have the most significant impact in UHIs.

Benefits: A map like this would be helpful for the City of Alexandria as it simplifies the process of implementing green roof strategies by identifying the best locations for the systems. It also highlights regions that could be doing more to mitigate the impacts of UHIs so that regulations, policies, or incentives can be offered to improve the City's overall efforts.

Data Sources:

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Green Roofs:

Northern Virginia Regional Commission

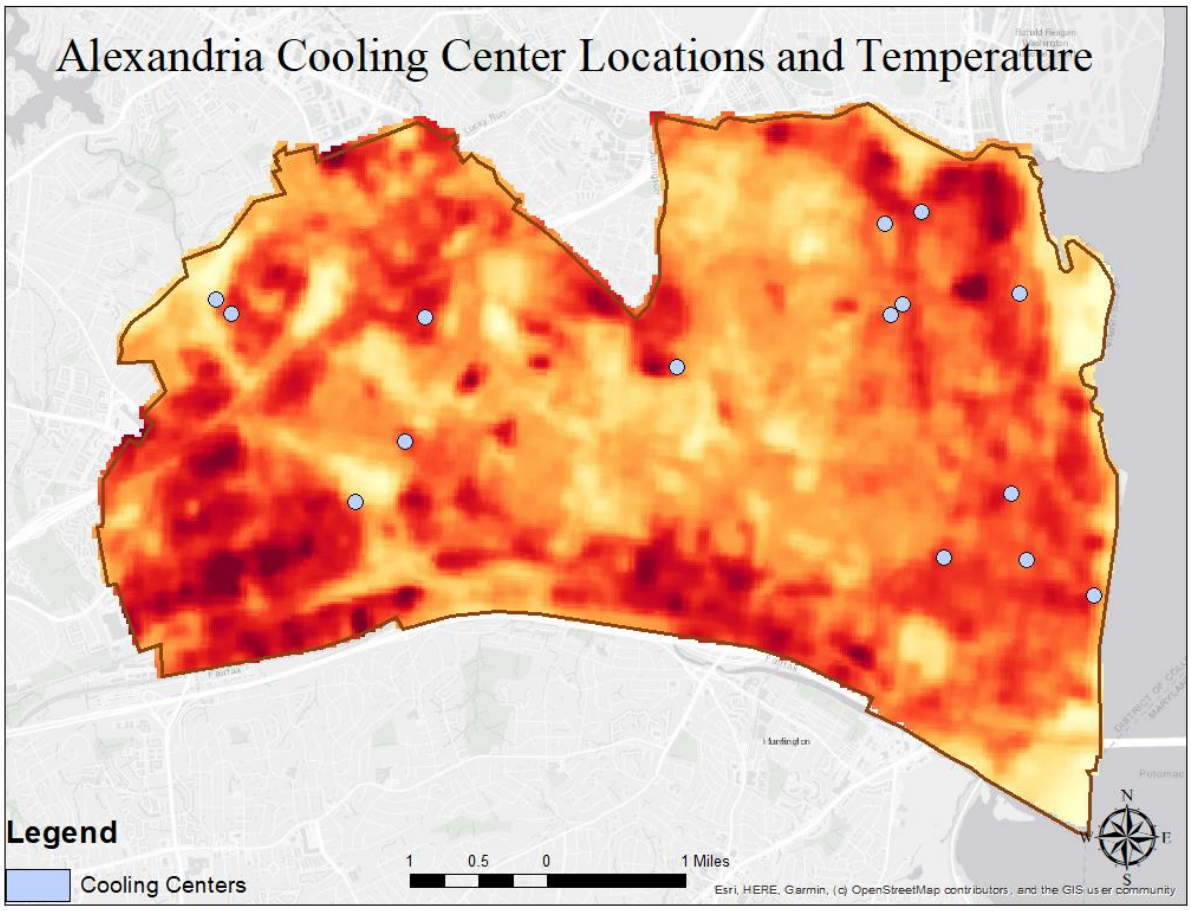

Figure 28. Map of Cooling center locations in Alexandria compared to land heat satellite data

Description: Figure 28 above compares the locations of cooling centers in Alexandria with the temperature readings from a satellite. In this map, the purple circles represent the locations of cooling centers in Alexandria.

Results: Notice that the cooling centers seem to be clumped together in the warmer regions of the City, and although these are the areas that need them the most, they should be spread out a bit more to minimize travel time from other hot areas of the City.

Benefits: A map like this would be useful for the City as it allows them to begin an analysis on the effectiveness of one of their most prominent UHI mitigation and adaptation strategies. From this map, the hottest areas of the City lack cooling centers, so the City should open public buildings in these regions to help their citizens. More research on the specifics of each cooling center and the scientific benefit of cooling centers needs to be conducted, but this map is a good start to the analysis.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Cooling Center Locations:

ArcGIS Editor with google maps

Alexandria Temperature and Population Density Maps

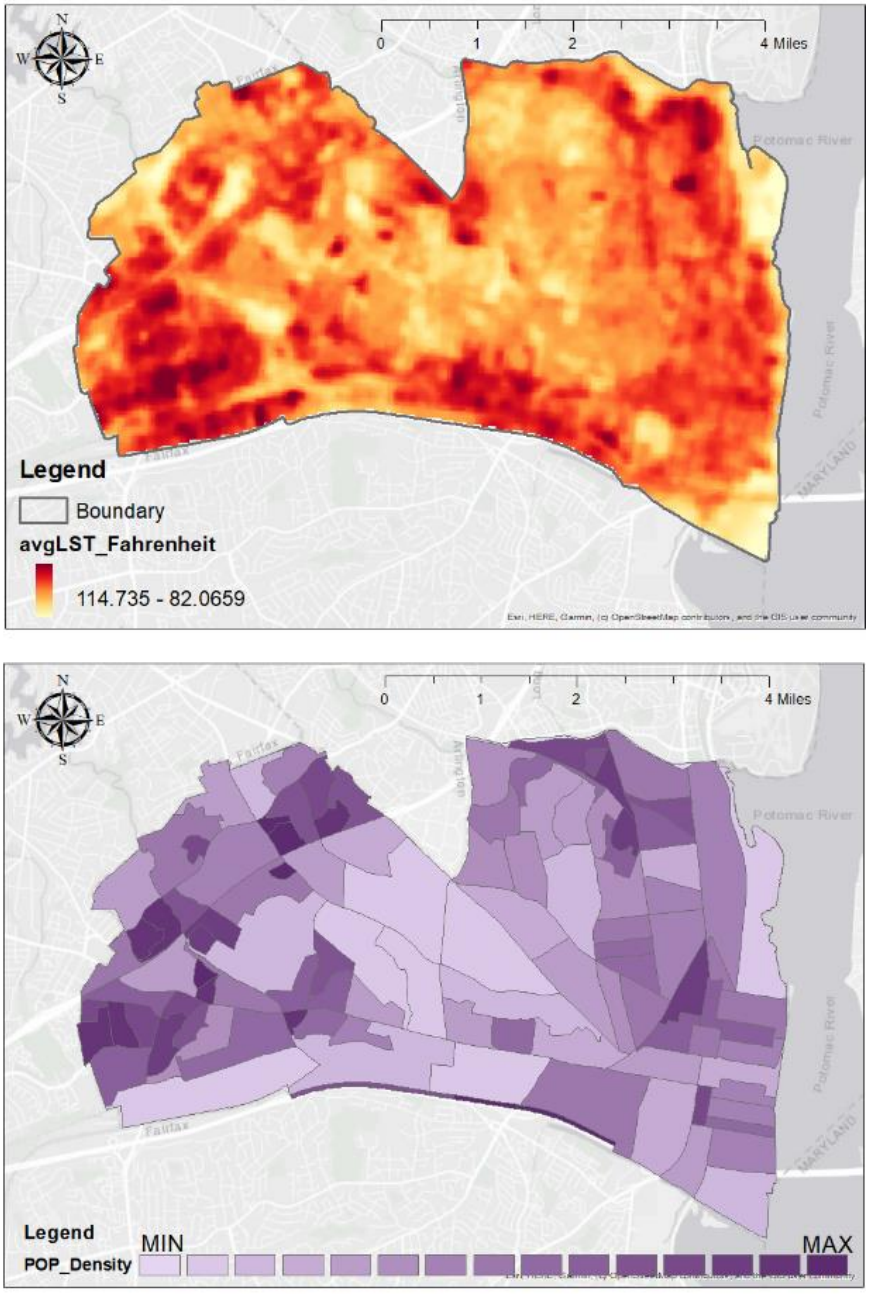

Figure 29. Map of the population density in regions of Alexandria compared to land heat satellite data

Description: Figure 29 above compares the population density of various areas of Alexandria with temperature readings from a satellite. In this map, the darker purple regions represent areas with a greater population density while the lighter purple regions represent areas with a lesser population density.

Results: Notice that the regions of greater population density are typically located in areas of higher temperature, thus indicating a possible connection between these two aspects.

Benefits: This map would be useful when analyzing which strategies would work for each area of Alexandria. Strategies like Cooling Centers and outreach could be targeted at specific regions of the City, which could make them more effective.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

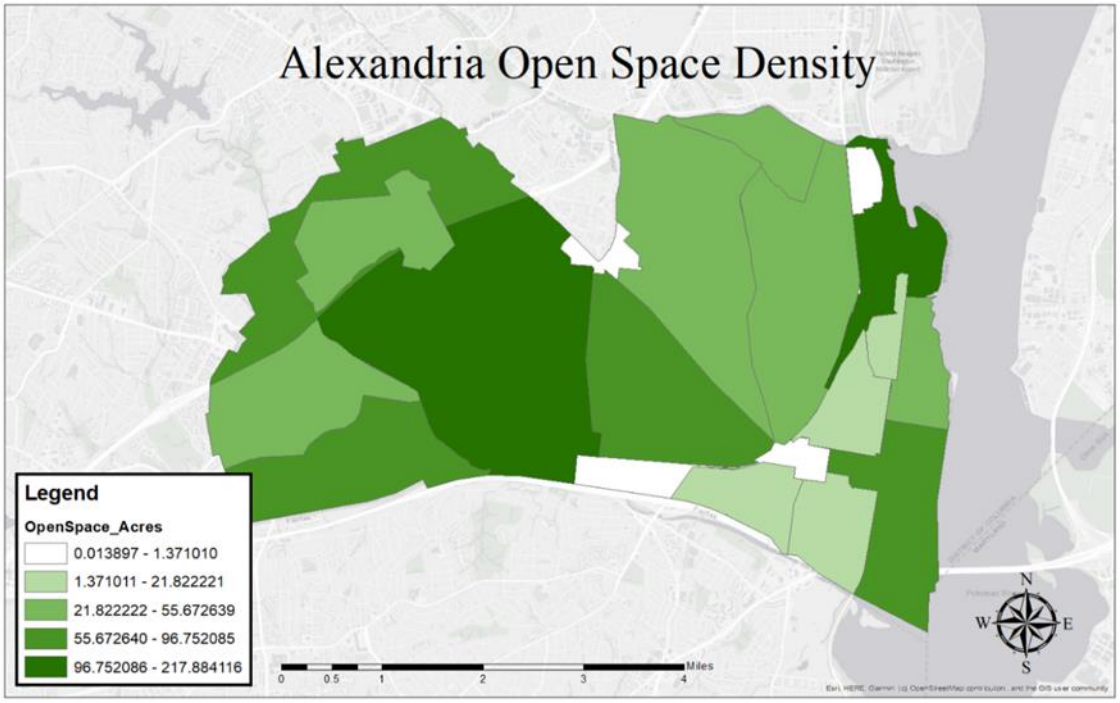

Figure 30. Map of the Open Space Density in Alexandria, Virginia.

Description: Figure 30 above displays the open space density of various regions in Alexandria. In this map, darker green regions represent areas with greater open space density and the lighter green regions represent areas with less open space density. The open space density is measured in terms of acres of land covered in open space areas.

Results: While **t**his map does not have a temperature under layer, the open space map shows that the City does have a lot of open area in some places but not a lot in others, which could be useful in understanding which mitigation strategies could be improved in specific areas of the City.

Benefits: This map would be useful to the City of Alexandria as it highlights areas where more open space and parks might be necessary to address the rising problem of UHIs in the City.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

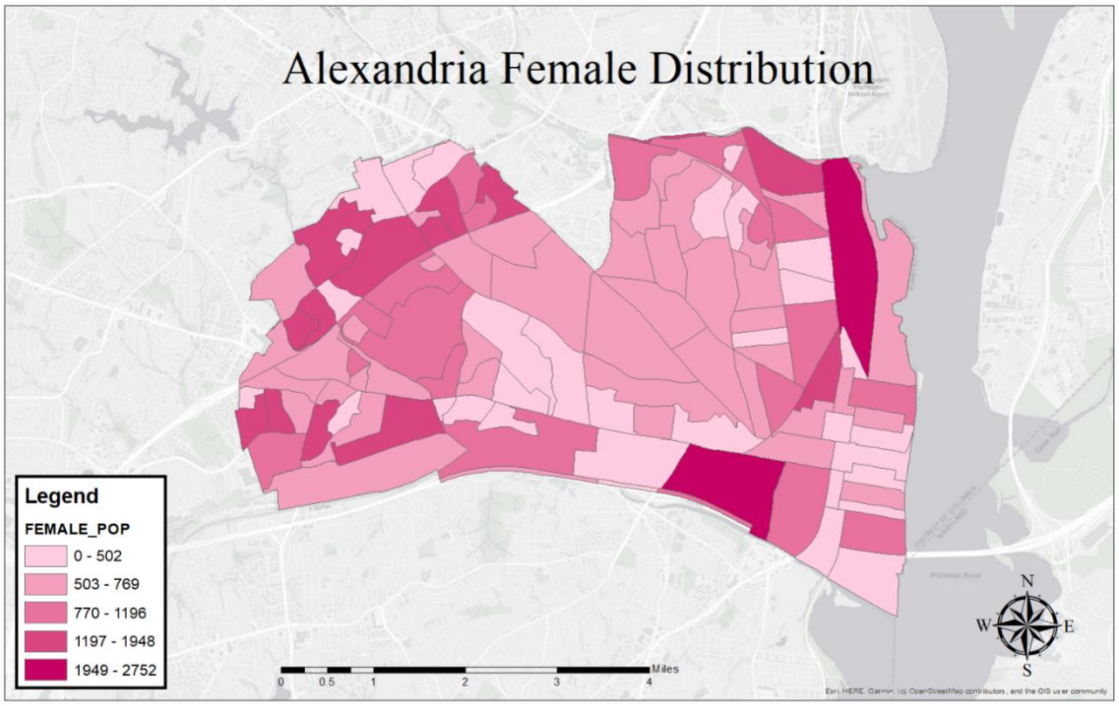

Figure 31. Map of the Female resident distribution through Alexandria.

Description: Figure 31 above displays the female population distribution in the City of Alexandria. In this map, the darker pink regions represent areas with a greater number of female residents whereas the lighter pink regions represent areas with a smaller number of female residents.

Results: This map shows the Alexandria Female Distribution, which on its own does not reveal much, but the intention of this map is to be a place holder for health data that the team did not have access to. This could be useful in identifying a vulnerable population (pregnant people), but it should be replaced once health data pertaining to this vulnerable population is acquired.

Benefits: A map like this is a good start to identifying another population that can be severely affected by extreme heat events, pregnant women. Although this map is not comprehensive, and more research needs to be done on the population's density, the effects of heat on pregnancy, and resources for pregnant people, this is a good start at filling this gap in the City's resources.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

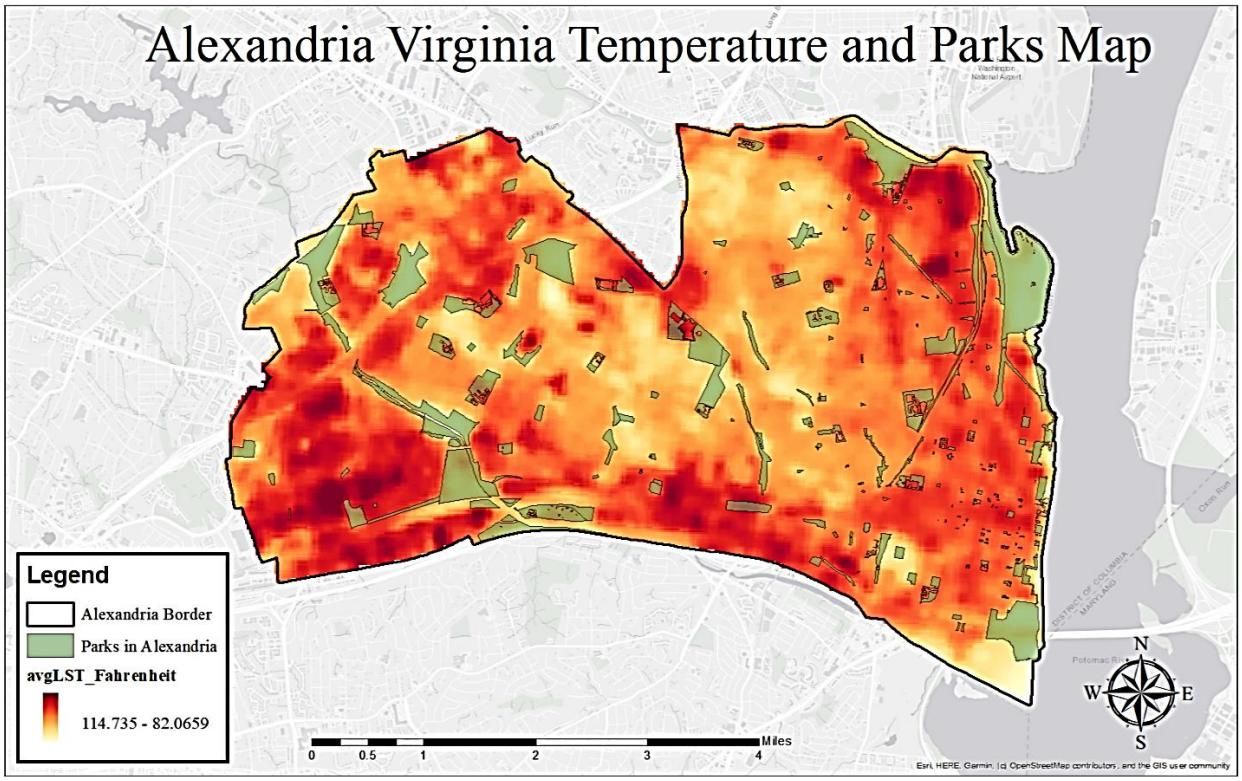

Figure 32. Map of the parks in Alexandria compared to land heat satellite data.

Description: Figure 13 above compares the locations of parks in Alexandria with the temperature readings from a satellite. In this map, the green regions represent the locations of parks in the City while the red, orange, and yellow markers indicate the relative temperature of the regions.

Results: Notice that almost all the parks in the City, except for a select few, are in regions of cooler temperatures. This seems to support the use of greenery, vegetation, and open space to mitigate the effects of UHIs. In the exceptions, the cooling effects of the parks located in warmer regions of the City may be overshadowed by the negative impacts of other sources like poor airflow from urban planning, extensive use of dense construction material in specific zones, or heavy traffic.

Benefits: A map like this would be helpful to the City as it makes the connection between parks and temperature to visualize and support the cooling effects of vegetation as a UHI mitigation strategy. It also indicates the specific locations of parks and highlights regions without them.

Data Sources:

Light gray base map:

Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Temperature Layer:

Jason.matney_AlexGIS

Alexandria Border:

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Alexandria Parks

Fairfax County, VA, VITA, Esri, HERE, Garmin, GeoTechnologies, Inc., USGS, EPA | Esri, HERE

Appendix B

Interview questions for subject matter experts and community organizations

This set of questions was designed to gather additional information about urban heat islands, their causes, effects, and mitigation strategies to expand and support our initial research and findings. The interviews were conducted both in-person and virtually with local subject matter experts and community organizations that were researched by the team or suggested by the sponsors. There were four groups whose departments and questions are listed below. The general research questions that were asked to all of the people we interview are listed below along with the department specific questions:

Group 1 Questions:

1. What programs have your department implemented to address extreme heat events?
    a. What are the most commonly utilized programs?
2. Are there future plans your department is working on to address EHEs and UHIs in the City?
3. How well do you believe the City does in addressing UHIs and EHEs?
    b. How do you believe they can improve their programs or efforts?
    c. Which aspects of current City practices does your department believe are the most important to keep in place in terms of UHI mitigation and adaptation?
4. Does your department track any specific data to help identify areas or subjects of interest when it comes to UHI mitigation (for example asthma attacks, heat related ambulance calls,...)?
5. Which of your programs, is any, are aimed at helping vulnerable populations mitigate extreme heat?
6. What resources do cooling centers traditionally have and what additional resources may be helpful to the community during extreme heat events?
    d. What is the recommended distance between cooling centers and are there any plans underway to minimize the travel distance between stations?

Health Department

7. What are the most common and the most severe health risks you have seen as a result of UHIs and EHEs?
    e. Have there been noticeable mental or emotional impacts on the community members as a result of EHEs?

Department of Community and Human services:

8. Can you talk a little about the access, process, and upkeep of the cooling assistance program?
9. Do you have training or workshops to inform the public about UHIs and the risks of extreme heat events and what aspects do they typically focus on?

Race and Social Equity

10. When addressing extreme heat events in the City, have there been any discrepancies in the types of areas the programs focus on in terms of race and social equity?
    f. How has your office worked to rectify certain heat related discrepancies?
    g. Has the City made any advancements in this area?

Office of Housing

11. Are there disparities where the lower income housing are more affected by UHIs
    h. How is this disparity gap being closed
12. What are the key differences in insulation for the housing of different areas of the City?

Group 2 Questions:

13. What are some of the major concerns of your Department during Extreme Heat Events?
14. Does your department implement any programs, strategies, or plans to respond to extreme heat events?
15. Are there future plans your department is working on to address EHEs and UHIs in the City?
16. What regulations, codes, or incentives has the City or your department implemented in attempt to mitigate or adapt to EHEs and UHIs Regulations or incentives or codes?
17. How effective do you believe the current City codes and regulations are in mitigating UHIs?
    i. How can these regulations, laws, codes, and incentives be improved upon to better address UHIs and EHEs in the City of Alexandria?
    j. Which aspects of current City practices does your department believe are the most important to keep in place in terms of UHI mitigation and adaptation?
18. How is your department using the demographics and census data to identify communities experiencing extreme heat events that are more susceptible?
    k. How does your department try to close the disparity gap that may arise from City-wide planning?
19. Does your department track any specific data to help identify areas or subjects of interest when it comes to UHI mitigation (for example, AC breakdowns on metro…)?
20. How do the people of Alexandria typically compensate or adjust during EHEs or in UHIs (do they tend to alter their form of transportation, do they use more AC energy…)?
21. How do you believe building energy consumption is affected by UHIs and EHEs?
22. What mitigation strategies have been proven to be the most effective in limiting the effects of UHIs and EHEs in the City?

Transportation

23. What transportation system do people typically select during extreme heat events?
24. What travel regulations has the City implemented that may help or interfere with travel during EHEs

25. Do electric or hybrid buses and cars have significant effects in the overall City emissions and does this translate into lower City temperatures?

Policy and Codes

26. What LEED codes do you require that might UHI?
27. What regulations, if any, are in place that focus on building placement in terms of encouraging efficient air flow through the City and aerodynamic air flow between buildings?
2. Do you see a significant increase in building energy consumption during EHEs and in UHIs

Parks

28. What impact do water features like pools and fountains have in urban heat islands?
    a. Are they worth the cost?
    b. Do they have a significant impact on the local temperature
    c. Do people utilize the current water features in the City?
    d. Would the City benefit from adding more water features?

Planning and Zoning

29. What factors does your department consider when developing new land in terms of limiting UHI impacts?

Group 3 Questions:

30. What is the average energy usage increase during an extreme heat event?
31. How does increased heat affect energy loss in power lines and substations?
32. What can you tell us about the new climate office?
    e. What positions will it include?
    f. What background is required or encouraged for each of these positions?
    g. What are the office's initial plans
    h. What parts of the office, if any, will focus primarily on combating UHIs or EHEs
33. How are water systems and sewers affected in UHIs or EHEs
34. Does your department implement any programs, strategies, or plans to combat or respond to extreme heat events?

Group 4 Questions:

These questions were asked to members of a local neighborhood organization in Alexandria

1. Is your community affected by extreme heat events or urban heat islands?
    - Regularly affected during summers
    - Rarely affected
    - Not affected
    - Comments: _____

2. What physical features of your community do you believe cause the community to be affected by extreme heat events or urban heat island effects?
    - Large areas covered by pavement
    - Large amount of the area covered by buildings
    - Lack of green space and tree canopy
    - Lack of air conditioning in housing
    - Inability to pay for increased air conditioning costs due to high heat events
    - Sensitive population (such as elderly, young, low-income)
    - Other: _____
3. What physical features of your community do you believe may reduce the impacts of extreme heat events and urban heat islands?
    - Availability of green space and tree canopy
    - Availability of air conditioning in housing
    - Nearby cooling center
    - Other _____
4. How aware are you of the City's efforts to address extreme heat events and urban heat islands?
    - Not at all
    - Have heard of City actions but do not know specifics
        - Heat emergency and cooling center availability
        - Planting trees and providing green space
        - Heat Vulnerability Index
        - Other: _____
    - Familiar with City actions
        - Heat emergency and cooling center availability
        - Planting trees and providing green space
        - Heat Vulnerability Index
        - Other: _____
5. How aware are members of your community of the City's efforts to address extreme heat events and urban heat islands?
    - Not at all
    - Have heard of City actions but do not know specifics
        - Heat emergency and cooling center availability
        - Heat Vulnerability Index
        - Other: _____
    - Familiar with City actions
        - Heat emergency and cooling center availability
        - Heat Vulnerability Index
        - Other: _____
6. How has the City done in mitigating the effects of extreme heat events and urban heat islands?
    a. Have their prevention and reduction programs been successful in your community?

- Yes
- Partially
- No

b. Has their responsive programs been successful?
   - Yes
   - Partially
   - No

c. How can these programs provide better results to support community efforts?
   - _____

_____

7. Does your association or community aid those affected by extreme heat events or urban heat islands?
   a. Does your association provide assistance or collaborate with other community groups in order to limit the impact of extreme heat events and urban heat Islands on your community?
      - Yes: Please briefly describe: _____
      - No
   b. Do other groups in your community help residents during extreme heat events?
      - Yes: Please briefly describe: _____
      - No

Appendix C

Informed Consent Disclaimer

Introduction: You are participating in an interactive qualifying project interview where you are asked to provide your opinions on the urban heat island effects. The urban heat island effect is a phenomenon that takes place when cities begin to absorb and retain heat causing the temperature to increase. These high temperatures can negatively impact the environment and community.

Purpose of the research studies: You are asked to participate in the interactive qualifying project interview to help provide additional information for our research. These interviews are designed to increase our knowledge of the urban heat island effect and its impact on communities.

What you will be required to do in this interview/survey: You will be asked to respond to a series of questions that are related to urban heat islands and extreme heat events. You are not required to answer these questions if you do not want to, but your input will be greatly appreciated.

Time required: You will be asked to participate in a short interview/survey that lasts between 30 and 90 minutes.

Risks to Participants: A WPI Institutional Review Board (Ethics Board) has reviewed and approved each study considering ethical considerations, the protection of human participants, and minimizing risks to participants.

Benefits to Participating: The major benefit of participating in this interview/survey is to inform the City of Alexandria to better help your community and the communities around you with strategies related to extreme heat events and urban heat islands.

Confidentiality: The information of the interview/survey will be used in a public report, but you can opt to not divulge your information. This means that the contents of the interview/survey will be used but will not be linked to you. Otherwise, your information will be assigned code numbers. The list connecting your name to this number will be kept in a locked file. Any data collected will be used only for statistical analyses. Names may be used in the final report, but you may opt to give information anonymously, and in that case, your name will never be used in the public report.

Voluntary participation: Your participation in these studies is completely voluntary. There is no penalty if you decide not to participate. If you do not wish to participate in these interviews/surveys, you should notify the team in advance.

Right to withdraw from the studies: You have the right to withdraw from any study at any time without penalty.

How to withdraw from studies: The consent form you sign for each interview/survey will tell you how to withdraw from the study. In most cases, you simply inform the interview/survey and quietly leave the room.

Whom to contact if you have questions about the studies: Project Advisor, WPI, Associated with Interdisciplinary & Global Studies, 100 Institute Rd., Worcester MA 01609, Professor Linda Looft, Tel. +1 (508) 831 5000 x5231, Email: lclooft@wpi.edu and Dr. Fred Looft, Project Advisor, WPI, Associated with Interdisciplinary & Global Studies, 100 Institute Rd., Worcester MA 01609 Tel: +1 (508) 831 5000 x5231, Email: fjlooft@wpi.edu

Agreement: I agree to participate in the studies described above. [If you do not agree, simply do not return this form]

Your Name [printed]_____

Your Signature_____ Date:_____

This form was adapted from the Informed Consent Agreement Research Experiments for Students in Psychology and Social Science Courses of the Department of Social Science, Worcester Polytechnic Institute.

Appendix D

NOAA UHI Mapping Campaign Proposal

Nicholas Culkin, Lexi Dahlquist, Gabriel Garbes, Jonathan Martin, Drevione Townsend
Worcester Polytechnic Institute

Introduction

With the rapid expansion of urban development in the City of Alexandria, a lesser known, yet vitally imperative obstacle that endangers the quality of life in the City has surfaced and grown in recent years, Urban Heat Islands (UHIs). UHIs are defined by the United States Environmental Protection Agency as "urbanized areas that experience higher temperatures than outlying areas*"* (Heat Island Effect, 2022). UHIs are most often attributed to a rise in temperature from reduced natural landscapes, increased human activity, and expanded urbanization (Heat Island Effect, 2022). In recent years, the increased population and industrialization in the City of Alexandria have been responsible for expanded urban growth and exacerbated Virginia's naturally warm climate into dispersed Urban Heat Islands (Energy and climate change action plan, 2022). As a result of UHIs, community members have experienced noticeable health and economic complications ("Heat Safety", 2022).

The increased temperatures, caused in part by the absorption and amplification of incoming heat by dense urban materials, pose a significant threat to human health, particularly in economically challenged neighborhood where medically compromised individuals can experience several adverse health effects, many of which may be life-threatening (Wang, 2021). The most common heat-related illness is dehydration, but other more serious problems such as heat stroke, cramps, and exhaustion can occur if people are exposed to high temperatures for an extended period of time. Citizens can also face economic struggles as the increased heat raises the total cost of energy due to cooling appliances. Disadvantaged individuals at lower income levels cannot always afford the air conditioning systems to remain cool in times of extreme heat. In addition, the energy cost in low-income housing is often greater because such housing often lacks efficient cooling retention as a result of inadequate building maintenance, "poor structural conditions and energy inefficiencies" (Hernández, 2015) ("Low-Income Household Energy Burden Varies Among States — Efficiency Can Help in All of Them," 2018). Even when resources like cooling centers are provided by City governments, such centers often require paid transportation or are not located near communities most in need.

While the City of Alexandria has taken some actions to address their UHI problems, they are seeking to expand and update their mitigation and adaptation practices in order to improve the quality of life for their citizens.

Community Involvement, Help and Role

The National Oceanic and Atmospheric Administration, or NOAA, has opened applications for their 2022 National Integrated Heat Health (NIHHIS) and Climate Adaptation Planning and Analytics (CAPA) Urban Heat Island Mapping Campaign. The City of Alexandria is seeking to improve its UHI mitigation and adaptation efforts, and admission into this mapping campaign will be invaluable. However, for the mapping campaign to have a significant impact on the reduction of UHIs in the City of Alexandria.

A community-wide campaign to engage volunteers in various aspects of the City's initiatives is needed. For example, volunteers are needed to help spread information about UHIs and extreme heat events in community workshops, presentations, and pamphlet distribution. This will help residents identify the warning signs of dangerous heat related illnesses sooner, thus allowing for earlier medical intervention. The volunteering efforts will also help residents remain mindful of their actions that may contribute to UHI development and exacerbation. The campaign relies on the help of citizen scientists who collect ground data using temperature and air quality sensors that can be attached to cars and bikes. The scientific supplies would be provided by NOAA and the City of Alexandria, but the effort and time of citizens is what would make this campaign successful and result in changes to reduce the development and impact of UHIs on City residents. In addition to time and effort, monetary and in-kind donations from local community members and organizations would help the City raise funds to support the campaign.

Alexandria Data Usage

Alexandria has taken some steps to improve their UHI mitigation processes by creating a task force specializing in climate health, establishing various cooling centers throughout the City, extending local pool hours, and conducting a heat vulnerability assessment. The City has also collected satellite thermal imagery of the City, which has proven useful in developing a general sense of the existence of UHIs in the City. While this satellite data has proven to be helpful, it can occasionally be outdated or unclear. Ground data from NOAA's UHI mapping campaign would help reduce the uncertainty of the satellite data and help in expanding and updating Alexandria's UHI mitigation practices.

NOAA's Data

For their UHI mapping campaign, NOAA provides members of the selected community with portable heat sensors to attach to cars and bikes in the summer. These citizen scientists then travel along assigned routes at three preselected times of the day (morning, afternoon, and evening), collecting "temperature, humidity, time and GPS location" (NOAA Seeks Applicants for 2023 Urban Heat Island Initiative, 2022) data. The organization's scientists then use this ground data and interpolate it with the help of existing satellite data to provide a fine-grained, high-resolution estimation of the region's air temperature landscape because it is not possible to

efficiently collect ground data for every point in the City (Shandas, 2019). With this data, NOAA creates three different heat distribution maps of the City, one for the morning, one for the afternoon, and one for the evening. The "Interactive, high-resolution web maps of the modeled air temperature" (Mapping Campaigns, n.d.) developed with a machine learning process also assign a heat index number to the area for better City UHI mitigation and adaptation focus. A short report will accompany each map to describe an "analysis of distribution of heat in the morning, afternoon and evening" (Mapping Campaigns, n.d.), which will be helpful as the City evaluates their current practices.

City-Wide Benefits and Data Integration

NOAA's UHI mapping campaign will be invaluable to the City of Alexandria's efforts to mitigate and adapt to UHIs and will be beneficial to the City as a whole. First, the generated maps and data will help fill in the gaps to the City's current UHI research because it will result in fine-grained ground data that the City does not currently have access to. Ground data is more helpful in analyzing the heat impact on residents than satellite data as it highlights the temperatures felt by people on the ground as opposed to the overall aerial temperatures of the City, which are not always the same as experienced temperatures. The campaign will also develop an analysis of the City's heat at different times of the day, which the City does not currently have and can be used to analyze the air quality or humidity in the City. In addition to the new data, information, and research NOAA's campaign will provide the City of Alexandra with, it will also generate a basis for a method to evaluate the effectiveness of current and future UHI mitigation and adaptation practices. The maps generated by the campaign can serve as a baseline to compare with future temperature maps or can be compared with older, possibly less accurate temperature maps. For example, if the City implements a new mitigation strategy in a region identified by NOAA's campaign as hot, and future temperature maps classify this region as cool, it can be concluded that these strategies seem to be effective in minimizing the heat felt by citizens in that region.

The City will also be able to visualize if a strategy has not been useful if the temperature of the region increases or remains constant when compared to other temperature maps. As described by NOAA, "[t]he maps and community reports also reveal how factors in urban environments — such as lack of green space and tree canopy or concentrated areas of pavement and buildings — can create neighborhood-level islands of heat that contribute to health inequities within a community" (NOAA Seeks Applicants for 2023 Urban Heat Island Initiative, 2022). The grain of the generated maps will allow different communities like neighborhood organizations to precisely locate areas to focus on because the current satellite data only allows for general region analysis. So, for example, neighborhood groups could determine exactly where to plant new tree canopies to best limit the heat there. This data will prove useful in developing new urban plans in the City as well because it will highlight areas to take into consideration when building structures that might increase or decrease the temperatures of a region to avoid the perpetuation of existing or future UHIs. In addition, these maps will be

helpful in tracking and predicting the City's overall and specific extreme heat as the given heat patterns can be used to aid future extreme heat advisories and public service announcements. Participating in NOAA's 2023 UHI mapping campaign will also help Alexandria take one step closer to becoming a community of practice for NOAA to use in future clime experiments, which will hopefully improve comfort levels in the City. Ultimately, this mapping campaign focuses on environmental justice and how green solutions can be implemented to better improve City UHI mitigation practices, which would be very helpful to Alexandria while they are working to improve their own systems.

Conclusion

Ultimately, it will take a community wide effort to mitigate the impacts of UHIs in the City of Alexandria. With the help of the entire community and NOAA's climate campaign assessment, the City will be able to begin to close the present gaps in UHI research, and, as a result, minimize the health and economic impacts on the vulnerable people of the community.

Appendix E

This Appendix shows a prospective pamphlet that could be used in the City of Alexandria. It highlights the causes, possible signs, and possible solutions to UHIs or EHEs. Although this is a prototype, it could be used as a model to what the City of Alexandria could do to better improve their outreach program.

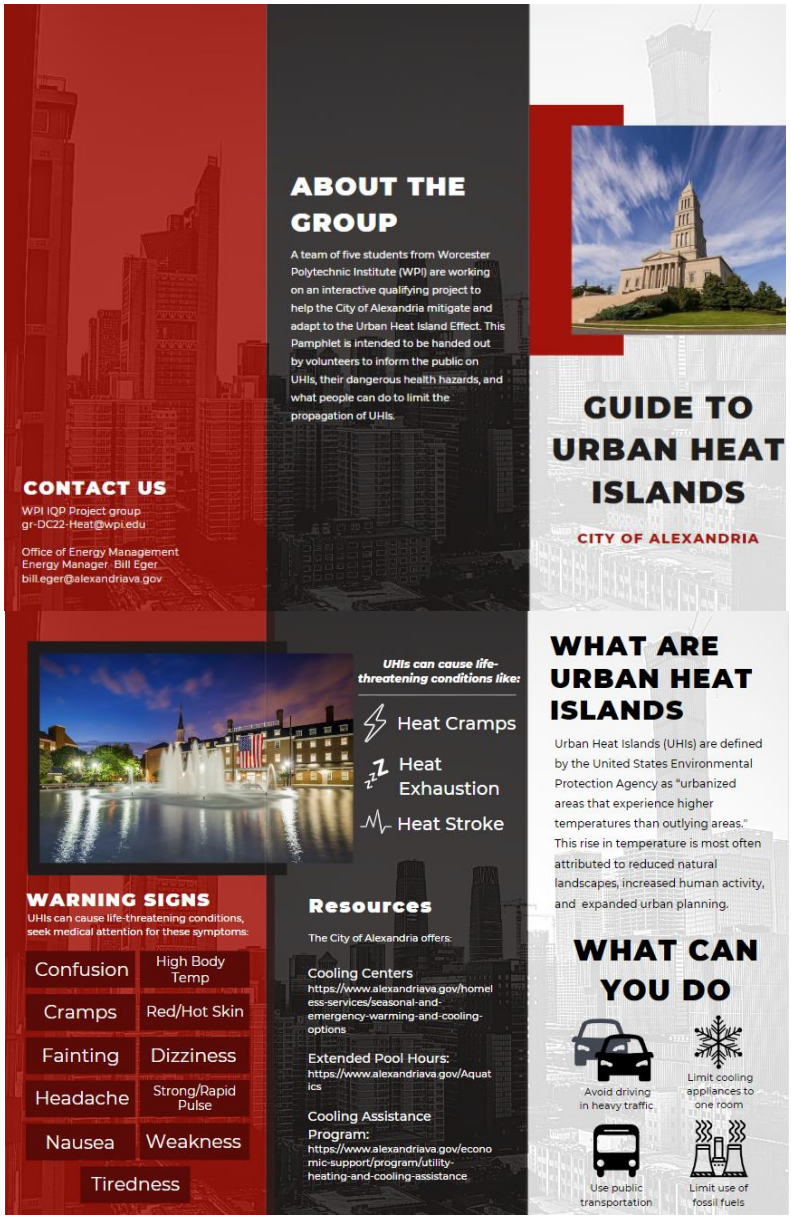

Figure 33. This is an example of a pamphlet volunteers can hand out to residents to inform them UHIs, their potential hazards, and the actions they can limit to prevent further UHI development.

Appendix F

This Appendix shows a summary of the results gathered from the community group questionnaire.

Table 5: Summary of the results obtained from the Alexandria community groups. These data show what the communities know about the City's mitigation strategies.

	Community 1	Community 2	Community 3	Community 4	Community 5	Community 6
1. Community effected?						
- Regularly			x		x	x
- Rarely		x		x		
- Not	x					
2. Physical features causing heat effects						
- Pavement area		x	x		x	X
- Building area			x		x	
- Lack of green space			x			X
- Lack of AC						
- Inability to pay					x	
- Sensitive populations			x		x	
3. Physical features reducing heat effects						
- Green space & tree canopy	x	x	x	x	x	X
- AC availability	x	x	x		x	X
- Nearby cooling center			x		x	
4. Respondent awareness of City efforts						

- Not at all	x			X		X
- Have heard			x			X
- Familiar		x			x	
5. Community awareness of City efforts						
- Not at all	x	x	x			x
- Have heard					x	
- Familiar						
6. Have City prevention programs been effective in your area						
- Yes						
- Partially			x		x	X
- No		x				X
6. Have City response programs been effective in your area						
- Yes						
- Partially					x	
- No						X
7, Association assistance						
- Yes			x			
- No	x	x		x	x	X
7, Other group assistance						
- Yes			x			
- No	x	x		x	x	X