COMMUNICATING CLIMATE CHANGE TO COMMUNITIES: A GIS-BASED FRAMEWORK TO SUPPORT LOCAL DECISION-MAKING

Masters of GIS Capstone Research Project

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Abstract

The IPCC's *Climate Change 2022: Impacts, Adaptations and Vulnerability* report further solidifies our scientific understanding of the severity of the potential consequences to our society and planet from a changing climate. However, scientific reports and national climate assessments, and other high-level writings about the impacts of climate change are not easily translated to actionable policy measures for local government officials who are on the front lines of facing the impacts of a changing climate. Many communities have already begun to experience the impacts of climate change and have developed or begun to develop climate action plans to help their communities prepare for and respond to the impacts of the changing climate. It is important that local leaders in these communities understand how to convey climate-related risks. So, how can we take this information – both observations and modeled predictions and make it meaningful for local decision-makers to utilize in their climate action plans? GIS is an extremely powerful and effective tool to not only communicate the data, but to help understand the data. GIS provides a wide variety of analytical tools to facilitate local decision-making.

This paper dives deeper into understanding how we can better utilize GIS to effectively communicate climate change impacts and find ways to help communities understand the importance and severity of climate change, which will ultimately help them make more informed decisions. To show how GIS can be properly communicated to communities and be used to help local decision-makers integrate climate risk into their planning, I chose to look at climate change from a local perspective within Allegheny County, Pennsylvania. This project utilizes vulnerability assessments to identify climate risks within the county and display the risks using GIS. To help local communities and local county decision-makers understand the risks, an ArcGIS Web App was built ArcGIS Experience Builder to communicate the findings with local decision-makers and local communities.

INTRODUCTION

Climate Change Actions

The IPCC's *Climate Change 2022: Impacts, Adaptations and Vulnerability* report further solidifies our scientific understanding of the severity of the potential consequences to our society and planet from a changing climate. However, scientific reports and national climate assessments and other high-level writings about the impacts of climate change are not easily translated to actionable policy measures for local government officials who are on the front lines of facing the impacts of a changing climate. How do we take this information – both observations and modeled predictions and make it meaningful for local decision-makers? GIS is an extremely powerful and effective tool to not only use to communicate the data visually, but it can also help decision-makers act upon the data. GIS provides a wide variety of analytical tools to facilitate local decision-making. Yet, even with this information, we are still finding communities confused and divided when it comes to the discussion and understanding of climate change.

> *"Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions, the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt." – IPCC, Climate Change 2022: Impacts, Adaptations, and Vulnerability*

This quote from the most recent IPCC report on climate change demonstrates the current and expected threats our communities and surrounding environments face. More than 64% of Americans find this 'somewhat worrying' and a majority of Americans agree that global warming is causing many environmental problems in the United States, such as extreme heat, wildfire, flooding, drought, etc. (Leiserowitz et al., 2022). A majority of Americans also agree that global warming is personally affecting their community and believe that the federal government is doing 'too little' when it comes to bipartisan action to reduce climate change (Tyson & Kennedy, 2020). Due to the significant polarization in the government on federal and state levels when it comes to climate change policies and regulations, the path to climate change resiliency has now begun to shift towards local governments and communities. If local governments start to adopt their own greenhouse gas emission policies and promote a more sustainable community (i.e., clean energy, greenspaces, improving public transportation) then their actions could influence their state government to take further actions (Basseches et al., 2022).

However, addressing climate change resiliency in local communities lies within the community's ability to understand the impacts of climate change on a local level; and it requires their ability to obtain resources to help reduce climate change impacts. Many disadvantaged communities may lack the people, the funding, or the necessary resources to make significant climate mitigation efforts in their communities. One way to begin the campaign to climate resiliency is by using a local community-driven framework that addresses ways communities can integrate climate change resiliency efforts into their lifestyle and create achievable climate solutions that will significantly reduce climate change impacts (Gonzalez, 2017).

More recently, the Pennsylvania Department of Environmental Protection (PA DEP) released a Climate Action Plan that outlines 18 strategies to help reduce state-level greenhouse gas emissions by 26% in 2025 and by 80% in 2050 (Pennsylvania Department of Environmental Protection, 2021). One of the strategies outlined in the plan is for state and local governments to lead by example by developing their own local climate action plans. To help this initiative, the PA DEP has developed a Local Climate Action Plan program to help local governments develop a climate action plan that is attenable in reducing greenhouse gas emissions and to help build local climate resiliency. This program has trained and helped 53 cities, townships, boroughs, counties, and regional organizations in Pennsylvania and will continue to do so in the next year (Pennsylvania Department of Environmental Protection, 2022). These climate action plans follow the community-driven resiliency framework and each plan highlights objectives and actions to help reduce greenhouse gas emissions and encourage climate mitigation/resiliency within the community.

A review of local climate action plans (see Appendix A) in Pennsylvania finds that these climate action plans contain important and useful information that can help guide communities to climate resiliency. However, how can these efforts and goals best be communicated to the public, to local businesses, and even to state and federal officials? Lengthy and technical writing is not the most effective way to communicate not only the problem but also the potential solutions to a wide audience of laypersons, stakeholders, and government officials. As we have seen from the Yale Climate Opinion Paper on Climate Change in the American Mind (2022), 48% of Americans believe that the United States is being affected by climate change right now and 43% of Americans believe that they have personally experienced the impacts of climate change. That still leaves 50% of the population who may be experiencing the negative consequences of climate change, but don't necessarily understand that it is related to climate change. Therefore, it is important to support a framework that will not only help communicate climate change and its impacts to local communities but will also help local decision-makers make climate decisions that will provide positive impacts to their community.

BACKGROUND

Communicating Climate Change with the Community in Mind

One way to help communicate climate change and its impacts is by using storytelling. Storytelling allows scientists to effectively communicate data using visualizations and narratives (Cote, 2021). Most people have grown up hearing stories from family members, teachers, friends, and even strangers. Storytelling is a part of everyday conversations and can inspire action from listeners and readers. When people are listening to stories it engages their brain and it allows them to comprehend, provide emotional responses, and empathize with the story (Cote, 2021). However, not all stories are generally positive ones, especially when related to climate change. Every day, people are reading and listening to stories related to climate change impacts that inspire fear. Stories use phrases like 'Soon it will be unrecognizable', 'worse than we realize', 'the perfect storm', or 'threatening to society' (Brian, 2022). While these articles may be providing accurate information, their alarming storytelling can cause fear, anxiety, and discouragement from action in their readers. These articles incorrectly leave the reader with the sense that no action can create meaningful change to improve the situation. Since fear is not the most effective motivator for change, it is important to provide climate change information that offers hopeful, meaningful action.

Katharine Hayhoe, author of *Saving Us: A Climate Scientist's Case for Hope and Healing in a Divided World* and Rebecca Huntley, author of *How to Talk About Climate Change in a Way that Makes a Difference* both discuss how fear should not be the leading factor in how we communicate climate change with people. Hayhoe says (2021, pg. 66), "Fear works well when coupled with uncertainty to induce inaction rather than action." To create that action, scientists and climate activists need to connect climate change impacts to individual interests and values. People bond over common interests and values and tend to help more and be more inspired when they are connected to that common interest or value (Hayhoe, 2021). For example, farmers may share an interest in learning why their crop yields are falling or why the weather is changing. This common interest can help scientists and climate activists to explain how climate change is impacting farming now, how it could affect farming in the future, and what steps we can take to minimize those negative impacts.

Therefore, a crucial piece to combatting climate change and reducing the impacts is to start small. Tackling the problems locally inspires confidence in action and instills a sense of agency in decision-makers and citizens alike. Utilizing policy diffusion tools and ideology is one way to address the issue of adopting climate adaptations and policies in local communities. One city's effort to combat climate change can inspire another city to start combating climate change and so on to many other cities, counties, and even states. Schoenefeld et al. (2022) discuss various ways policy diffusion can be associated with climate change adaptations. They detail how it is important to understand the internal and external drivers and barriers a community may face that can impact their decision-making (Schoenefeld et al., 2022). These drivers and barriers can be influenced by politics, financial status, resource constraints, and even weather events (Schoenefeld et al., 2022). The other key aspect Schoenefeld et al. (2022) discuss is how interests and ideology can motivate policy diffusion. Therefore, it is important to tie personal interests and ideology to climate change adaptation strategies, as it allows communities to make more personal connections to the issues.

How to Support Local Climate Action Policies

Another way climate scientists can better support local decision-makers in the community is by supporting the community's current climate actions and policies. Many of these communities have already developed climate action plans that are focused on the local impacts of climate change, such as localized flooding, air quality impacts, and extreme weather events. Ever since the United States made the decision to not ratify the Kyoto Protocol and with the more recent act of dropping out of the Paris Climate Accord, communities all over the United States have begun to adopt stricter climate policies. According to Markolf et al. (2020), over 600 local governments in the United States have developed climate action plans and have pledged to reduce greenhouse gas emissions. Within those 600 local governments, 45 of the 100 largest cities in America have set greenhouse gas reduction targets and have created a greenhouse gas inventory baseline (Markolf et al., 2020). Collectively if just those 45 cities met their target reductions, then the United States would see a 7% reduction in greenhouse gas emissions (Markolf et al., 2020). However, reaching these targeted emission goals can be challenging for many communities.

The overall success of these actions and policies is ultimately in the hands of these communities. However, since these communities are working from the 'bottom-up', they may be lacking resources and support from state and federal-level organizations. According to Gallup (2018), "The key to effectively activating the potential of a bottom-up approach lies in communicating both the goals of behavioral changes as well as the best strategies for implementing these changes to have maximum impact." Therefore, it is imperative for the scientific community to learn how to better support local communities and their initiatives to create implementable climate actions.

One-way scientists can help is by finding ways to communicate important information to communities by utilizing their local climate action plans. Many of the local climate action plans that have been created already highlight the climate impacts, actions, and goals of the community. These climate action plans can be a valuable resource to scientists who are trying to develop tools that will help support local climate change decision-making.

A valuable tool used frequently in the climate science community are mapping tools (i.e., Esri's ArcGIS and QGIS). Mapping tools, such as interactive web maps or apps, allow climate scientists to create more accessible information for the public. Mapping tools not only allow climate scientists to easily share information with the public, but they also allow people to view a wide variety of maps within one single app or website. By being able to create a wide variety of maps, decision-makers and community members will have access to more information by only visiting one site. Creating these tools will not only help decision-makers save time, but it can also help them be more informed of the major climate threats and impacts that their community is currently facing or will face in the future. These tools can also provide decision-makers with information on how they can better support their community in reaching their climate resiliency goals.

A GIS Framework to Climate Change Knowledge and Actions

Understanding a changing climate is inherently spatial. Due to the geographic nature of climate change, maps are an important piece of visual representations of climate change (Fish, 2020b). Not only are maps important and impactful for visually viewing climate change impacts, but they can also be a useful tool for decision-making. Over 65% of people are visual learners and the presence of social media has increased the need for visual images (Jawed et al., 2019). Since maps combine both the visual and informational aspects of communication, maps can be an ideal medium for providing impactful and persuasive content related to climate change. Climate change maps have been used by policymakers and decision-makers all over the world to develop climate mitigation policies (McKendry & Machlis, 2008). However, very little research has been done discussing the integration of communicating climate change to local communities and the impact of climate change maps (Fish, 2020b).

The following considerations provide best practices on ways to develop maps to effectively communicate the impacts of climate change for local decision-makers.

One of the major aspects to consider when developing climate change impact or risk maps is the complexity of the map. Studies have found that poorly designed and overly complex maps, like some IPCC climate change maps, lead to more confusion rather than comprehension (Johannsen et al., 2017). Not everyone who is involved in making climate policy decisions will have background knowledge on climate change and its impacts. Therefore, to help decision-makers understand climate change and its impacts it is important to bring the information down to their level of understanding. To do this, scientists and cartographers need to evaluate their audience to better understand the knowledge and needs of the audience, which will ultimately lead to a more customized map for the decision-makers. To evaluate the audience, the following provides a list of questions that can be used to gather important background information on the audience.

Audience:

- Who is the map for?
  - What age range will this map attract?
  - What are their reading comprehension levels? [According to The Literacy Project (Marchand, 2017) “The average American reads at a 7th to 8th-grade level”.]
- What type of previous knowledge or background would average viewers/users have on the topic?
- What is their role in society?
  - Where do they work?
  - Where do they live?
  - What do they value?

- For stakeholders and decision-makers, it’s important to identify their daily tasks, goals, and needs.
    - Who are they making decisions for?
    - What are their daily tasks?
    - What goals are they trying to achieve?
    - What information and tools do they need in order to achieve their tasks and goals?
    - What information and tools do they already have to help them achieve their tasks and goals?

A second aspect to consider when developing climate change maps is the Cognitive Load Theory. This theory goes together with map complexity, and it can explain “why an overly complex set of visuals may distract viewers from the content of the map.” (Johannsen et al., 2017). When viewers are looking at a map, they are not only seeing the visual contents (extraneous cognitive load), but they must also think about and conceptualize the content (intrinsic cognitive load) (Johannsen et al., 2017). Therefore, cartographers should be conscious of map clutter, such as too much text and too many graphic elements, to keep an intrinsic focus (Johannsen et al., 2017). When developing a series of maps about complex topics, such as climate change risks, it is important to convey messages simply and directly. Taking Cognitive Load Theory into account helps ensure that the maps will be simple, yet informative. Figure 1 is an example of an overloaded map displaying climate zones. While the map is very detailed and explains the climate zones more complexly, it could be distracting for some people (Taylor, 2021). Whereas Figure 2 is more simplistic and is better in situations where cognitive load is of concern.

Figure 1. Example of an Overloaded Climate Map (Maps of the World, 2013)

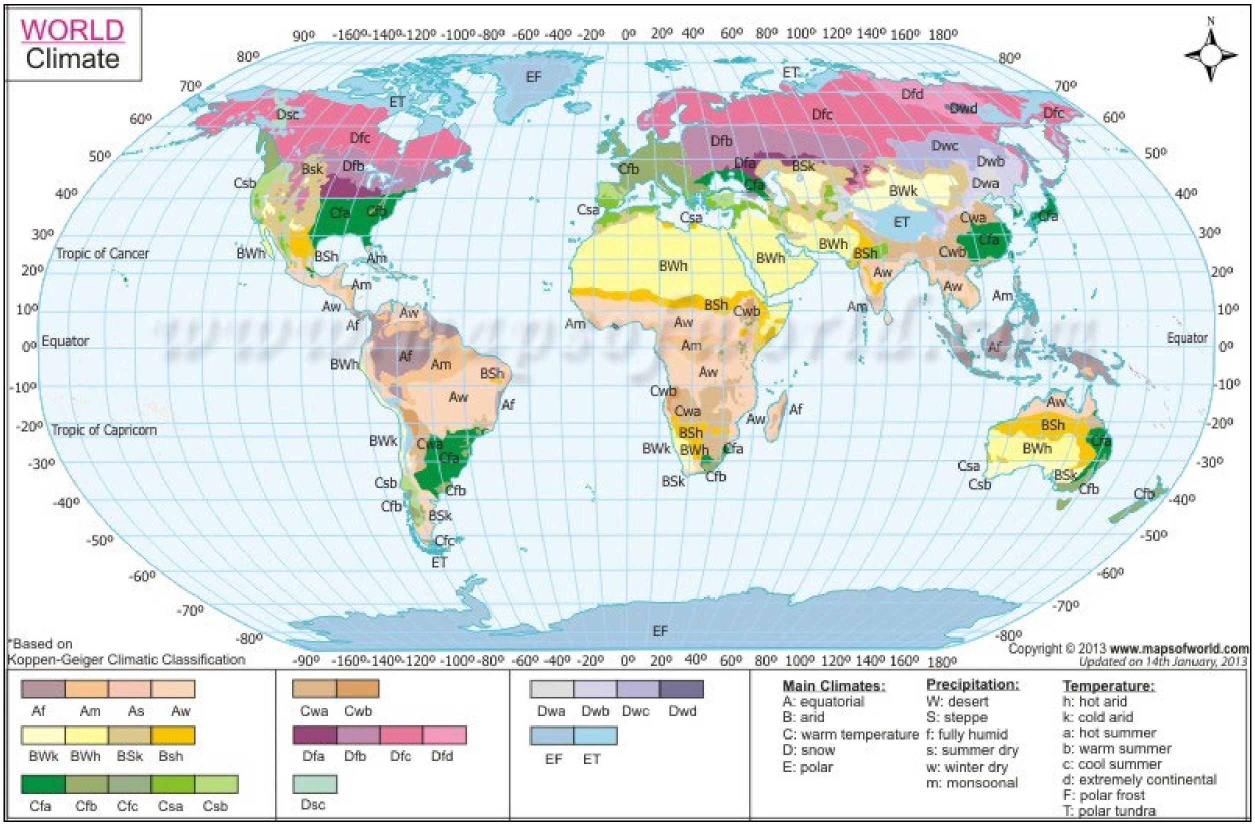
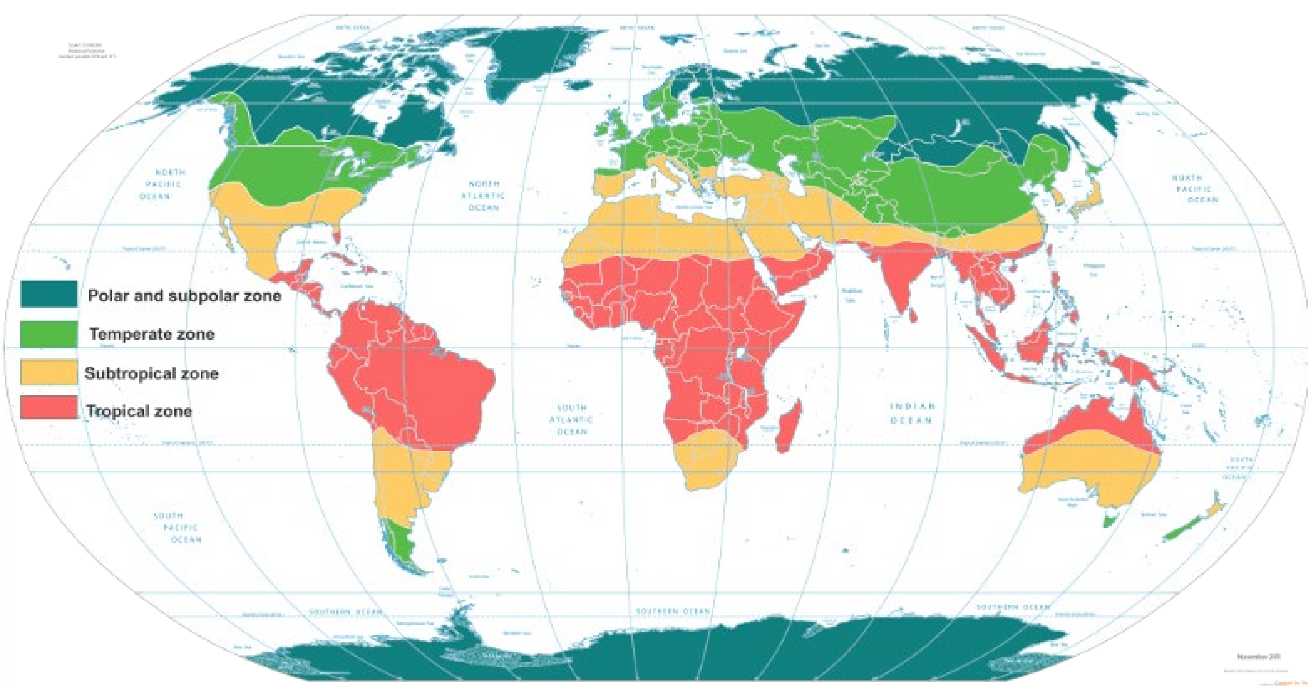


Figure 2. Example of a Simplified Climate Map (Dalton, 2023)



The third and final detail to consider in climate change risks map creation is content. The information being communicated in a map needs to be coherent, comprehensible, and personal to the reader. Therefore, it is important to place value on the content that is going to help community members and decision-makers visualize impacts within their own communities. For example, a community member may not understand the impacts of coastal flooding if their community is located inland and hundreds of miles away from any type of large body of water. However, those community members may be more interested in learning about the impacts that their local factories may have on the air quality in the area. As previously discussed, when creating and discussing climate change information, climate scientists need to create personal connections to climate change. One way to create those personal connections is by using storytelling and framing. Storytelling allows readers to visualize and make connections to the content. Fish (2020a) found that storytelling can reduce the complexity of the topic by creating metaphors to help understand abstract information and by making key data more noticeable. Framing, on the other hand, can be defined as "the central organizing idea or storyline that provides meaning to an unfolding strip of events." (Gamson & Modigliani, 1989; Schäfer & O'Neill, 2017). Framing can be used to enhance and open dialog related to climate change with people of different values or socio-political views (Scheufele, 2018; Badullovich et al., 2020).

Combining these cartographic principles can not only help improve the value of the map, but it can also make impactful changes for the viewers and readers. In this context, climate scientists can use these tools to create maps that will help communities and decision-makers make more informed and effective climate policies/decisions by reaching their core values and interests. Most decision-makers are basing their decisions on their community's collective values and needs. Therefore, if most of the community has the same views and values as their decision-makers, then the whole community is left with no choice but to act. The key to creating this action is by finding their core values and creating a story or a dialog that will pique their interest.

To help motivate local climate action and to find a story that will pique a person's interest, it is useful to find out what issues and problems the community already cares about and connect those issues to climate change. This does not only help motivate the community, but it can help to diffuse the political drama that surrounds climate change, and it can help to build consensus across party lines for true collaboration. For example, in Allegheny County, there have been a lot of concerns regarding landslides. To help the community better understand the situation, Allegheny County has created a landslide portal to provide education and guidance regarding landslides to the community. This portal contains landslide history, causes, types, & effects of landslides, best practices to prevent landslides, map tools, and resources for landslides assistance. Creating a resource, such as this landslide portal, is a great way to not only help improve the value of the county's landslide map, but it is also useful, relevant, and impactful for members of the community. This resource can also be helpful when explaining to community members how climate change has been impacting the frequency and severity of landslides within their community.

METHODOLOGY

Developing a GIS Climate Change Model to Meet the Needs of Local Communities

The foundational key to addressing climate change impacts, policies, and mitigation efforts is to develop a basis for good climate decision-making. According to the IPCC, a good climate decision emerges from people who are explicit about their goals, which means that people are looking at consequences, trade-offs, alternate options, and the views of the advantaged and dis-advantaged (Parmesan et al., 2022). These goals need to be implementable, effective, and have defined measurable criteria for success. The IPCC states that "These decisions need to be backed by information on climate, its impacts, potential risks, and vulnerability to be integrated into an existing or proposed decision-making context." (Parmesan et al., 2022). However, one unanswered question is who is in charge of making these good climate change decisions? Who has the knowledge, the resources, and the power to implement the policies necessary to reduce the causes and prepare for the impacts of a changing climate?

The responsibility for these climate action decisions often falls to local governments. Yet, many communities lack elected officials or staff with background knowledge or resources to establish climate policies or implement reduction actions and resiliency measures. Therefore, government entities, scientists, and climate activist groups have begun to create information and tools that can help these communities combat climate change impacts and achieve climate resiliency (i.e., FEMA National Risk Index, EPA's Climate Resilience Evaluation and Awareness Tool (CREAT), Yale Climate Opinion Map, NASA Sea Level Projection Tool).

Two important tools used in climate adaptation and mitigation strategies are risk and vulnerability assessments. The purpose of a risk assessment is to identify any potential hazards and to analyze the potential impacts of the risk occurring (U.S. Department of Homeland Security, 2022). A risk assessment will first identify the hazard, analyze the vulnerabilities, and determine the impact. For this study, I will be looking at climate change risks and impacts in Allegheny County, Pennsylvania.

Identify the Community

For this study, I am looking to identify, analyze, and communicate the impacts of climate change in Allegheny County, Pennsylvania. Allegheny County is in the Southwestern part of Pennsylvania and its topography is well known for its distinct steep slopes, especially along the three rivers (the Allegheny, the Monongahela, and the Ohio). Due to its distinct topography and unstable soil known as the "Pittsburgh red beds", the county is known to have unstable slopes that lead to frequent landslides. Also, due to the location of the three rivers and other tributaries, the area is prone to flash flooding and urban flooding. As for the climate, the county is in a humid subtropical environment, which means they experience hot and humid summers, and cold to mild winters (Britannica, 2023). However, with global temperatures continuing to rise, this area will be severely impacted by the increasing temperatures and the increasing fluxes between periods of drought and heavy precipitation.

In addition to understanding the environmental impact of climate change, it is also important to understand and analyze social and health factors as they can influence the overall resiliency of a county. As for the social factors of the county, Allegheny County is the 2nd most populous county in Pennsylvania and is home to about 1.238 million people (U.S. Census Bureau, 2023). Within the population, 79.4% of the population is White and 13.5% Black (U.S. Census Bureau, 2023). The median household income in 2021 is $66,659 and 11.3% of the population is in poverty (U.S. Census Bureau, 2023). As for health factors, many different health risks can be impacted by climate change. For example, people with cardiovascular diseases and respiratory diseases are at a higher risk to be impacted by poor air quality and extreme heat events. To see how Allegheny County and its municipalities rank among county, state, and national health data in key public health topics, the county has created an interactive dashboard displaying Allegheny County Community Indicators.

Allegheny County was chosen as my research community because the area is already impacted by climate change and many of the municipalities and community organizations have been actively working on building climate resiliency. One of the major climate issues that is affecting the county is air quality. Due to the steel industry and other industries in the county, the Allegheny County region is ranked in the top 25 for the worst air quality by year-round particle pollution and by short-term particle pollution (American Lung Association, 2023). Residents of the county have been highly concerned for their health due to the state of the air in the region. Due to this concern and due to other climate concerns within the region, the city of Pittsburgh, surrounding municipalities, and the county have been working on initiatives to build a healthy and climate-resilient community. The city of Pittsburgh and surrounding county municipalities have been working on creating Local Climate Action Plans (LCAP) to help understand how climate impacts their communities and how they can work on mitigating and/or adapting to these climate impacts. As for Allegheny County, the county has created an Office of Sustainability to help coordinate and implement sustainable practices within the county. Additionally, the county has developed a plan for a healthier community, which addresses environmental health concerns, such as climate change (Allegheny County Health Department, 2023).

Background on Building a Climate Assessment Framework

According to Weis et al. (2016), "Climate change adaptation assessments tend to focus on social structures, such as the human condition or human processes, and aim to develop policies that will reduce risks associated with climate change." Therefore, when conducting climate risk and vulnerability assessments, it is important to assess both environmental and social impacts. The following studies sought to use GIS to assess climate change risk and vulnerability in multiple spatial settings with different climate variables.

Many climate vulnerability assessments include indices that evaluate the vulnerability on a scale from high to low. Weis et al. (2016) developed a vulnerability index that "measure (s) the vulnerability of communities to flooding from present-day storms as well as storms under possible future sea level scenarios.". The index uses three sub-indices (exposure, sensitivity, and adaptive capacity), which were chosen based on their relevance to the study area and the types of risks that were being identified (Weis et al., 2016). Kienberger et al. (2016) has a similar approach where they created an agriculture vulnerability index and a pastoralism vulnerability index with three sub-indices: climate suitability, sensitivity, and adaptive capacity. The sub-indices were developed using impact chains that looked at various “socio-economic, political, environmental and climatic factors creating the specific vulnerability profile of the region” (Kienberger et al.,2016). Following methods from Kienberger et al. (2016) and Weis et al. (2016), I will create a vulnerability index that will combine the three sub-indices, exposure, sensitivity, and adaptive capacity. These three sub-indices (exposure, sensitivity, and adaptive capacity) also fall in line with how the IPCC frames vulnerability to climate change (IPCC, 2023a). In addition to these sub-indices, I will also use impact chains to identify the climate risk and the potential impacts that the risks could have on the community. Once the climate risks and indices are identified the next step is to classify the risks on a number scale from low to high impact.

Hawchar et al. (2020) used a number scale to identify their assets when evaluating climate change risk on critical infrastructure. For their infrastructure, they used an important index from 1 (low importance) to 4 (high importance) and for the relationship level between climate threat and infrastructure system they used a vulnerability index from 0 (none) to 3 (high) (Hawchar et al., 2020). Shepard et al. (2011) took a similar approach with their indexes, but they scaled their values to 1 – 100, with low vulnerability being in the range of 1 – 44 and very high vulnerability being in the range of 67 – 100. For this project, I will be using an indexing system from 1 (low risk) to 5 (high risk) because it provides enough details on low-risk, average risk, and high-risk areas, while still being simple enough for local decision-makers to understand.

Finally, it is important to highlight that the best way to convey the climate indices and risks is through interactive maps. Stieb et al. (2019) highlight “Graphical materials are often seen as effective communication tools, and maps in particular are a potentially powerful means of conveying spatial information visually.” However, Stieb et al. (2019) also mention the importance of understanding the knowledge and risk perception of your user. With this idea in mind, it is important to make sure that any climate change maps that are being used in local climate planning adhere to the understanding and geographical capabilities of the users. The users who are using these maps may not have background knowledge on climate change and more importantly, they may not have a cartographic and geographic background. Therefore, Stieb et al. (2019) discuss the importance of adhering to cartographic best practices, such as making simplified maps and graphics, choosing the appropriate class boundaries for qualitative data, and making sure to use appropriate color gradients and color choices. Therefore, for my interactive maps, the goal is to use a simplified color scheme and to make sure that the data displayed on the maps is simple yet informative.

Based upon research and findings, it was found that in order to support a GIS climate change model and framework that meets the needs for local communities should include, but is not limited to:

- Understanding the values and connections that hold communities together.
- Understanding the climate risks and impacts of local communities.
- Developing a risk assessment that highlights the risks with the highest impact and highest level of community concern.
- Develop a vulnerability assessment that focuses on the most impactful risks and encompasses the community's concerns.
- Communicate the risks and vulnerabilities in an impactful way that will help decision-makers and the community with climate change decisions.

Developing Climate Indices

Before calculating the individual vulnerability indexes, I needed to first decide which climate indices I wanted to focus on.

To help determine which climate indices were important to the residents in Allegheny County, I used the U.S. Climate Resiliency Toolkit to help understand and determine the county's potential climate hazards. The first step in understanding the county's climate hazards is to identify the common values and goals the residents of Allegheny County care about protecting. These values and goals can include people, places, and services that power the economy and make the area special or unique to the residents (U.S. Climate Resiliency Toolkit, 2023). After evaluating a series of Local Climate Action Plans from municipalities and communities in Allegheny County (See Appendix A) it was found that the residents of Allegheny County share the common values of reducing CO2 emissions, improving public health, improving the economy, reducing environmental risks, protecting waterways, increasing sustainability efforts, and improving social equality. Understanding these goals is an important step when building climate plans, because you want to make sure that any future resiliency plans highlight protecting these shared values and goals. This quote from Etna's Vision Statement in their Local Climate Action Plan highlights Etna's goal of integrating sustainability and resiliency within their community to help build a thriving and vibrant environment.

Etna's Vision Statement from their Local Climate Action Plan

"We believe that everyone in Etna deserves the opportunity to thrive and live a life to their fullest potential. As a step toward achieving this goal, it is our mission to make Etna a more vibrant place to live, work, and play by 1) supporting projects and programs that integrate equity, sustainability, and resiliency into the fabric of our community, and 2) engaging, empowering, and activating Etna's community members to take ownership over their futures."

The next step in developing climate indices was to use the Local Climate Action Plans in Allegheny County (See Appendix A) to help find potential hazards that could damage these shared community values. After evaluating the Local Climate Action Plans, I found 12 potential hazards that impact Allegheny County. To help limit the number of hazards to assess, I used

FEMA's National Risk Index to determine the level of risk (low, medium, or high) these hazards potentially have on the county. Additionally, I determined a level of community concern (low, medium, or high) to complement each potential hazard. The level of community concern was determined based on the level of importance in each communities Local Action Plans. Table 1 outlines the rank (low, medium, or high) of each potential hazard based on their level of risk and the level of community concern. Utilizing both the level of risk and the level of community concern, helps me to determine which potential hazards are the most important to assess for local decision-makers.

After evaluating each potential hazard, I was able to narrow down my focus to five potential hazards, 1) Air Quality, 2) Flooding, 3) Heat Health, 4) Landslides, and 5) Water and Stormwater. These five potential hazards had some of the highest levels of risk and highest levels of community concern. To further concentrate the potential hazards, I split the potential hazards into three focus areas, Air Quality, Land Vulnerability, and Social Vulnerability. Within those three focus areas, I assessed the five potential hazards and additional indices such as social vulnerability, environmental justice areas, and large industrial greenhouse gas emitters (See Table 2). Additionally, I added a sustainability topic to the focus areas to help add a positive aspect to the assessment. The sustainability focus area will look at current sustainability efforts that are being done within Allegheny County, such as green infrastructure, greenways, and community gardens.

Table 1. List of Potential Hazards with Risk Levels and Community Concern

Potential Hazard	Level of Risk	Level of Community Concern
Air Quality	High	High
Cold Wave	High	Medium
Drought	Medium	Medium
Flooding	High	High
Heat Wave	Medium	High
Ice Storm	Low	Low
Landslide	High	High
Lightning	Low	Low
Strong Wind	Medium	Low
Tornado	High	Low
Water and Stormwater	High	High
Winter Weather	Medium	Medium

Note: Level of Risk determined from The National Risks Index for Allegheny County
Drought level determined from drought monitor.
Level of concern was determined based upon Local Climate Action Plans.

Table 2. Allegheny County Climate Assessment Focus Areas

Focus Areas	Potential Hazard/Social Indices/Sustainability Effort
Air Quality	Large Industrial Greenhouse Gas Emitters and Particulate Matter 2.5
Land Vulnerability	Flooding, Landslides, and Land Use
Social Vulnerability	Social Vulnerability, Environmental Justice Areas, and Heat Health
Sustainability	Green Infrastructure, Greenways, and Community Gardens

Data Collection & Tools Used

For this climate impact assessment, I used a variety of ArcGIS tools from Esri to analyze climate data, present the climate risk indexes, and to display sustainability efforts. The tools I used in the assessment were ArcGIS Pro, ArcGIS Online, and ArcGIS Experience Builder. ArcGIS Pro and ArcGIS Online were used to analyze and manipulate GIS data. While ArcGIS Experience Builder was used to create a platform where I could display climate data and information that focused on climate impacts in Allegheny County. I chose to use ArcGIS Experience Builder as it was a platform that allowed the use of interactive ArcGIS Online maps, was easy to use, and was accessible to the public.

Before analyzing the climate risks in ArcGIS Pro, I collected GIS data for the climate indices in shapefile and CSV format from various public data resources (See Table 3). Since one of the goals of this project is to be widely accessible, I wanted to use public data sources. With that in mind, a majority of the county and climate data were sourced from the Western Pennsylvania Regional Data Center, which is an open GIS data portal. For most of the social vulnerability data and sustainability data, I utilized ArcGIS's Living Atlas and other open GIS data portals for more public data. In addition to the data being publicly available, I also wanted to make sure that the data was easy to use and replicable. Another major goal of this project is to encourage other municipalities and counties to create their own climate impact assessments. By utilizing easy to use and publicly assessable data, I can show other communities that they are able to easily create their own assessment without any complex data and information.

The collected data was downloaded to ArcGIS Pro to use in developing risk levels and various types of climate risk map layouts. ArcGIS Pro was also used to manipulate CSV data, used to create supplemental maps (i.e., Environmental Justice Maps and Sustainability Maps), and was used to export the maps to ArcGIS Online. To be able to add maps to ArcGIS Experience Builder, I had to use the exported map layers and create online web maps on ArcGIS Online. Once the web maps were created using ArcGIS Online, then the maps could be imported into ArcGIS Experience Builder.

Before discussing how each risk level was found for the climate indices, it is important to note that not all the data I found was able to be developed into a risk index. Some of the data used in the web app was point data that would not be useful to aggregate such as, the large industrial greenhouse gas emitters, the community gardens, and the green infrastructure data. Additionally, the PM 2.5 and the Environmental Justice Areas data was not used to create risk levels, as the spread of the data was too minimal.

Table 3. List of GIS Data, Sources, and File Format

Name Of Data	Source	File Format
2021 Green House Gas Emissions from Large Facilities	EPA Flight	CSV
Allegheny County Census Tracts 2016	Western PA Regional Data Center	Shapefile
Allegheny County Greenways	Western PA Regional Data Center	Shapefile
Allegheny County Land Cover Areas	Western PA Regional Data Center: Allegheny County – GIS Open Data	Shapefile
Allegheny County Municipal Boundaries	Western PA Regional Data Center: Allegheny County – GIS Open Data	Shapefile
Community Gardens	Grow Pittsburgh	CSV
Environmental Justice Areas (2015)	PA DEP GIS Portal	Shapefile
Green Infrastructure	3 Rivers Wet Weather	Shapefile
Heat Health Census Tracts	ArcGIS Living Atlas Created by: mgilbert_climatesolutions	Shapefile
Landslide Pomeroy	Allegheny County - GIS Open Data	Shapefile
National Risk Index Census Tracts	ArcGIS Living Atlas Created by: FEMA_NationalRiskIndex	Shapefile
Particulate Matter 2.5 (2011)	Western PA Regional Data Center	Shapefile
USA Flood Hazard Areas	ArcGIS Living Atlas Created by: Esri_Landscape 2	Shapefile

Calculating Indices & Developing Risk Maps

For each climate impact, I calculated a risk level based on 1 – 5, with 1 being low risk and 5 being high risk. Each climate index's risk level was determined based on different factors relating to their climate impact. For the assessment I determined a risk level for flooding, heat health, land use, landslides, and social vulnerability. I also determined an overall risk level for both the municipality scale and the census tract scale. The overall risk level was determined based upon combining the risk levels for flooding, heat health, land use, landslides, and social vulnerability.

Base Map

Data Sources: Allegheny County Census Tracts 2016 and Allegheny County Municipal Boundaries from the Western Pennsylvania Regional Data Center

For each of the risk maps, I analyzed the data on the census tract scale. I choose to analyze the data using census tracts as most of the data I used was based off the census tracts, so it made joining the data easier. Also, by analyzing the data on a census tract scale, it can give decision-makers a more local perspective of how the risks are impacting their communities. If I would have analyzed the data on a municipal scale, it may skew the risk levels in each municipality. Additionally, by analyzing risk levels on a census scale, you can easily determine which areas in the community may need more help with climate resiliency efforts then others. However, since most decision-makers in Allegheny County view the county on a municipal scale, I also decided to overlay municipal boundaries on each map. By overlaying the municipal boundaries, it can help decision-makers easily find their municipality of interest.

For all of the maps, I used the following coordinate system: NAD 1983 State Plane Pennsylvania South

Flooding

Data Source: USA Flood Hazard Area from the ArcGIS Living Atlas

This layer contains polygons of special flood hazard areas, which are normally used to help determine Flood Insurance Rate maps. The attribute I used to determine the risk level, was flood zone subtypes. For Allegheny County, I only focused on the subtypes that were 1% Annual Chance, 0.2% Annual Chance, Regulatory Floodway, and Area with Reduced Risk due to Levee, as these were the only subtypes present in the county.

The first step in finding the risk level was to convert the flooding polygon to a raster. The polygon needed to be in raster format to be able to reclassify the flooding subtypes to their associated risk levels. Next, I used the reclassify tool to change the flooding subtype to their associated risk level as shown in Table 4. The risk level for the flooding subtypes was determined based upon the inherent risk to the community. Regulatory floodways are the areas in which the rivers normally flow so there is no risk for that subtype, whereas the 1%

annual chance has a risk level of 5 and 0.2% annual chance has a risk of 3 due to their chance of occurring. According to FEMA (2020), a 1% annual chance is also referred to as a base flood or 100-year flood and a 0.2% annual chance is referred to as a 500-year flood. As for the area with reduced risk due to levee, I decided to classify it as 1, since a levee is meant to help control flooding but can't necessarily stop all flooding.

After reclassifying the flooding subtypes, the raster was converted back to a polygon. Next, I used the summarize within tool so that I could combine the flooding polygon with the census tract layer. For the summary field, I used standard deviation to help identify the overall risk level of the new flooding layer (See Table 5). In this new flooding layer, the lower the standard deviation the lower the risk and the higher the standard deviation the higher the risk. I determined that the lower the standard deviation the lower the risk level, based upon the fact that not every census tract contained a flooding polygon. The flooding polygons were only located in areas that contained a river or stream. So, by understanding the location of the flooding polygons I was able to determine that the more flooding polygons present in a census tract meant that the census tracts risk level was higher. I can also double check the risk area based upon the locations of rivers/streams and based upon areas that I know have flooded in the past.

Table 4. Flooding Subtype Risk Levels

Flooding Risk	Risk Level
1% Annual Chance	5
0.2% Annual Chance	3
Regulatory Floodway	NODATA
Area with Reduced Risk due to Levee	1

Table 5. Flooding Standard Deviation Risk Levels

Flooding Risk - Standard Deviation	Risk Level
0.0 – 0.229349	1
0.229350 – 0.594736	2
0.594737 – 0.843733	3
0.843734 – 1.125207	4
1.125208 – 1.600675	5

Heat Health

Data Source: Heat Health Census Tract from ArcGIS Living Atlas

This layer has over 25 demographic and environmental variables that can be related to heat health. There are variables that relate to temperature, impervious surface, age, race, and income. In this layer, the variables are displayed as a percent and as a z-score. To determine the risk level for heat health, I used the z-score data.

For the heat health risk level, I decided to include a temperature variable, an impervious surface variable, and a population variable. After careful consideration, I determined the best variables to use from each type were average temperature anomaly, impervious surface, and population below poverty. I chose these three variables, as they better represented the variables that impact heat health the most in Allegheny County. After picking these three variables, I added their corresponding z-scores together for each census tract and then I was able to determine the risk levels (See Table 6). To calculate the risk levels, the lowest negative z-scores represented the lowest risk level, and the highest positive z-scores represented the highest risk level. The z-scores that are closest to zero represent the average and are therefore considered to have a medium risk level in the community.

Table 6. Heat Health Z-Scores and Risk Levels

Heat Health Index – Z-Score	Risk Level
-4.524899 - -1.884771	1
-1.884770 - -0.446846	2
-0.446845 – 1.310587	3
1.310588 – 3.454512	4
3.454513 – 9.089480	5

Land Use

Data Source: Allegheny Land Cover Areas from the Western Pennsylvania Regional Data Center

Since the land cover data, I used was in polygon form, I first had to convert the data from a polygon to a raster. I needed the data in raster form so that I could reclassify the land cover areas based upon their land cover and their risk level. First, I used the grid code data and reclassified the grid code to new values that grouped certain land cover areas together (See Table 7). The grid code numbers and information were provided in a data dictionary from Allegheny County. I grouped similar land cover areas together, such as residential areas, industrial areas, and forest/agricultural areas. to scale down the number of land cover areas. After reclassifying the land cover, I then used the reclassify tool again to reclassify the new land cover areas to their complimentary risk levels on a scale of 1 (low risk) to 5 (high risk) as shown in Table 8. The risk levels for the land cover, were determined based upon a multitude of factors, such as risks that can be associated with those types of areas of land or inherent local risks to those land areas. For example, water and flooding is huge concern for the community, therefore the risk level is going to be high. After reclassifying the land cover areas into their risk levels, I then had to convert the raster back into a polygon. Then I used the summarize within tool to merge the polygons into the census tracts based on standard deviation. As seen in Table 9, the lower the standard deviation, the lower the risk and the higher the standard deviation, the higher the risk.

Table 7. Land Cover Areas Old Grid Code and New Grid Code

Type	Grid Code	New Value
Water	1	4
Transportation	2	2
Forest	3	1
Grasslands	4	1
Agriculture	5	1
Low-Density Residential	6	2
Medium-Density Residential	7	2
High-Density Residential	8	2
Identified Malls	9	3
Commercial	10	3
Light Industry	11	5
Heavy Industrial	12	5
Strip Mine	13	5
Non-Veg	14	3

Table 8. Land Use Groups and Risk Levels

Land Use Groups	Risk Level
Water	4
Transportation	2
Forest, Grasslands, Agriculture	1
Residential	2
Commercial, Malls	3
Industrial, Strip Mine	5
Non-Vegetative	3

Table 9. Land Use Standard Deviation and Risk Levels

Land Use – Standard Deviations	Risk Level
0 - 0.274611	1
0.274612 - 0.646262	2
0.646263 - 1.045949	3
1.045950 - 1.570486	4
1.570487 - 2.381216	5

Landslides

Data Source: Landslide Susceptibility Data from the Allegheny County Landslide Portal

Within the landslide susceptibility data there are a few types of ways the landslide data is classified. One of the ways is by using the Pomeroy Method, which is a method developed by J. S. Pomeroy to classify types of landslide susceptible areas in Allegheny County and Western Pennsylvania (See Table 10). The other way the data is classified is by landslide level. The landslide level uses numbers from 0 – 56 to classify the type of landslide susceptibility. For the assessment, I utilized the landslide level to calculate the risk level of the susceptible areas (See Table 11). After researching the data, I found that the lower the landslide level the lower an area is susceptible to landslides, therefore, the lower the risk. Since the landslide susceptibility data is in individual polygons, I used the summarize within tool to find the landslide risk for each census tract based on standard deviation (See Table 12).

Table 10. Types of Landslide Susceptibility

Types of Landslide Susceptibility
Recent Landslide
Prehistoric Landslide
Slopes with Conspicuous Soil
Outcrop Area with Thick 'Red Bed' and Associated Rock
Relatively Stable Ground
Steep Slopes Susceptible to Rockfall
Ground with Highly Variable Slope Conditions
Manmade Fill

Table 11. Landslide Susceptibility Level and Risk Level

Landslide Susceptibility Level	**Risk Level**
0 – 7	1
8 – 17	2
18 – 28	3
29 – 41	4
42 – **56**	5

Table 12. Landslide Susceptibility Level: Standard Deviation and Risk Level

Landslide Susceptibility Level – Standard Deviation	**Risk Level**
0 – 2.139604	1
2.139605 – 5.509763	2
5.509764 – 8.922909	3
8.922910 – 13.451604	4
13.451605 – 23.645710	5

Social Vulnerability

Data Source: FEMA's National Risk Index – Social Vulnerability from ArcGIS Living Atlas

The National Risk Index is a tool used to explore natural hazard risks for the census tracts in the United States. The social vulnerability index is calculated based on "the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood" (FEMA, 2023). The score each census tract receives is a relative score that is compared to all other communities at that level (FEMA, 2023).

Before I could use this data, I first had to clip the data to Allegheny County, since the layer displayed the FEMA Risk Index for all the census tracts in the United States. After clipping the data to just Allegheny County, I filtered out all the data that wasn't associated with social vulnerability. Next, I added a risk level column to the data table and used the social vulnerability score as shown in Table 13 to calculate the risk levels. The lower the social vulnerability score, the lower the risk level and the higher the social vulnerability score, the higher the risk level. Once the risk levels were determined, I used the calculate geometry tool and select by attribute tool to add the risk levels in the columns by each risk level group.

Table 13. Social Vulnerability Score and Risk Level

Social Vulnerability Score	Risk Level
7.938209 – 24.535845	1
24.535846 – 31.017223	2
31.017224 – 35.405306	3
35.405307 – 45.508770	4
45.508771 – 61.210881	5

Overall Climate Risk

The final map I created for the risk analysis, was an overall climate risk map. This map displayed an overall risk level for the county on a municipal and census tract level. The overall climate risk was determined by adding together the risk levels for flooding, heat health, land use, landslides, and social vulnerability. To determine the overall climate risk, I had to first convert all the risk level layers from a polygon to a raster. Next, I had to reclass each risk layer so that it displayed just the risk levels from 1 – 5. It is important that when reclassifying the data that the 'No Data' value is equal to zero and that we do not check the box beside the 'change the missing values to no data'. If I have any no data values in the maps, it will not add together correctly when using the raster calculator. Any area that has no data, may mean that there is no risk for that area. Next, I used the raster calculator tool to add all the new reclassed risk layers together. Since, I am adding the five risk layers together, the lowest score a census tract or municipality can receive is 0 and the highest score it can receive is 25. Therefore, the lower the score, the lower the risk and the higher the score, the higher the risk.

Next, I converted the single raster layer to a polygon. Then I used the summarize within tool to add the overall climate risk to both the census tracts and the municipalities. In the summarize within tool, I used the gridcode for field use and maximum for the statistics because if there are multiple gridcodes in the tract or the municipality, it will look for the highest risk levels. Table 14 and Table 15 show the combined risk level scores for both the census tracts and the municipalities. It is important to show the overall risk levels for both the census tracts and municipalities as they both can tell us a different story. Displaying the climate risk on a municipality level gives a more summarized look at the overall risk in Allegheny County. However, displaying the climate risk on a census tract level shows a more localized and neighborhood level. It is important to display both levels, as a municipality may have a high-risk level, but when you look at the risk level on a census tract scale, you can see exactly which areas are causing the municipality to be labeled as high-risk.

Table 14. Combined Climate Risk Levels for Census Tracts

Combined Risk Level Score	Risk Level
1 – 5	1
6 – 8	2
9 – 11	3
12 – 14	4
15 - 20	5

Table 15. Combined Climate Risk Levels for Municipalities

Added Risk Level Score	Risk Level
0 – 3	1
4 – 9	2
10 -12	3
13 – 15	4
16 - 19	5

Additional Map Data

In addition to the risk maps, I also supplemented the web app with additional maps that complement the idea of climate resiliency. The additional map data used is Large Industrial Emitters, Particulate Matter 2.5, Environmental Justice Areas, Green Infrastructure, Greenways, and Community Gardens. One of the reasons I decided not to include this data into the risk analysis is that a lot of these maps utilize data that is difficult to develop into a risk level, such as point data.

Large Industrial Emitters 2021 & Particulate Matter 2.5

Data Source: Large Industrial Emitters Data from EPA Facility Level GHG Emission Data (FLIGHT) 2021 Reporting Year and Particulate Matter 2.5 Data from the Western Pennsylvania Regional Data Center

One of the major sources for air pollutants in Allegheny County comes from industrial sources, such as manufacturing, electricity generators, and landfills. One major area of concern is the industrial facilities located along the Monongahela River. These communities located along the Monongahela River are concerned for the health and well-being of the residents who live near these factories. The communities near these major factories are known to have air quality issues and rank high among the socially vulnerable. With air quality being a major concern in the community, I wanted to make sure that I included map data and information surrounding air quality. However, air quality data is hard to work with and it can be difficult to create maps to display the overall risk for communities.

For the Large Industrial Emitters, I used the most recent reporting year (2021) data from the EPA FLIGHT tool. Since this data came in CSV form, I had to geocode and convert the CSV into XY data points. The Large Industrial Emitters in the 2021 data are required to report annual data about greenhouse gas emissions to the EPA yearly as part of the Greenhouse Gas Reporting Program (U.S. EPA, 2022c).

The facilities are required to report if (U.S. EPA, 2022c):

- GHG emissions from covered sources exceed 25,000 metric tons CO_2e per year.
- Supply of certain products would result in over 25,000 metric tons CO_2e of GHG emissions if those products were released, combusted, or oxidized.

As for the particulate matter 2.5, this data is based on a combination of 2012 model and monitored data from the U.S. Environmental Protection Agency's Office of Air and Radiation. The data for PM 2.5 displays the areas with the highest concentrations of PM 2.5 in Allegheny County. The area with the highest concentration is in the southeastern portion of the county, which consequently is also where a lot of large industrial emitters are located, like the U.S. Steel facilities.

Environmental Justice Areas

Data Source: Environmental Justice Areas Layer from PA Department of Environmental Protections (DEP) Open GIS Portal

The U.S. EPA (2022b) defines environmental justice as "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies". The goal of environmental justice is to make sure that everyone has equal access and equal protections to live in a healthy environment. However, there are many communities that may not have access to resources or funding to help improve their environment and to protect their residents from environmental and health hazards. Due to the inequality of access, it is important for counties to understand which communities may be struggling to reach their healthy goals. Outlining environmental justice areas is one way to help communities understand where they need to increase collaboration efforts and strengthen resources.

The PA DEP (2023) defines an environmental justice area as, "any census tract where 20 percent or more individuals live at or below the federal poverty line, and/or 30 percent or more of the population identifies as a non-white minority, based on data from the U.S. Census Bureau and the federal guidelines for poverty". This data is based on percentages of those whose income is below the federal poverty line and the percentages of those who are minorities.

Green Infrastructure

Data Source: Green Infrastructure Atlas from 3 Rivers Wet Weather

3 River Wet Weather (3RWW) is a nonprofit organization that supports Allegheny County in addressing the issues associated with wet weather overflow. 3RWW is dedicated to improving Allegheny County's water resources and addressing the issue of untreated sewage and stormwater affecting the waterways of the region (3 Rivers Wet Weather, 2023b). They are also committed to assisting and education the public about issues surrounding wet weather (3 Rivers Wet Weather, 2023b). Green infrastructure can help with climate resiliency by managing floods, help mitigate drought, reduce urban heat islands, lower building energy demand, protect coastal areas, and helps to spend less energy managing water (EPA, 2022b). It is also a cost-effective way to improve water quality and control stormwater runoff. Green infrastructure is not only beneficial to protecting water quality and quantity, but it can also help with air quality, improve habitat and wildlife, and it can provide positive impacts to communities by increasing property values and creating recreational spaces (EPA, 2022a).

One solution to minimizing the volume and rate of stormwater runoff is by implementing green solutions. Green solutions mitigate the quantity and quality of stormwater runoff by better utilizing the land to control stormwater at the site where precipitation falls (3 Rivers Wet Weather, 2023a). These practices can either be structural or operational. For the green infrastructure map, I used the green infrastructure projects data from 3RWW and displayed each project by its location and type.

Greenways

Data Source: Allegheny County Greenways from the Western Pennsylvania Regional Data Center

Greenways are permanent, open spaces that serve to protect natural resources and to connect people to nature (City of Pittsburgh, 2023). Greenways can incorporate water or land-based features, and often encompass abandoned railways, canals, ridge tops, rivers and stream valleys (Allegheny County Economic Development, 2008).

Implementing greenways in urban areas can provide a positive impact on both the community and on climate resiliency. Greenways can provide shade which will help to decrease surrounding temperatures and it can lead to reducing the cooling needs in homes (Shaikh et al., 2020). The landscaping in greenways can also help soak up rainwater and slow the flow of water during a heavy precipitation event.

For this map, I decided to display the greenways as a percent area based on the area in each census tract. I choose to display the data as a percent, because it will allow community members to see which communities have the highest percentage of greenways in the area and which have the lowest. This can help local decision-makers find which communities could benefit from more parks and greenways.

Community Gardens

Data Source: Grower's Map Database from Grow Pittsburgh

Community gardens are a type of green infrastructure that can provide many benefits to the community and to the climate. The gardens can reduce urban heat islands, increase stormwater retention, provide benefits to ecological systems, and can provide as a healthy source of food for communities (Scott, 2022). In addition, many of these gardens tend to be planted in vacant lots or old industrial sites.

Grow Pittsburgh is a program that develops and supports food-growing programs across the region. Their goals are to teach people how to grow food, grow food in the community using urban farm sites, and to support school gardening programs (Grow Pittsburgh, 2022b). The Grow Pittsburgh program has a user-generated map that shows where gardens are located throughout the region. These gardens can be a community garden, a school garden, a commercial urban farm, or community farm. In total, there are about 55 different types of gardens registered on this map. The map I created displays the type of garden and the locations of the registered gardens on the Grow Pittsburgh database.

Results

Maps

Using ArcGIS Pro and the steps outlined in the methodology section, I created a series of maps that were used in my interactive web app. Figures 4 – 11 (See Appendix B) display the series of maps that were created based upon the climate indices and additional map data.

Overall Climate Risk

The overall climate risk maps for the municipalities and census tracts (Figure 4), outline the areas in Allegheny County that have the lowest and highest overall risk to climate change. Seventeen out of 130 municipalities in Allegheny County are considered high-risk. The municipalities that are ranked as having a risk level of five (high risk) are Rankin, McKeesport, West Mifflin, Clairton, North Braddock, City of Pittsburgh, Harrison, East Pittsburgh, Port Vue, Bridgeville, Monroeville, Swissvale, McKees Rocks, Scott, Robinson, White Oak, and Penn Hills. Most of these high-risk areas have a variety of vulnerabilities that contribute to the municipality being labeled as high-risk. For example, West Mifflin, which is a municipality that is considered high risk, has a very high risk in land use, as the area contains a lot of industry. More specifically, the municipality is home to U.S. Steel Irvin Works, which is a large industrial emitter (384,878 metric tons of CO_2 in 2021 (U.S. EPA, 2022a)). Additionally, West Mifflin has been found to be susceptible to flooding, landslides, and heat waves. However, if we were to look at West Mifflin on a more localized, census tract scale, a difference in the risk levels emerges. In West Mifflin, there are six census tracts. In these six census tracts, three of them are high risk, one is medium to high risk, one is medium to low risk, and one is low risk. Therefore, looking at the overall climate risk on a municipality scale does not necessarily speak for the whole municipality. It is vital that decision-makers look at their municipality not only as a whole, but also at the smaller neighborhood levels. Looking at risk on a localized scale will allow decision-makers to see where they need to put more resources and funding into building climate resiliency efforts. Therefore, 12 out of the 13 maps I created utilize census tracts to more accurately convey the localized risks within the county.

Air Quality

In the air quality section, I created a map displaying large industrial emitters and a map that displays particulate matter 2.5. The large industrial emitters map (Figure 5) shows the point locations of the industrial facilities that emit more than 25,000 metric tons of CO2 per year (U.S. EPA, 2022c). Many of these large emitters are factories associated with the steel industry, waste management, or power/energy companies. The PM 2.5 map (Figure 5) shows the concentration of PM 2.5 within the Allegheny County census tracts. Since this map only shows three levels of concentrations of PM 2.5, I was not able to compute an accurate risk analysis for the county. That being said, this map does help show decision-makers where the highest concentration of PM 2.5 tends to fall. The areas with the highest concentrations tend to fall in more industrial areas, such as southern Allegheny County where more industrial facilities are located. Additionally, areas lacking air quality monitors in 2011 may not accurately reflect the level of PM 2.5 actually present in the area today.

Land Vulnerabilities

The maps that fall under the land vulnerability category include flooding, land use, and landslides. In the flooding risk analysis map (Figure 6), the census tracts with the highest risk are the ones that are located near the three rivers and areas located near smaller streams/tributaries. For land use (Figure 6), the census tract areas that have the highest risk are the tracts that have a lot of industrial facilities and areas with large urban development. The areas with large urban development, tend to be shopping centers, airports, and places that lack green space and permeable surfaces. The areas that do not have greenways and permeable surfaces are prone to having higher surface temperatures and localized flooding in roadways, parking lots, and other low-lying areas. As for landslides (Figure 7), the areas that have the highest risk are tracts that have had recent landslides and census tracts that contain an outcrop of thick 'Red Bed' soil. The "Pittsburgh Red Beds" are a type of red mudstone, claystone, and shale that have been linked to areas that have a high susceptibility to landslides (Pomeroy, 1982). Pomeroy's (1982) study on landslides in the Pittsburgh region has also shown that areas with steep slopes and slopes with conspicuous soil creep areas are also leading causes of landslides in the region.

Social Vulnerability

There are three maps that fall under the social vulnerability category, social vulnerability, environmental justice areas, and heat health. In the social vulnerability risk map, the census tract risk levels are determined based upon 28 different socioeconomic variables. Taking into consideration the 2021 Allegheny County Community Need Index Report and the social vulnerability risk map (Figure 9), we can see similar patterns of vulnerability. The Allegheny County Department of Human Services (2021) Community Needs report states "higher levels of need are located in A) Pittsburgh's Hill District, upper eastern neighborhoods, South Hilltop, sections of the Upper Northside and sections of the West End, B) McKees Rocks and Stowe, C) sections of Penn Hills and Wilkinsburg, D) much of the Monongahela River Valley, and E) sections of Harrison Township". This concentration of areas that are high levels of need also correlates with the areas that have high levels of social vulnerability risk. To complement the social vulnerability risk map, I also included Environmental Justice Areas (EJAs). The EJA areas outlined in Figure 9 are based on race and income. The areas shown in Figure 9 also correlate to areas that are considered high risk in the social vulnerability risk areas.

The final map in the social vulnerability category is heat health. The heat health risk areas were based on three variables, average heat anomaly, percent impervious surface, and percent of population below the poverty level. Looking at the high-risk areas in the heat health map (Figure 8), I can see a pattern start to emerge. Many of the high-risk tracts tend to be in more developed areas, such as downtown Pittsburgh and the neighborhoods that surround downtown. Downtown Pittsburgh has a high risk to heat health because there are a lot of impervious surfaces, there is old infrastructure, and there are minimal green space areas. Additionally, some of the neighborhoods in and near the city are also areas with high social vulnerability risk, as they tend to be low-income neighborhoods. The tracts on the outer boundary of the county are more forested and less developed, therefore they have less risk to heat health impacts.

Sustainability

Within the sustainability category, there are three different maps, green infrastructure, greenways, and community gardens. Looking at the green infrastructure map (Figure 10) most of the projects tend to be located in or around the city of Pittsburgh. The reason many of the projects tend to be in and around the city is due to the partnerships the City of Pittsburgh has created. The City has been working with Pittsburgh Water and Sewer Authority, ALCOSAN, and the Pittsburgh Parks Conservancy to develop and implement green infrastructure within the city. The issue with green infrastructure is that it can be expensive, and it requires a great deal of resources and funding. Therefore, many of the smaller municipalities may not have the funding or partnerships to help develop major green infrastructure projects. As for greenways, these tend to be a little easier and less expensive to implement for smaller communities. Additionally, many of the municipalities may already have the needed infrastructure to host or implement recreational greenways, such as the Great Allegheny Passage and the Erie to Pittsburgh Trail. Looking at Figure 11, you can see that the areas with the largest percentage of greenways are the outer municipalities near the borders of the county. These areas tend to be less developed than the City of Pittsburgh and they contain more forested and agricultural areas. The final map in this category is community gardens. The community gardens map (Figure 10) contains the types and locations of the various community gardens within Allegheny County. According to Grow Pittsburgh (2022a), there are 17 community gardens, 20 community farms, 14 school gardens, 3 commercial urban farms, and 1 Grow Pittsburgh Site. Again, many of these gardens are located in or around the City of Pittsburgh. There are a few sites that are located along the outer municipalities of the county.

ArcGIS Experience Builder

After completing the risk analysis in ArcGIS Pro, I began to build my web app in ArcGIS Experience Builder (Figure 3 in Appendix B). ArcGIS Experience Builder is a web app builder from Esri that allows users to develop multiple pages of information, include text information, and create interactive ArcGIS maps. ArcGIS Experience Builder is an easy-to-use interface that allows for the integration of maps from ArcGIS Pro. The web app created for this project integrated the risk analysis maps created from ArcGIS Pro. For the maps to be interactive and useable in ArcGIS Experience Builder, the risk analysis maps had to be imported to ArcGIS Online. Once the interactive web maps were created using ArcGIS Online web map builder, then I could begin the process of building the Allegheny County Climate Impacts Tool on ArcGIS Experience Builder.

The design goal for the web app was an easy-to-use and understandable visualization of climate risk data for a broad audience of non-climate expert decision-makers in local government. In addition to the interactive web maps, the web app contains supplemental text information explaining the climate impacts and local climate resiliency and links to external websites that can help further explain concepts to community members. The goal of this web app was not only to help explain local climate change impacts for Allegheny County, but it was also created to be used as a tool to help with local climate resiliency planning. When creating local climate resiliency plans, it can be hard to find information that pertains specifically to your community. This web app can help local decision-makers and community members find information regarding their local community's climate impacts in a user-friendly way.

DISCUSSION

The Impacts of GIS and Climate Change Integration in Local Communities

After presenting the Allegheny County Climate Impacts Tool to Allegheny County municipalities and members of the Allegheny County community, it was clear that more GIS tools, like this web app, are needed to help local decision-makers and stakeholders within the county. Members of the community expressed how they could have utilized this GIS tool when they were creating their local climate action plans and expressed that this tool could be used for future local climate action planning because it provides them with a consolidated platform for understanding climate risks and the associated resources for managing them.

Additionally, members of the community expressed the need for more data, maps, and information that relates to climate change impacts within the community. This community feedback has further solidified the importance of simplifying climate change information and placing it into an interactive and comprehensible format. There is an overwhelming need for more easily accessible and understandable local community resources for climate change. Local decision-makers are concerned for the health and well-being of their communities, so we need to address those concerns by providing information that is relevant to their community.

A major concern that was brought up through the development of this web app, was the need for municipalities to find climate change information that is directly related to their community. Many of the municipalities in Allegheny County are drafting local climate action plans and have addressed the issue of finding local resources and information pertaining to climate change impacts. This web app was created with the idea that municipalities will use it as their first stop when they are beginning to draft their action plan. The web app can provide municipalities with an idea of their community's overall climate risks and vulnerabilities. Furthermore, this web app also shows what is currently being done in their community regarding climate actions and sustainability. Using the web app can help lead municipalities to other local resources that can help them gather more information that pertains to their community.

Overall, this project has helped community members and local decision-makers understand how we can better utilize GIS to effectively communicate climate change impacts and find ways to help communities understand the importance and severity of climate change, which will ultimately help them make more informed decisions.

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Appendix A – List of Plans

Pennsylvania Climate Plans

Pennsylvania Climate Impact Assessment 2021
Pennsylvania Regional Greenhouse Gas Initiative

Climate Action Plans

Local Climate Action Plans (LCAP) is a policy outlined by local governments, municipalities, communities, and organizations to reduce greenhouse gas emissions and to mitigate/adapt to the impacts from climate change. The LCAP program in Pennsylvania is a program provided by the Pennsylvania DEP that leads local communities into developing their own climate action plan.

State Climate Action Plan

Pennsylvania Climate Action Plan 2021

Municipalities in Allegheny County with Local Climate Action Plans

Carnegie
City of Pittsburgh
Etna
Forest Hills
Millvale & Millvale EcoDistrict Plan
Munhall

Communities in Allegheny County with Local Climate Action Plans

University of Pittsburgh
The Congress of Neighboring Communities (CONNECT) Climate Action Plan
The Sustainability Initiative at Carnegie Mellon University

Local Plans in Allegheny County That Help Build Climate Resiliency

Plan for a Healthier Allegheny 2023 -2027
Allegheny County Sustainability Report 2022

Appendix B – Images and Maps

Figure 3. Screenshot of the Home Screen from the [Allegheny County Climate Impacts Tool](https://experience.arcgis.com/experience/20198bba5d0d4e3cbfec7a34c40a78ca/)

Allegheny County Climate Impacts Tool

Planning a Climate Resilient Community

ⓘ Web App Help

Overall Climate Impact | Planning Climate Resiliency ⌄ | Impacts to Your Community ⌄ | Sustainability & Climate Actions

Overall Climate Impact

As climate change continues to impact communities all over the world, it is vital to make smart and well informed decisions to protect communities in the future. One way to mitigate the impacts of climate change is by building climate resilient communities. The Center for Climate and Energy Solutions states, "Climate resilience is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate. Improving climate resilience involves assessing how climate change will create new, or alter current, climate-related risks, and taking steps to better cope with these risks."

The key to building a climate resilient community is to start small. It is critical for local governments and community organizations to start building resiliency in their communities, with actions such as tree planting or green infrastructure projects. Building resiliency in one community can encourage other communities to start building climate resiliency in their community.

This map displays the overall climate impact for municipalities in Allegheny County, Pennsylvania. The impact is shown on a scale from 1 (low risk) to 5 (high risk). The risk levels were determined by compiling the risk levels scores from the land use, social vulnerability, heat health, flooding, and landslide risk level maps. To find out the individual risk score for each municipality, click on a municipality of choice and it will display a popup. In the bottom left corner of the map there is a filter that can filter risk level areas by municipalities with a high risk level, an average risk level, or a below average risk level.

To view a more detailed map of the climate risks within municipalities, see the Overall Climate Risk for Census Tracts in Allegheny County.

To learn how to use and interact with the maps click here

Link to Web App:
https://experience.arcgis.com/experience/20198bba5d0d4e3cbfec7a34c40a78ca/

Figure 4. Overall Climate Risk for Municipalities (Top) and Census Tracts (Bottom) for Allegheny County (Scale 1:430,000)

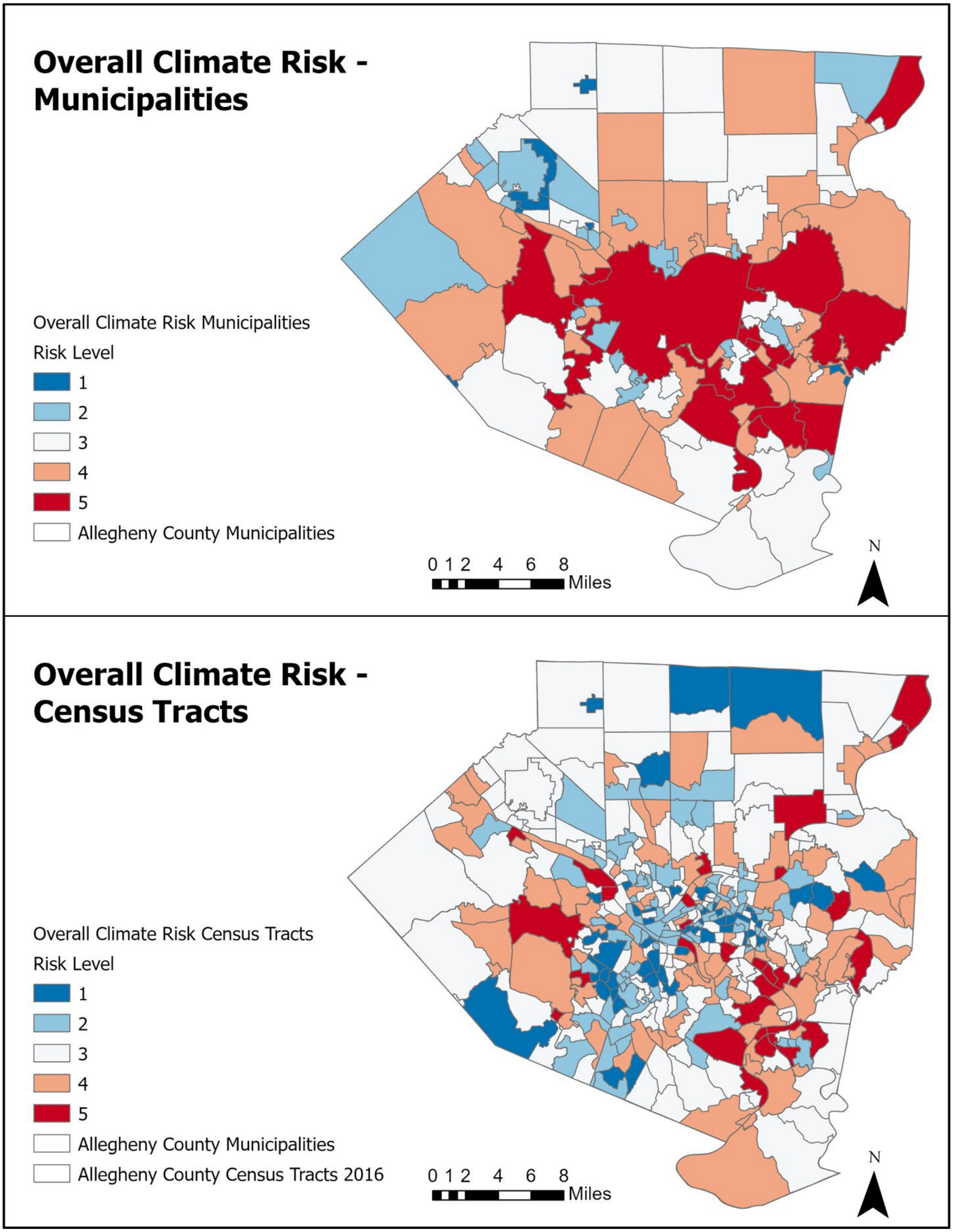


Figure 5. Air Quality Maps for Allegheny County. Top map displays Large Industrial Emitters and Bottom Map Displays Particulate Matter 2.5. (Scale 1:430,000)

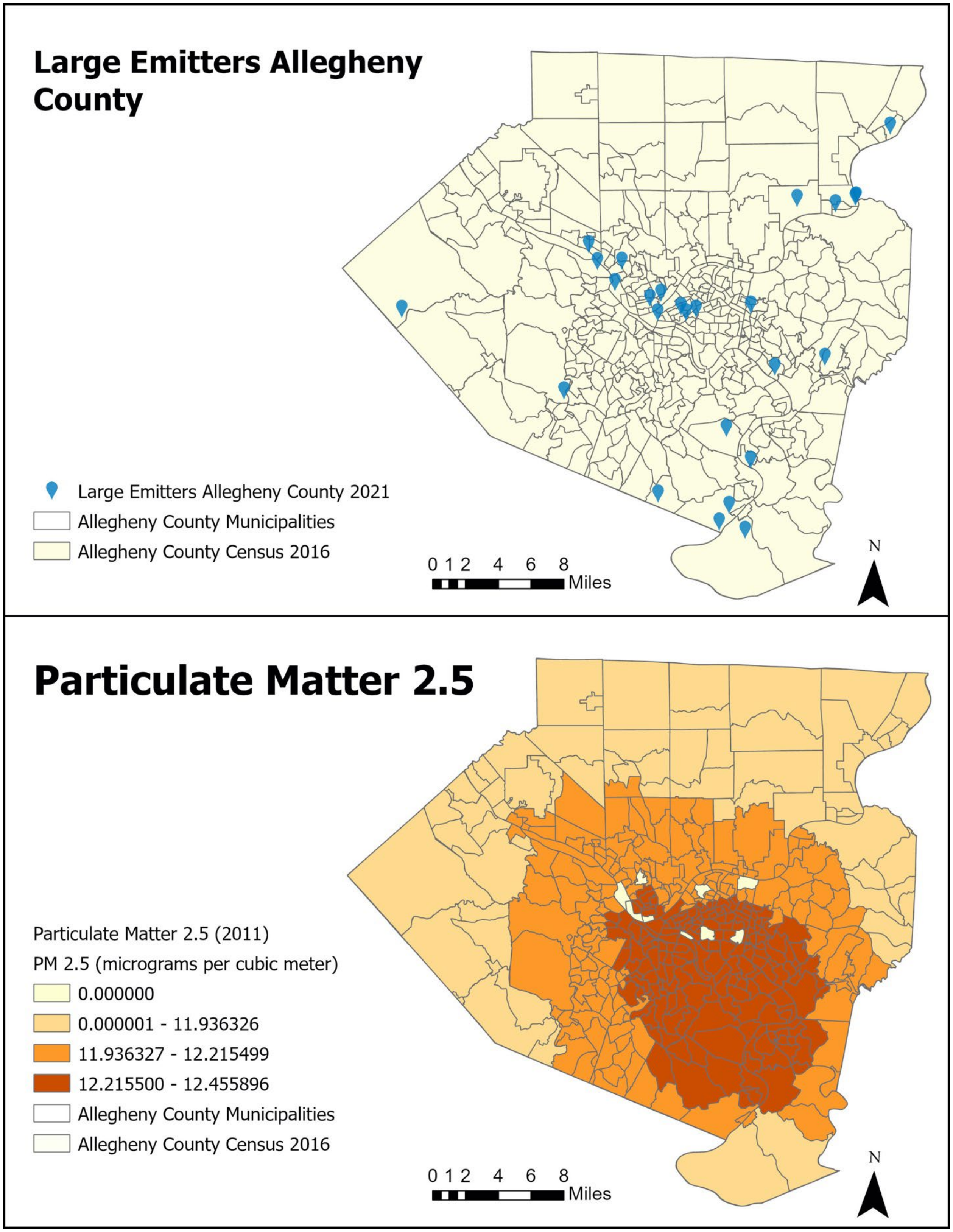
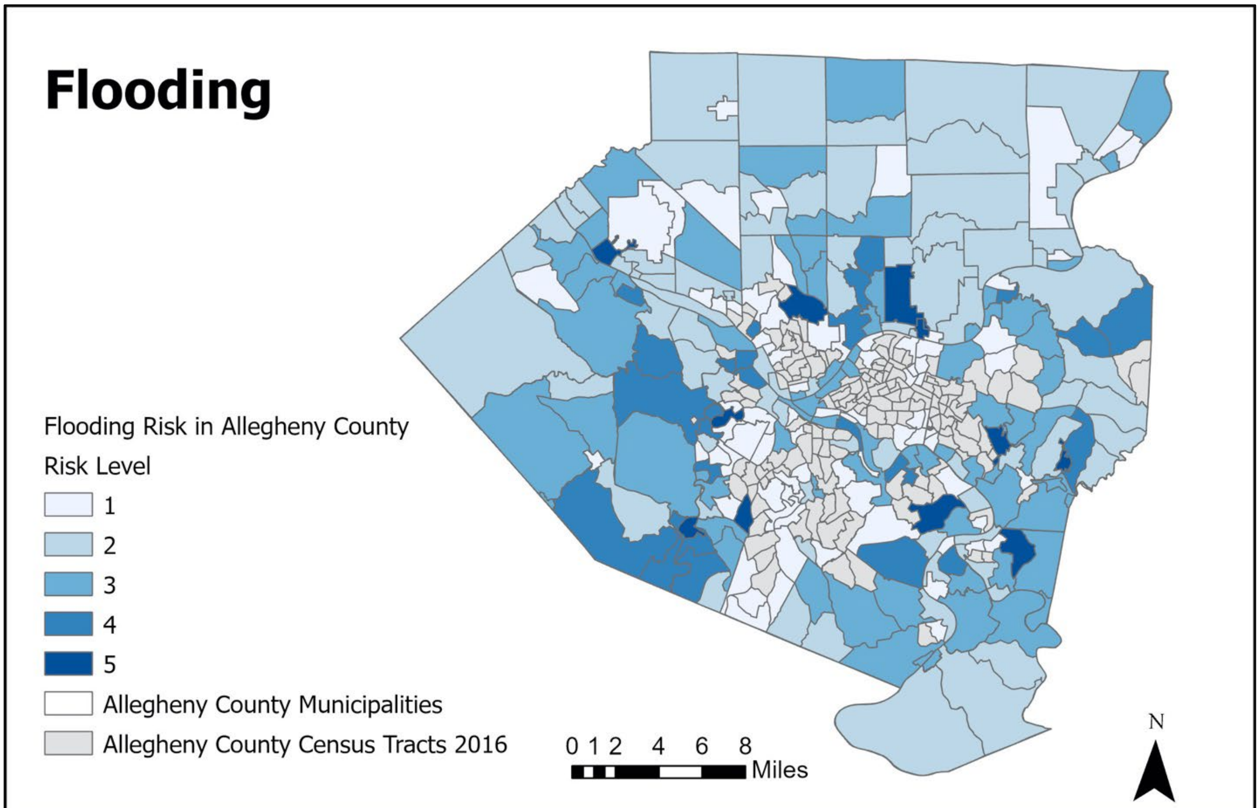


Figure 6. Land Vulnerability Maps for Allegheny County. Top Map Displays Flooding Risk and Bottom Map Displays Land Use Risk. (Scale 1:430,000)



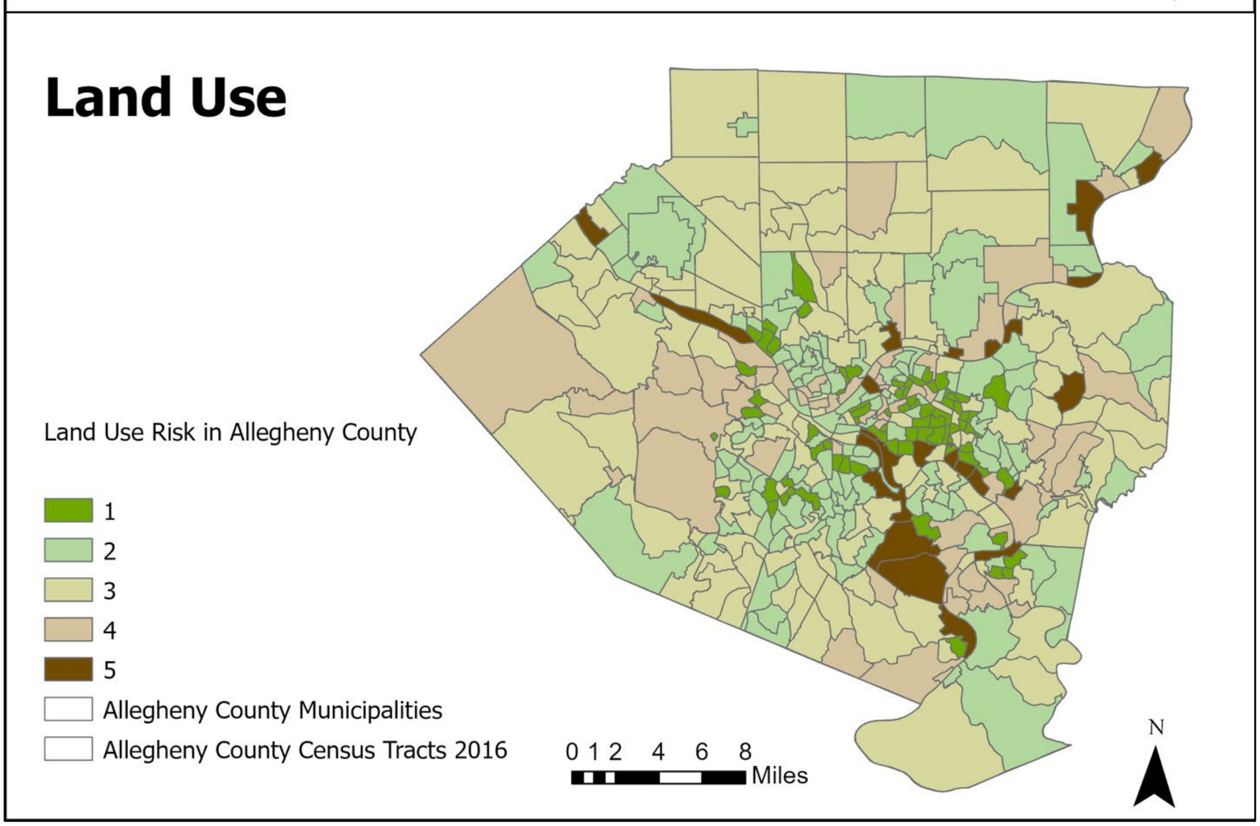


Figure 7. Land Vulnerability Map of Landslide Risk for Allegheny County. (Scale 1:430,000)

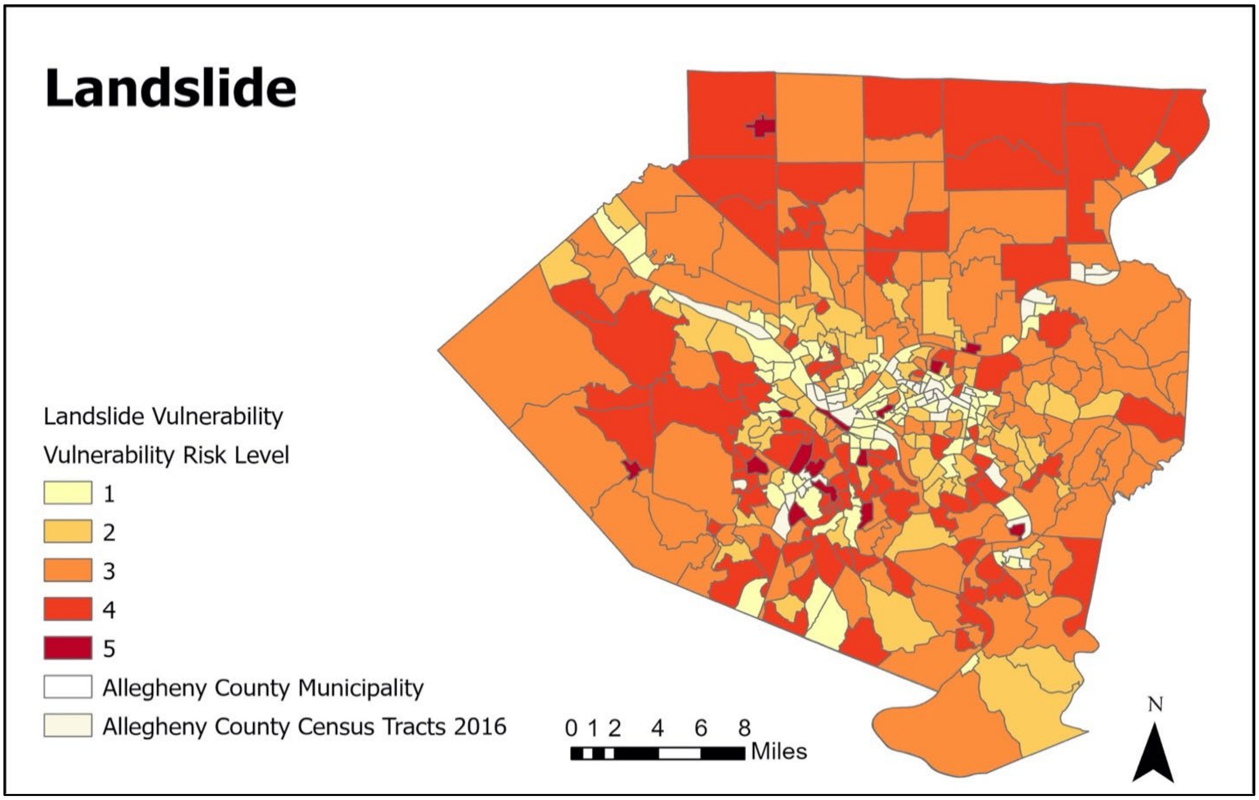


Figure 8. Social Vulnerability Map of Heat Health Risk for Allegheny County. (Scale 1:430,000)

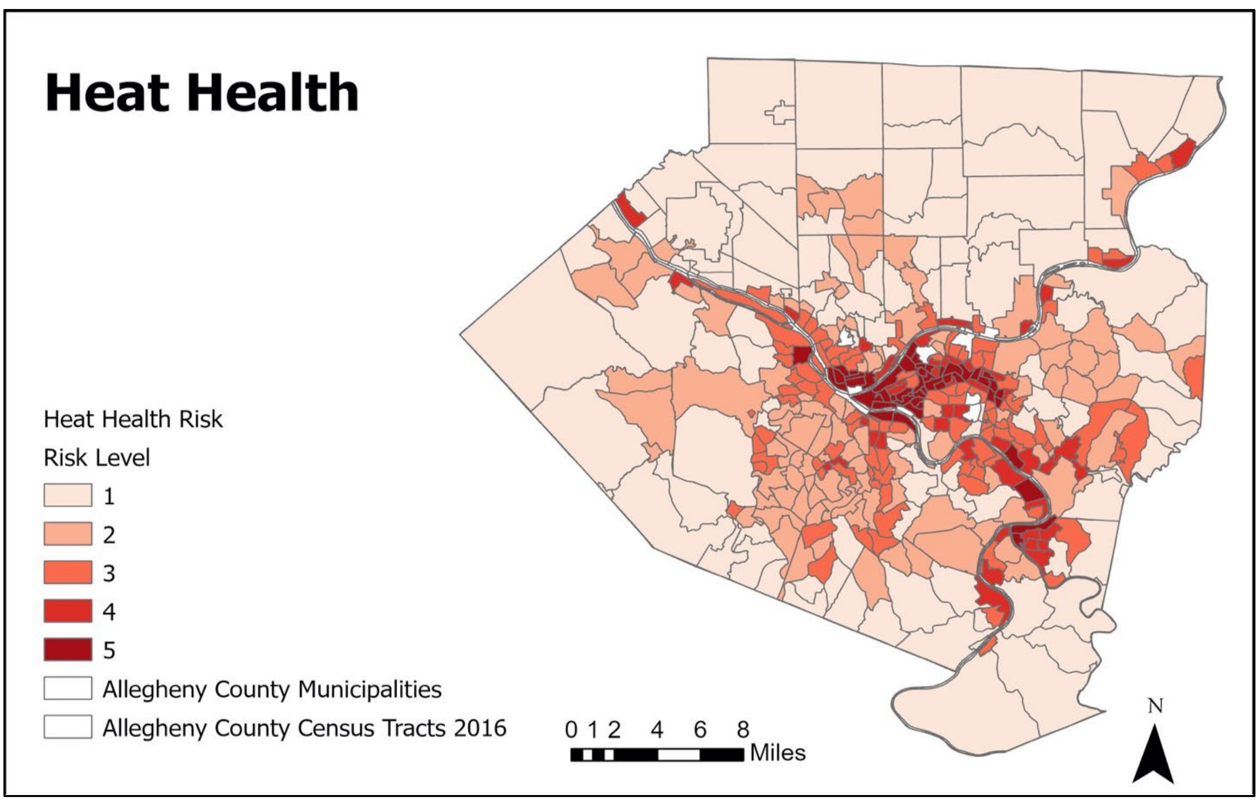


Figure 9. Social Vulnerability Maps for Social Vulnerability Risk and Environmental Justice Areas in Allegheny County. (Scale 1:430,000)

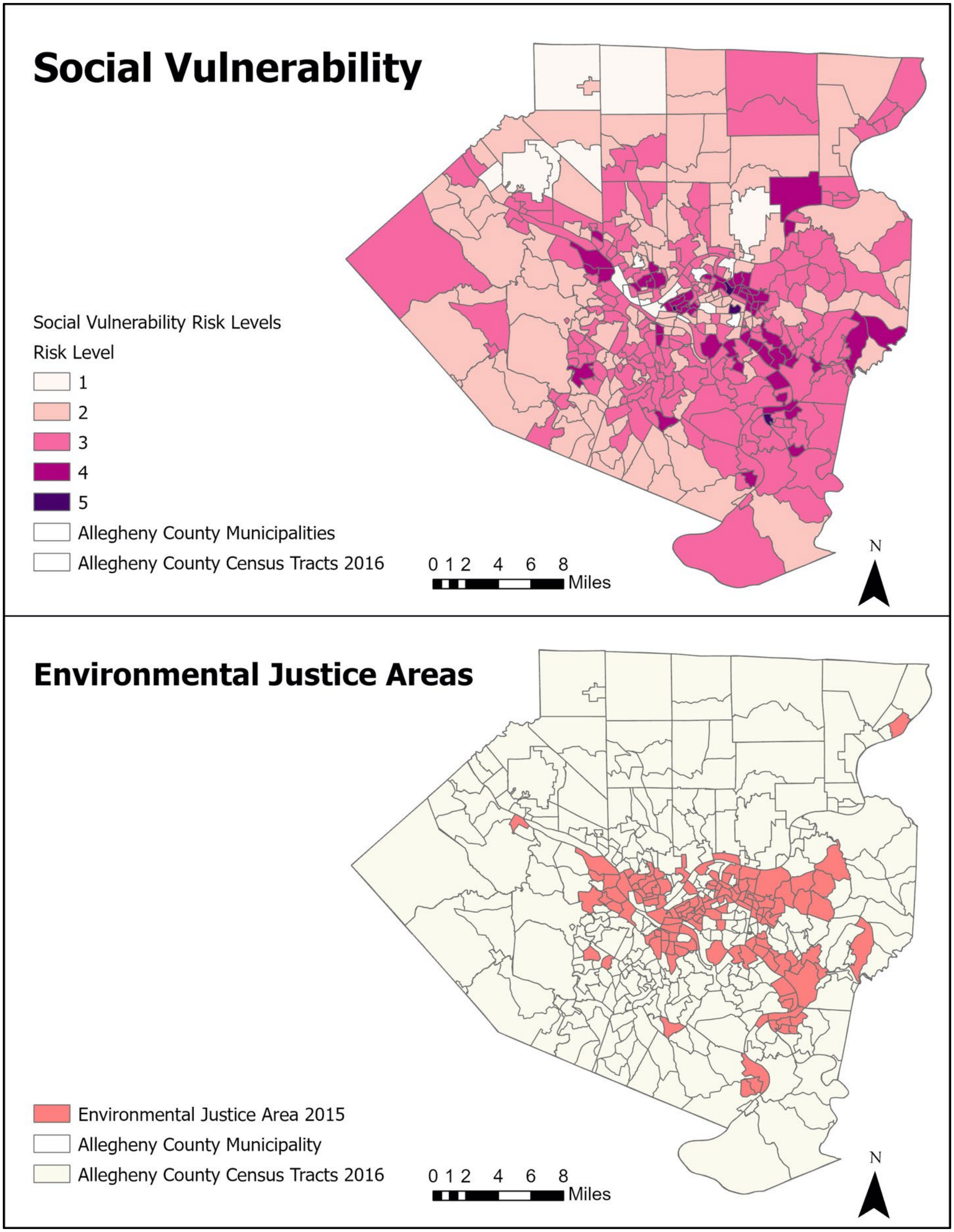


Figure 10. Sustainability Maps for Green Infrastructure Project Locations and Community Garden Types and Locations in Allegheny County. (Scale 1:430,000)

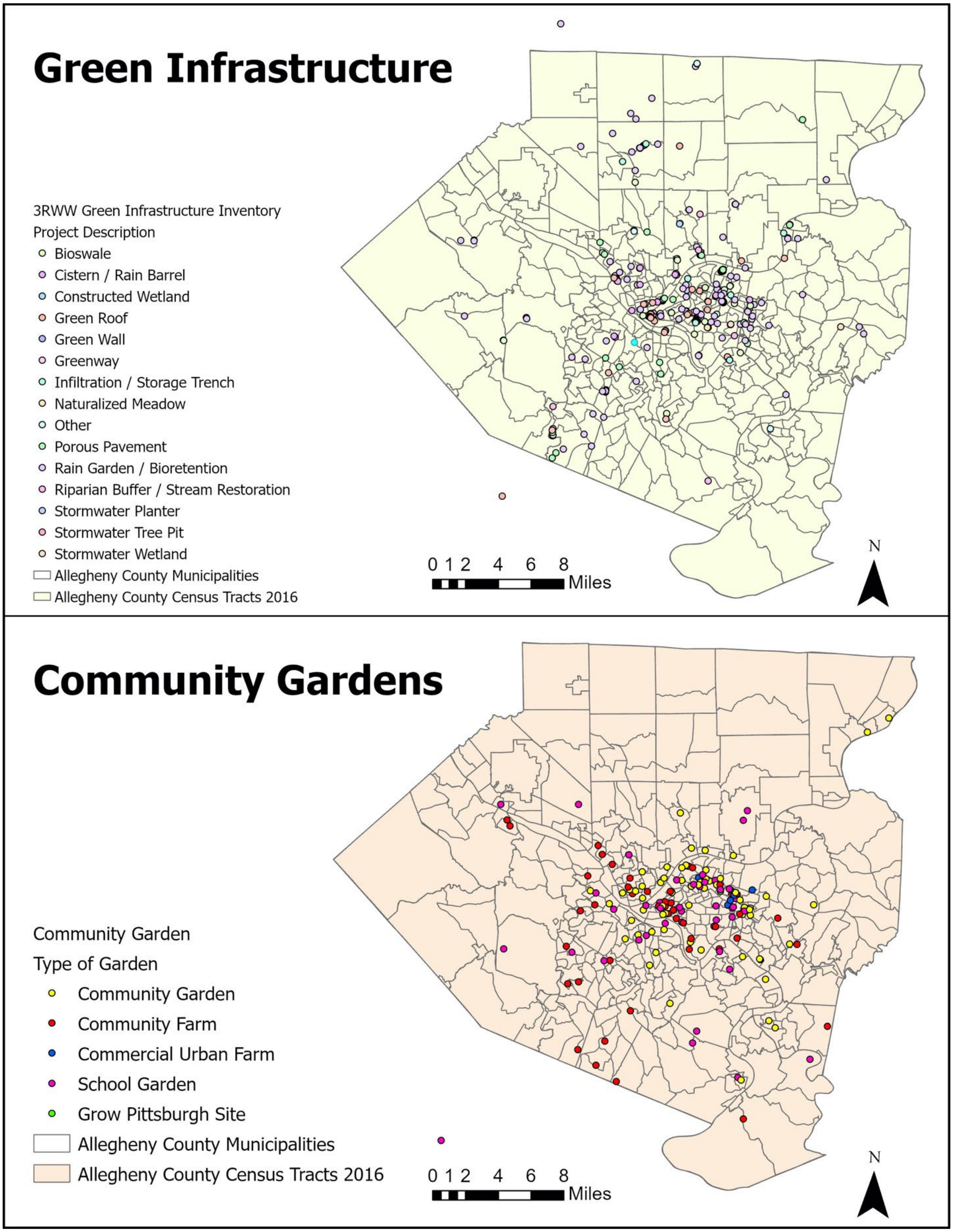


Figure 11. Sustainability Map of Percent Area of Greenways in Allegheny County. (Scale 1:430,000)