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Pathogenic Detection Using Wastewater Surveillance and the Impacts of Microbial Hazards of Atlanta's Flood Water and Residential Tap Water Sources

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Master of Science in Geosciences, Georgia State University, 2019

Advisor: Marlene Wolfe, Ph.D.

An abstract of

A thesis submitted to the Faculty of the
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Abstract

Pathogenic Detection Using Wastewater Surveillance and the Impacts of Microbial Hazards of Atlanta's Flood Water and Residential Tap Water Sources

By Tamara M. Spikes

This thesis is a description of a proposed research design that seeks to explore systemic differences in communities vulnerable to environmental burdens and health inequalities and evaluate how researchers engage with communities at increased risk; the proposed work aims to assess the ability of wastewater monitoring to characterize disease burdens and health disparities for a highly stigmatized and localized disease, mpox, and to evaluate the community engagement process used to develop a partnership with a marginalized community in Atlanta. The proposed research explores the performance and utility of monitoring infectious diseases, such as mpox, in wastewater in Atlanta by evaluating the relationship between DNA viral concentrations of mpox and mpox clinical cases and determining whether sociodemographic and community factors modify the relationship. Furthermore, the proposed work evaluates the community engagement process used to develop a partnership with a marginalized community in Atlanta in hopes of using the findings to inform corrections to program implementation or to give insight into the implementation process of community-focused projects aimed at examining the flooding impacts, behaviors, and perceptions amongst Atlanta's historically marginalized communities.

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OBJECTIVES AND SPECIFIC AIMS

Communities of color often face disproportionate health risks associated with overlapping exposures to multiple environmental hazards.[1] These communities are susceptible to health effects related to environmental impacts rooted in racialized and socioeconomic disparities. The differential exposure to health risk factors encountered by marginalized groups defines differential access to resources.[2,3] According to the Georgia Budget & Policy Institute, 1.4 million Georgians do not have health insurance, and Georgia's uninsured rate of 13.7 percent is the third highest in the country. 20.2% of Georgia's African American population is uninsured and experiences a significantly higher disease burden compared to non-minorities. Additionally, the increasing frequency of hospital and healthcare facility closures within Georgia's metropolitan communities is prompting adverse consequences, including a lack of access to healthcare that disproportionately burdens minority and low-income communities and leads to incomplete disease surveillance.[4–6] There is a need to have and use alternative tools that can enhance disease monitoring within communities lacking access to traditional clinical surveillance, and researchers need to engage communities well in the work they are already doing.

Infected individuals can shed pathogens into wastewater through urine, feces, and other bodily fluids down drains and municipal wastewater. Wastewater can, therefore, act as a composite sample of the community. Measuring markers of pathogens in this composite sample representing a large group of people can provide insight into the presence of these pathogens and changes in concentrations over time and space, which can provide information about the trends and levels of a disease at a population level.[7] Wastewater monitoring has become an essential tool to support public health. It can significantly enhance surveillance for diseases that are difficult to monitor and within communities not well represented in traditional clinical surveillance.[8] Among these same communities, there is increasing recognition of communities' role in promoting the health of the people who live there. For example, communities of color often rely on community-led facilities as an asset that creates support and resiliency amongst members to promote health. These and other assets, including solid social networks through faith-based and social service organizations, are relied upon in efforts to address health disparities.[9] Healthcare organizations and public health departments often provide services in these communities, but historically, they have not engaged with community leadership when executing critical strategies to improve community health. Therefore, evaluating community-based collaborations with healthcare institutions, providers, and researchers is needed to improve the success of partnerships to enhance community health and hold institutions accountable.

To explore systemic differences in communities vulnerable to environmental burdens and health inequalities and evaluate how researchers engage with communities at increased risk, the proposed work aims to evaluate the ability of wastewater monitoring to characterize disease burdens and health disparities for a highly stigmatized and localized disease, mpox, and to evaluate the community engagement process used to develop a partnership with a marginalized community in Atlanta. This research will address these gaps through the following specific aims:

1.1 Specific Aim 1: Explore the performance and utility of monitoring mpox in wastewater in Atlanta by evaluating a) the relationship between the concentration of mpox DNA and clinical cases of mpox amongst four Atlanta-area publicly owned treatment works (POTWs), b) whether the relationship is modified according to socio-demographic and community factors, and c) the use of wastewater data by the GA DPH during summer 2022 to present and its value to inform real-time public health response.

1.2 Specific Aim 2: Evaluate the planning and implementation approaches of a community-engaged study examining the flooding impacts, behaviors, and perceptions among Peoplestown residents.

SPECIFIC AIM 1

2.1 Background of Specific Aim 1: According to the Georgia Department of Public Health, African Americans make up the second largest group of uninsured Georgians (13%) and experience moderate to severe inequalities as a group, contributing to poor health outcomes.[10] These communities are also disproportionately faced with inadequate healthcare access due to insurance coverage restrictions, hospital closures, and instability of traditional healthcare systems.[11,12] The recent closure of the Atlanta Medical Center, which serviced central and South Atlanta communities, deepens a trend of healthcare inaccessibility amongst vulnerable and low-income populations.[13] In addition to threatening patients' access to care, the closure of this hospital detrimentally impacts traditional disease surveillance, which is primarily done through reporting from health institutions, physicians, public health laboratories, hospitals, and health providers, by limiting case ascertainment within the affected population.[14] Complementary surveillance measures are necessary to detect, measure, and track infectious diseases throughout the year.[15] Alternative surveillance measures, such as wastewater-based approaches, can enhance disease monitoring within communities lacking access to traditional clinical surveillance. This approach provides a comprehensive picture of public health trends by monitoring the presence of infection within a community and identifying trends using passively collected inputs from all who are connected to the network. The methods have been shown to provide valuable information demonstrating spatial and temporal differences in disease levels between communities. This approach provides a comprehensive picture of the presence of symptomatic and asymptomatic infected individuals contributing to a wastewater system and infection trends within the community contributing to the sewershed.[7,16–18]

Measurements of RNA or DNA targets specific to pathogens can be detected and quantified in wastewater, and past work has shown that these measurements are related to community disease incidence for a number of important infectious diseases.[19,20] Thus, this information can support efforts to understand disease circulation and identify the presence of under-ascertained infections among communities lacking access to clinical surveillance systems. Wastewater monitoring is a beneficial tool that captures the presence of viral shed by symptomatic and asymptomatic people.[16] By evaluating disease circulation at the community level, this tool can inform clinical case finding and mobile-based contact tracking systems and enhance partnerships between environmental and clinical science communities by integrating wastewater surveillance approaches into traditional healthcare system platforms and databases.[21,22] The data retrieved from this surveillance method can inform community engagement strategies to educate individuals on disease prevalence within their communities, identify and integrate significant surveillance gaps to further consult public health priorities, and gather evidence for use amongst community groups to address environmental health inequities. Wastewater monitoring has been used most recently by local public health departments to complement traditional disease reporting when tracking cases associated with infectious disease outbreaks, including the 2022 mpox outbreak.

In 2022, the World Health Organization declared the multi-country outbreak of mpox- a viral zoonotic disease caused by the mpox virus, a member of the *Orthopoxvirus* genus. In November 2022, the Centers for Disease Control (CDC) reported over 28,000 and 1,900 confirmed mpox cases in the United States and Georgia, respectively. During the 2022 mpox outbreak, an estimated 95% of cases occurred in men who have sex with men (MSM), and 40% of cases appeared in those living with HIV. More specifically, in the Southeastern United States, mpox disproportionately affected African Americans, as they accounted for 33% of U.S. mpox cases and 86% of deaths.[23] Atlanta, Georgia has the fourth highest-HIV rate of U.S. metropolitan cities; along with the increasing pattern of hospital closures throughout the city this means that African Americans in Atlanta are particularly vulnerable to mpox.

The global and local spread of mpox prompted a swift public health response. In Spring 2022, the Georgia Department of Public Health (GADPH) partnered with the CDC to establish the Georgia National Wastewater Surveillance System (NWSS). During that time, the GADPH also partnered with researchers at Emory, leading a program for wastewater monitoring focused on expanding the panel of targets monitored in wastewater and generating evidence for their use in public health. WastewaterSCAN introduced testing for mpox in the metro Atlanta area in July 2022, during the early days of the mpox outbreak in the US. Though this tool was effective in monitoring cases at the community level in California at a time when clinical surveillance systems experienced challenges that hindered disease reporting[24], further investigation is needed to determine the relationship between clinical surveillance of mpox and reported concentrations of mpox in wastewater in other settings, if this relationship is modified based on notable disparities influenced by sociodemographic and community factors, and how public health programs have utilized this data.

2.2 Specific Aim 1 Objective and Research Questions: To understand how wastewater monitoring can be used to support the tracking of cases and influence public health action in Atlanta for mpox, this aim will explore the performance and utility of monitoring mpox in wastewater in Atlanta by evaluating a) the relationship between the concentrations of mpox DNA and clinical cases of mpox amongst four Atlanta-area publicly owned treatment works (POTWs), b) determining whether the relationship is modified according to sociodemographic and community factors, and c) describe how the use of wastewater data by the Georgia Department of Public Health (GADPH) during the summer 2022 mpox outbreak informed real time public health response. The aim is driven by the following research questions:

1. What is the relationship between the concentration of mpox DNA and clinical cases of mpox amongst four Atlanta-area publicly owned treatment works (POTWs)?
2. How is the relationship between the concentration of mpox DNA and clinical cases of mpox modified according to sociodemographic and community factors?

3. Did the use of wastewater data by the GADPH during the summer of 2022 to inform real-time public health response?

A comparison analysis of wastewater data provided through WastewaterSCAN and clinical data provided by Georgia DPH will be conducted to evaluate the relationship between the concentration of mpox DNA and clinical cases of mpox amongst four Atlanta-area publicly owned treatment works (POTWs), determine whether the relationship is modified according to socio-demographic and community factors, and understand how the use of wastewater data by the GA DPH during summer 2022 to present informed real-time public health response.

2.2.1 Hypotheses: I hypothesize that wastewater surveillance to detect mpox in the observed sewersheds reflect patterns of disease incidence, thus serving as a complementary tool to traditional disease surveillance. I also hypothesize that case counts among communities suffering from healthcare inaccessibility- due to healthcare coverage restrictions, hospital closures, and instability of conventional health systems – and lower socioeconomic status will be lower than expected based on wastewater data compared to areas with improved healthcare access. If no differences are observed, it might indicate challenges present within state case reporting or the representativeness of wastewater samples is impacted during sampling, impacting data collection and reporting. There may also be a lack of case data to determine the significance of the differences. I expect that this relationship will indicate that marginalized and low-socioeconomic communities are vulnerable to underreporting and under ascertainment, leading to decreased public awareness and concern about the danger of disease transmission.

2.2.2 Significance: Wastewater surveillance comprehensively detects and estimates the presence of pathogens by detecting and quantifying DNA and RNA markers from pathogens that are shed into municipal sewersheds. This method provides a holistic overview of the presence or absence of viruses, informs our understanding of the evolution and emergence of new viral variants, and provides indications of changes in community levels of pathogens. Through the collection of pooled sewage samples, wastewater surveillance provides a brief and quick view of population averages for target indicators at a greater frequency than traditional surveillance systems.[25] This approach aids in compensating for potential resulting bias in reporting positive cases to state public health departments. Wastewater surveillance can enhance individual and community knowledge by bringing awareness to the public health significance of infectious disease threats and providing valuable community-level data to inform public health action. The objective of this project is to defer to the emerging use of wastewater surveillance to identify differences in disease rates across communities and compare these findings to data retrieved from traditional healthcare monitoring systems to understand if differences are present in case ascertainment rates across communities and how state public health departments use this surveillance method as an adjunct monitoring tool that complements state-based notifiable disease surveillance systems- which are mandated systems used by health care providers to report cases to local health departments who then forward the disease report to the state health department and further informs the public health surveillance process.

To understand how wastewater surveillance complements public health surveillance, this research will examine wastewater surveillance data as an indicator to track and evaluate the relationship between mpox viral presence within wastewater and state-reported cases across a diverse metropolitan area. Furthermore, the study will rely on a long-established partnership with the GADPH to evaluate if the comparison to cases is different across four selected locations, which would be indicative of different ascertainment rates for cases by clinical testing across the city, understand whether surveillance data vary by communities due to varying sociodemographic findings, and determine if the sociodemographic factors modify the relationship between mpox viral presence within wastewater and state-reported cases, and describe how wastewater surveillance data supported their response to the 2022 mpox outbreak and facilitated public health action that promotes health equity.

2.3 Approach: To evaluate presence and trends of mpox at the population level (Fulton County, Georgia), trends will be evaluated using data on the concentration of mpox DNA in copies per gram of wastewater solids generated by Dr. Wolfe's WastewaterSCAN program and clinical data from the Georgia DPH using a comparative descriptive statistical analysis method. Data retrieved from WastewaterSCAN will be used to evaluate mpox trends from July 2022 to the present day amongst four Fulton County wastewater treatment plants (WWTP), including the Camp Creek Water Reclamation Plant, the RM Clayton Water Reclamation Plant, the South River Water Reclamation Plant, and the Big Creek Water

Reclamation plant. Furthermore, with approval from the Georgia DPH, clinical case reporting data will be retrieved from the Georgia DPH Notifiable Disease Surveillance System to assess mpox prevalence from July 2022 to the present. Concentrations of mpox and PMMoV targets will be acquired along with associated sewershed mpox incidence rates. Incidence rates will be compared to mpox RNA concentrations normalized by PMMoV concentrations, an indicator that accounts for the variation in fecal content of individual grab samples.[26] The social vulnerability index (SVI) data retrieved from the Centers of Disease Control and Prevention/Agency for Toxic Substances and Disease Registry ranks the social vulnerability of Fulton County. The SVI ranks individual social factors and groups them into four related themes- socioeconomic status, household composition and disability, minority status and language, and housing type and transportation- and yields one overall vulnerability summary rank. Percentile rankings range from zero to one, with a lower value indicating a low social vulnerability. For this research study, SVI rankings of minority status and language and socioeconomic status and overall vulnerability will be utilized. Lastly, a descriptive case study approach will be used to understand the Georgia DPH's perception of disease reporting preferences following the use of real-time WastewaterSCAN data following the 2022 mpox outbreak and how the use of wastewater-based epidemiological methods will be used in the future to support traditional disease reporting methods.

2.3.1 Data Sources: To do this, I will work with the following previously collected data, available through public repositories and data use agreements as described below.

2.3.1.1 WastewaterSCAN data from Fulton County, Georgia: Routine wastewater sewage samples, which are collected by participating wastewater plant employees three times per week, are obtained from four wastewater treatment plants, including the Camp Creek Water Reclamation Plant, the RM Clayton Water Reclamation Plant, the South River Water Reclamation Plant, and the Big Creek Water Reclamation plant from July 2022 to present. Within 48 hours of collection, wastewater samples are tested for genetic markers for mpox which demonstrates if mpox viral DNA is present in untreated community wastewater. The data also quantitatively measures mpox DNA in copies per gram of wastewater solids. These measurements have been shown to be related to the number of cases of disease in the community and aids in evaluating changes in the prevalence of infectious diseases on the population level.

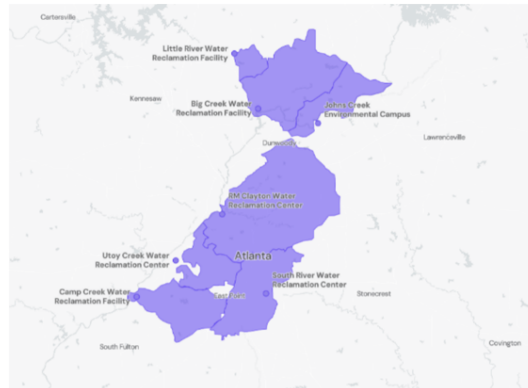

Figure 1. WWSCAN POTW sites within Fulton County, Georgia.

2.3.1.2 Clinical data on mpox cases in Fulton County, GA: In addition to the wastewater monitoring data, clinical disease reporting will be examined through a collaboration with the GADPH, which oversees the State Electronic Notifiable Disease Surveillance System (SendSS), which is an electronic disease reporting system. Cases residing within the sewershed boundaries will be summarized and counted. All Georgia physicians, laboratories, and other healthcare providers must report patients with conditions listed under the GADPH's notifiable disease condition reporting requirements based on a specific time period, depending on the disease reported.

2.3.1.3 Sociodemographic data: Sociodemographic factors, including race, income, and educational attainment- will be cross-examined with the wastewater surveillance data and traditional disease reporting trends to understand differences in case ascertainment among communities with varying sociodemographic factors. Data will be retrieved from the CDC/ATSDR Social Vulnerability Index (SVI) maintained by the Geospatial Research, Analysis, and Services Program (GRASP). The SVI is a database based on US census data. It links critical variables, such as socioeconomic status, household characteristics, racial and ethnic minority status, or housing type and transportation, that assist in understanding and visualizing various combinations of social factors that increase a community's social vulnerability index.

2.3.2 Data Analysis: Clinical data retrieved from GDPH's SendSS electronic data reporting system will be compared to the wastewater surveillance data from July 2022 to the present to determine the relationship between concentrations of mpox in wastewater and clinical cases. Nonparametric Kendall's tau and Kruskal-Wallis methods will test for associations and trends amongst sewersheds. Linear regressions will be performed to estimate the relationship between incidence rates and mpox concentrations normalized by PMMoV for each POTW.[27] The Spearman Rank Correlation and Kendall Rank Correlation will be used to determine the association between each socioeconomic factor and mpox cases, and the association between socioeconomic factors and wastewater viral concentrations. Multiple linear regression will be used to estimate the relationship between multiple independent variables, including socioeconomic status and racial and ethnic minority status, and a single dependent variable.[28] Data collection, organization, and average calculations will be performed using Microsoft Excel. All statistical analysis will be performed using RStudio Software.

2.4 Potential Challenges: Ongoing data analysis will be conducted by WastewaterSCAN and the Georgia Department of Public Health, and I do not anticipate any technical issues with obtaining the data. However, results from the WastewaterSCAN program show detection primarily in the summer and fall of 2022, and differences between sites may be hard to estimate due to low levels of a rare disease. Furthermore, I anticipate potential limitations with using Georgia Department of Public Health data due to differences in population datasets and plausible delayed processes in making the data available. The team is already working with the Georgia Department of Public Health to request access to datasets, and this data will be compared to data provided through WastewaterSCAN. Variations in patterns of infectious diseases can result in data scarcity, limiting comparisons. If presented with this challenge, I will prioritize work using a descriptive case study approach to evaluate stakeholders' perceptions of the feasibility of implementing wastewater monitoring to support early monitoring of infectious disease outbreaks.

SPECIFIC AIM 2

3.1 Background of Specific Aim 2:

3.1.1 Urban Flooding and Community Mobilization: The city of Atlanta remains highly racially segregated despite recent demographic transitions, and evidence suggests racially differentiated exposure to environmental hazards among Atlanta's marginalized communities.[29–33] The long history of socio-ecological segregation, including redlining and other discriminatory practices of the mid-20th century, concentrated African American and low socioeconomic residents to areas of higher environmental risk and has created inequitable conditions for racial minorities, making their communities more susceptible to natural disasters, urban flooding, and sewage and plumbing problems.[34,35] Research provides evidence of the effects of redlining on present-day environmental risks, including flooding and health exposure. The redlining housing policy pursued by the Homeowners Loan Corporation (HOLC) was conducted using maps to demarcate neighborhoods according to their perceived lending risks. Using this information, HOLC maps aided in assigning risk grades to discrete areas. These maps reflected lending risk characteristics, including housing age and prices and the racial composition of neighborhoods.[36] Although redlining was outlawed in the 1960s due to its discriminatory nature, novel evidence documents this policy's lasting effects on communities' exposure to environmental and climate risks.[36,37] Evidence suggests that environmental risks, including flood risk and heat exposure, significantly increase as the HOLC grade worsens for properties in HOLC areas. Furthermore, higher environmental risks are partly driven by a decline in environmental capital in redlined areas.[36] Combined with racial segregation and discrimination, these communities also suffer from the lack of attention to water and sanitation infrastructure, which produced years of uneven access to water and wastewater services, resulting in growing threats to human and environmental health.[38]

Combined sewer overflows (CSOs) present a significant public health threat due to the potential for pathogenic fecal bacteria to contaminate waterways that supply drinking water to Atlanta residents. Historically, Atlanta has relied on an antiquated combined sewer system to collect and transport rainwater runoff, domestic sewage, and industrial wastewater to the nearest sewage treatment plant. However, this sewer system has the potential to overflow following flooding and heavy storm events, discharging a release of stormwater, untreated human and industrial waste, and pollutants, presenting significant challenges as overflows can lead to property damage and health problems for the exposed populations.[29,38–40] [39,40]Although the construction of combined sewer systems is no longer permitted, existing stormwater collection and treatment systems continue to impact Atlanta communities. Atlanta combined sewer systems overflowed more than 1,925 times, dating back to 1988, primarily impacting African American and low-income communities in south and west Atlanta.[40]

Persistent urban flooding and combined sewer overflows (CSOs) in Atlanta continue to affect marginalized communities, exacerbating existing environmental burdens, health disparities, and structural inequalities. In response, these communities have established community-based organizations to identify priority issues as defined by residents themselves and to mobilize efforts toward finding solutions that address critical concerns.[33] In East and West Atlanta neighborhoods, for example, several community-based organizations have been established, including the Peoplestown Revitalization Corp, Environmental Community Action (Eco-Action), the Proctor Creek Stewardship Council, and the West Atlanta Watershed Alliance. These organizations have been working independently and in collaboration with other community organizations to address discriminatory wastewater treatment practices threatening residents' health and quality of life.[41]

3.1.2 Community Engagement in Public Health: Community-academic partnerships can serve as a catalyst for putting science into practice to improve community health by valuing community agencies as equal partners in developing, designing, and implementing projects.[42] This co-collaboration can provide benefits to the communities involved and strengthen all aspects of the research process by shaping the scientific community's relevance, rigor, and reach. In the environmental health sciences, for example, community engagement has promoted new lines of scientific inquiry and helped shape scientific fact-making by reflecting the cumulative impacts of environmental stressors faced by vulnerable communities.[43] Although the community-engaged research approach has been increasingly utilized, gaps remain in how this process is applied and how the success of partnerships is evaluated.[43]

3.1.2.1 Community Engaged Research: Community engagement is defined by the Centers for Disease Control and Prevention as the "process of working collaboratively with and through groups of people affiliated by geographic proximity, special interest, or similar situations to address issues affecting the well-being of those people."[44] Community engagement (CEnR) is a transformative concept that addresses the missing link to improving the quality and outcomes of public health research studies by engaging community members in the research process. However, it requires a long-term process that builds trust, enlists new resources, values contributions to stakeholders, creates better communications, and fosters longstanding collaborations.[45,46]

CEnR is presented as a continuum of community participation, starting with minimal outreach and moving toward involvement, collaboration, and shared leadership.[44,46–48] On the furthest point of the continuum, shared leadership, is where community-based participatory research (CBPR) resides, implying a bidirectional and equitable relationship between researchers and the community.[48]

In order to reduce the challenges of community participation in public health research, CBPR was developed and commonly cited, serving as the gold standard approach to CEnR.[49] CBPR provides foundational principles established to ensure equitable community members' involvement throughout the research process.[50,51] Through this approach, CBPR introduced a framework for research in which researchers, organizations, and community members collaborate on all aspects of a research project from start to finish.[50,52,53] In addition to CBPR, several models for community engagement in research exist, including empowerment evaluation[52], participatory or community action research[53], and participatory rapid appraisal.[54,55]

Although CEnR studies established metrics to assess the research rigor and adherence to CBPR principles, the metrics possibly created a rigid standard that unintentionally served as a barrier to CEnR due to variations in the quality of research methods and the actual degree of community engagement in the research process.[46,54] **3.1.2.2 Nine Guiding Principles of Community Engagement:** Recognizing that community involvement is essential to the identification of community health concerns and interventions, the Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry created a task force aimed at updating the Principles of Community Engagement. These are nine guiding principles for engaging community members in projects, providing tools for those leading efforts to improve population health through community engagement, and providing practical information on mobilizing community members to partner in research initiatives.[44]

Nine Principles of Community Engagement	
Principle 1	Be clear about the population/communities to be engaged and the goals of the effort.
Principle 2	Know the community, including its norms, history, and experience with engagement efforts.
Principle 3	Build trust and relationships and get commitments from formal and informal leadership.
Principle 4	Collective self-determination is the responsibility and right of all community members.
Principle 5	Partnering with the community is necessary to create change and improve health.
Principle 6	Recognize and respect community cultures and the other factors affecting diversity in designing and implementing approaches.
Principle 7	Sustainability results from mobilizing community assets and developing capacities and resources.

Principle 8	Be prepared to release control to the community and be flexible to meet its changing needs.
Principle 9	Community collaboration requires long-term commitment.

Table 1. CDC's Nine Principles of Community Engagement. Adapted from the first edition of the Principles of Community Engagement (CDC, 1997)

These principles are used to guide community-focused research and provide tools that aid in deepening one's understanding of how to improve population health through community engagement. The *Principles of Community Engagement* differ from other approaches, given they were developed to recognize the need for attention to the engagement of communities affected by health issues and promote the idea that engagement for health improvement can be initiated and led by the community rather than professional groups.[44]

3.1.3 Importance of Process Evaluation in Community Engagement Work:

Community engagement is based on ongoing co-learning to enhance collaborations. The evaluation of community engagement programs provides the opportunity to enhance these programs.[44] Evaluating the functioning of community-academic partnerships and their fidelity to community engagement principles is necessary to understand the relationship between these partnerships and achieving improved outcomes.[55] Comprehensive evaluation of community-based partnerships includes the evaluation of process objectives, which focuses on characteristics of the implementation process, impact objectives, and intermediary goals considered to attain the outcome.[56] Process evaluation methods to measure community participation include reviewing data sources, including participant surveys, event or activity logs, key informant interviews, focus groups, observation of meetings, and review of existing documents such as meeting agendas, attendance rosters, minutes, and annual reports.[57] Indicators of community participation include the opportunities and levels of decision-making, amount and duration of time devoted to goal activities, degree of local ownership perceived and/or achieved, representativeness of member and leader groups, satisfaction with the participation process, and achievement of long-term goals.[57] The measurement of these indicators is often used to produce a set of recommendations for program improvement focused on collaborative decision-making and governance. However, measurement of process indicators alone is insufficient, and there is an increased need for researchers to tie process evaluation to intermediate and long-term goal attainment.[57] Evaluation during program implementation could be used to inform corrections to program implementation or to give insight into the implementation process.[44]

3.1.4 The Peoplestown Pilot Project: In 2022, Dr. Marlene Wolfe and the Emory University HERCULES Community Engagement Core initiated a research project to address the community concerns regarding floodwaters and tap water following heavy rain events in the Peoplestown neighborhood of Atlanta.

3.1.4.1 Project Objectives: The study's objective was to generate preliminary data on microbial hazards in floodwaters and residential tap waters in Atlanta and on critical health risks and behaviors. This collaborative project focused on identifying hazards associated with floodwater and tap water sources in communities susceptible to increased flooding by characterizing disease burdens and health disparities. In addition to maintaining effective communication to ensure data sharing is provided, the Emory research team sought to collaborate with the Peoplestown community to leverage resources that will inform community mobilization for decision-making and social action. At the core of this community-based study is a beneficial partnership with the Peoplestown community, whereby community members' voices are heard and valued, and they become co-researchers who guide the research process. Process evaluation of this project is necessary to assess its effectiveness and efficiency. Conducting process evaluation on this project will assist in analyzing the procedures and workflows to identify areas of improvement and enhance its overall success.

To characterize community concerns and behaviors around flooding events, the Emory research team attended monthly community meetings led by the Peoplestown Revitalization Corporation. During this time, the Emory team shared earlier results with the Peoplestown community based on a 2016 pilot study that examined the Peoplestown floodwaters. From this, the Emory team shared potential next steps and asked the community how they wanted to proceed, which informed the current project's focus. The project focus is driven by collaborating with identified community members who have either expressed concerns about residential flooding and tap water quality or live in areas likely to be impacted by floodwaters. Those interested in participating in the project signed up to join the Peoplestown Working Group- a community-centered group appointed to participate in focus group discussions that 1) provided information on the frequency and location of flooding, 2) identified behaviors associated with flooding, and 3) increased the knowledge and perception of risks associated with flooding.

Additionally, the Working Group assisted in developing the recruitment process for community residents interested in collecting tap water samples needed to characterize tap water quality in homes before and after flooding events. Project participants were recruited via IRB-approved flyers, email correspondence, word-of-mouth, and community leader referrals. Participants will receive tap water sampling kits, including sampling protocols and tutorials that will guide them in collecting tap water samples. These samples will be collected by the Emory team and carried to the laboratory for processing. Following the analysis of samples, information will be shared with the Peoplestown community on the hazards associated with flooding in their neighborhood to support community action and to provide preliminary data for further collaborations on the hazards related to flooding.

3.1.4.2 The Need for Program Evaluation: To determine the effectiveness of the Peoplestown Pilot Project, program evaluation is necessary to determine whether the project achieved its intended goals and objectives. Evaluation offers insight and helps identify strengths and weaknesses in the project design, implementation, and management, enabling academic researchers to learn from successes and failures and make improvements for future direction.

3.2 Specific Aim 2 Objective and Research Questions: To explore the Peoplestown pilot project in depth regarding the effectiveness of community-engaged strategies**,** this aim will evaluate the planning and implementation of the Peoplestown pilot project. Given that the project focuses on assessing the impact of environmental exposures and how they impact human health at the community level, the *Principles of Community Engagement* were selected to evaluate the project's community engagement process. Although the Peoplestown pilot project facilitates a community-engaged partnership critical to initiating conversations between environmental health researchers and community members regarding urban flooding exposure, evaluating the planning and implementation of this study is necessary to determine if the study has met its objectives.[42,58] This aim seeks to answer the following questions:

1. How many Principles of Community Engagement were applied during the participatory process?

2. Were community priorities, resources, and needs effectively integrated into the project plan based on the Principles of Community Engagement that were applied?

3.2.1 Hypothesis: The planning and implementation of the community-engaged study adheres to at least five of the nine Principles of Community Engagement collaboratively identified by the U.S. Centers for Disease Control and Prevention, the National Institutes of Health, the Health Resources and Services Administration, and the U.S. Department of Veteran Affairs.

3.2.2 Significance: Evaluating the approach utilized in executing the Peoplestown Pilot Project serves to ensure accountability for community-engaged initiatives, assessing whether they achieve their intended outcomes and impacts. This evaluation provides a systematic method to determine if the research aligns with the needs and expectations of the Peoplestown community. Apart from identifying strengths and weaknesses in the approach, this evaluation aids academic researchers in refining their methods, strategies, and approaches to serve the community better and achieve desired outcomes. Furthermore, it has the potential to a) facilitate the collaboration between community partners and academic researchers by guiding efforts and shaping research priorities based on community needs and b) evaluate the sustainability of community-engaged research initiatives by analyzing their long-term impacts and identifying factors contributing to or hindering success. To gauge the effectiveness of the Peoplestown pilot project and its approach, this research will employ the nine Principles of Community Engagement as a guiding framework to understand the essential considerations for successful engagement.

3.3 Approach: A three-step methodology will be used to explore the Peoplestown pilot project in depth as it relates to the effectiveness of community-engaged strategies. This three-step approach was chosen to provide an example that affirms broader community-engaged processes that can be applied to other occurrences of environmental and social injustices.

3.3.1 Three-Step Methodology: Three steps will be employed to conduct the evaluation process for the Peoplestown pilot project, which are described in greater detail below.

3.3.1.1 Step 1: Document Review: Review documents that reflect the community engagement strategies and activities deployed during the project. A document review will be conducted to understand the step-by-step community engagement process carried out to facilitate the project.

3.3.1.2 Step 2: Create a Descriptive Timeline: Develop a descriptive timeline reflecting community involvement at all stages of the project. A document review will be conducted to develop a project timeline which is a visual representation of project tasks and activities.

3.3.1.3 Step 3: Evaluate the Application of the Nine Principles of Community Engagement: The project documents, which include project goals, meeting agendas, email and text communication, recruitment process, sampling protocol, project results, and report back, and the project timeline are the data sources that will be uploaded to and analyzed using MAXQDA- a computer-assisted qualitative data analysis software. The documents will be subjected to open coding by two investigators to extract thematic constructs. Content analysis will be conducted using a developed coding scheme based on the nine Principles of Community Engagement.

3.3.2 Data Analysis: The chronological sequence of the approach will be reviewed using MAXQDA, including a document review, using deductive codes developed based on the *Principles of Community Engagement* to code the text. Once documents are coded, the data will be explored further to look for patterns and themes and identify the frequencies of specific codes to determine how often specific codes have been applied to the data source. This process will be repeated for all data sources. Once all documents are correctly coded, code frequencies will run again to confirm results and generate a frequency table, providing descriptive statistics revealing the number of documents containing each code and the frequencies of specific codes. The next step in the analysis process will be to compare how frequently the *Principles of Community Engagement* were applied throughout the approach used.[44] Using the MAXQDA Code Relations Browser, the relationship between the principles and the type of approach used to carry out the project goals will be examined. Lastly, MAXQDA's Summary Grid tool will summarize coded data and compile it into a summary matrix. The resulting table will concisely summarize steps within the approach that demonstrates the Principles of Community Engagement.

Coded evidence will inform the development of a matrix, displayed below, that summarizes the principles of community engagement illustrated by the case study. The matrix will also include the rationale of the applied principles.

Peoplestown Pilot Project- Community Engagement Evaluation Matrix									
Data Sources	Principle 1	Principle 2	Principle 3	Principle 4	Principle 5	Principle 6	Principle 7	Principle 8	Principle 9
Project Goals									
Meeting Agendas									
Email and Text Communication									
Recruitment Process									
Sampling Protocol									
Project Results									
Data Analysis and Report Back									

Table 2. The Peoplestown Pilot Project- Community Engagement Evaluation Matrix

3.4 Potential Challenges. Ongoing data analysis will be conducted using MAXQDA, and I do not anticipate any technical issues with obtaining the data. The documents that inform the document review process were developed without considering project evaluation. This challenge can deviate from proposed outcomes that best meet the community's needs based on current circumstances. A structural coding process will be used to interpret various segments of text. To assess my data analysis, I propose utilizing the interrater reliability tool, where I will seek debriefing on my interpretations by conducting multiple rounds of reliability checks. One plausible challenge to this approach is identifying both knowledgeable researchers and those willing to dedicate themselves to coding lengthy transcripts. Also, differences in coding interpretation can lead to loss of context, data fragmentation, and the risk of overlooking uncommon codes. This challenge will be addressed by soliciting support from my project team members to assist in the coding process. After coding the transcripts, we will interpret each text segment and then calculate the level of concordance to determine intercoder reliability and agreement. If differences are present, the method of the negotiated agreement will be used to reconcile said differences by recording how many differences were reconciled, how many disagreements prevailed, and how reconciliations will be achieved. This process will be repeated for multiple rounds of reliability checks.

RESEARCH IMPACT

Many urban regions throughout the United States are susceptible to environmental health hazards driven by various factors, including natural disasters, urban flooding, and aging infrastructure.[1] Urban communities continue to experience flooding and heavy rainfall, and water infrastructure networks such as combined sewer systems more frequently become overwhelmed, resulting in sewage overflows.[40,59] Elevated levels of pathogenic bacteria and viruses have been evaluated in floodwaters, and flooding and combined sewer overflow events have been associated with enteric and respiratory disease outbreaks.[60–62] Although studies have characterized microbial hazards in floods, few have 1) utilized alternative surveillance methods to understand how case ascertainment is shaped by hospital accessibility and demographic factors within communities already facing environmental burdens and 2) evaluated CBPR partnerships to ensure that success in following community engagement principles fosters long term outcomes that will contribute to improved community health and quality of life. Through diverse methods, results from this work will demonstrate how alternative surveillance methods can complement traditional disease surveillance in efforts to enhance pathogen surveillance and inform public health response. Furthermore, this research will determine appropriate strategies for those initiating community engagement processes to promote community-engaged environmental health promotion and research.

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