Implementation of Gray vs. Green Infrastructure in Urbanizing Cities in Emerging Countries: A Case Study of Perungudi, Tamil Nadu, India

Priyanka Venkatesh

ABSTRACT

Water management has been a priority at an international scale with increasing water scarcity. There is a discernible difference in infrastructural implementation based on the economic background of each country: developed nations are opting into green infrastructure and emerging countries are investing in gray infrastructure. Perungudi is a small suburb of Chennai, the largest city of the Indian state of Tamil Nadu. Due to rising urbanization and poor land management practices, much of Perungudi's natural wetland landscape has been reduced to provide space for new gray infrastructure for water management. This new infrastructure came into question in 2015 when Chennai experienced record-high levels of rain; new retention walls, dams, and levees were all overwhelmed, causing deadly floods. In order to contextualize the differences in infrastructure implementation, I conducted a case study of Perungudi. Using MODIS NDVI data and Landsat 5 images I quantified wetland reduction in the last decade to see if motivations to implement green technology had changed. I observed that in the last decade there has been a significant reduction in the amount of vegetation and wetland area. I used Google Trends to observe if attitudes towards infrastructure had changed in the region at a local and national scale and found that concerns about flooding were mostly at the state level. Finally, I surveyed a local community in Perungudi to understand the gravity of the 2015 floods and found that several residents of the community felt that government support was insufficient and that the current infrastructure was inadequate.

KEYWORDS

stormwater management, urban floods, wetland loss, concrete, environmental engineering

INTRODUCTION

In an increasingly exacerbated global climate crisis, water is now a considerably scarce resource due to an average reduction of precipitation in certain regions, water pollution, and excessive water consumption (Li, W. et. al, 2020, Liu, J. et. al 2017). Concerns have driven the need to innovate new ways to conserve, control, and move water resources to maintain productivity and human health in highly urbanized areas (Hanoon, S. K. et. al 2022). Worldwide, governments are facing major decisions on how to respond to this water crisis; however there is no consensus on what technologies should be pursued at an international scale. A quantifiable difference exists between western countries and countries that are currently considered "emerging." This "emerging" status stems from the economic development of these countries, derived from factors such as systemic presence (in terms of GDP, population, and exports), market access, and income levels, all measured by the International Monetary Fund or IMF (Duttagupta, R., and C. Pazarbasioglu 2021). The difference in technological pursuits in developed and emerging countries lies in the implementation of green infrastructure vs. gray infrastructure along with government aid in implementation. Various case studies of developed western countries report a general push towards the expansion of green technology. This is due to growing research illustrating how prior implementation of gray infrastructure has led to a degradation of natural environments and currently causes issues of pollution and water contamination (Sinkhonde, David 2022, D. Jacques et. al 2010). This push for green infrastructure is typically seen in post-industrialized cities, the same cities that once required gray systems to urbanize.

While there is evidence to support the use of green over gray infrastructure, many growing cities in emerging countries are opting into western-conceived methods of expansion, graying their green to grow quicker (Nasr, M., and A. N. Shamroukh 2020). Finding a way to sustainably grow a city with direct implementation of green systems over gray systems altogether could be the solution for emerging cities worldwide. (Haq, S. M. A 2011). There currently isn't enough research assessing cities in these emerging regions and there is little to no contextualizing of why these countries don't opt into green infrastructural adaptations immediately. This review aims to identify the major differences in approaches to stormwater and flood management from this lens, and points out a need for more case studies to be done to

assess the potential for implementing green technologies in growing cities in emerging countries. It also aims to focalize the clear post-colonial sentiments of regions, and the seemingly up-hill battle of motivating leaders to reverse their gray-green infrastructure ratio.

Most economically-developed nations have had their hand in developing various gray technologies in order to rapidly industrialize. However, many emerging countries are currently attempting to follow this same path of establishment, and in the process, are tearing down current natural "green" infrastructure to pave the way for concrete systems. Internationally, governments are at different stages in terms of priorities; some governments are prioritizing surmounting health concerns on top of stormwater issues while other governments are prioritizing the catalysis of urbanization. While these two priorities are seemingly different, the core responsibility of all governments is to save water, which can be done through sustainable methods and city planning. Based on the qualitative analysis of case studies where green infrastructure was implemented over current industrial gray systems, I observed that most of these studies are done in cities in predominantly white, European, and wealthier countries. Typically, these case studies cite governmental motivations for the betterment of populations as a motivating factor for the implementation of such green initiatives to manage stormwater, as well as several citations linking health, both human and environmental, as being a proponent of change to combat internal issues of oppressive systems. The same, however, cannot be said for less wealthy cities in non-white regions, where designing for green spaces is seen as a financial burden and a hindrance to economic growth.

To address this gap, this study will aim to tackle the following questions: **CRQ:** Is there growing potential in implementing new green infrastructure in place of growing gray infrastructure for proper stormwater management and flood mitigation in regions undergoing urbanization? To explore this further, I framed my research into three sub questions: **SQ1:** What are the differences between green and gray infrastructures and what are the similarities between cities that are currently implementing green infrastructure over gray infrastructure? **SQ2:** What factors affect implementation of types of infrastructure? **SQ3:** What are the potential barriers to implementation?

EXTENDED INTRODUCTION

Background

"Gray" vs. "green" infrastructure: a look at western countries

The first matter to be addressed is the differentiation between green and gray infrastructure, and the motivations and hindrances of implementing green over gray infrastructure. Gray infrastructure, specifically with regards to water quality and stormwater retention, is typically a network of canals, pipes, dams, and retaining walls aimed at slowing down the flow rate of stormwater in order to mitigate floods and reduce pollutants from entering waterways (Nicholas Institute). Developed countries have historically used gray infrastructure to urbanize. One example is the United States, which has green-lit the construction of over 12,000 kilometers of levees in Upper and Lower Mississippi River Basins and over 14,000 kilometers of levees in California for flood management (Hamlin, S. L., & Nielsen-Pincus, M. 2021). While gray infrastructure played and continues to play a pivotal role in urbanization, it has several flaws. One such flaw is the 'gray' part of this infrastructure, which involves mainly concrete. Most concrete contains lime for higher strength, which leaches into soils and increases the pH, negatively impacting local biodiversity. Furthermore, concrete exacerbates global warming through its production, yielding about an 8% increase in CO_2 emissions annually with the production of cement (Sinkhole, D. 2022).

Due to these concerns, several cities in western countries have moved away from the use of concrete and towards a new 'modern' innovative solution to managing stormwater: green infrastructure. Mark A. Benedict and Edward T. McMahon define green infrastructure as the support system of the United States, a system made up of interconnected waterways, wetlands, and wildlife habitats that support native flora and fauna and maintain natural ecological balances that help maintain the health of communities (Benedict et. al 2002). This upwards trend in the use of green infrastructure and corresponding terminology is fairly evident in the number of articles that discuss the greening of urban environments in countries similar to the United States in terms of economic development. One such article discusses the importance of implementing green infrastructure and green spaces in new designs for urban spaces, describing the motivations

and government support for developing a sustainable city that centers the concerns of environmental and human health (Wang et. al 2022). This study focuses on the Ruhr Metropolitan Area in Germany, which happens to also be the largest metropolitan area in the country. Another such article discusses the implications of designing for green spaces in Northern Italy, yet another European nation. The authors aim to corroborate new "network scenarios" in order to maximize the positive effects of preserving green areas (Staccione et. al. 2022). A study of cities in the United Kingdom argues for the importance of green spaces and provides plans to alter systems in order to manage stormwater in these concentrated areas (Ellis, J.B 2013). These are only a few of the many studies conducted in western countries and regions. It is important to note that most of these studies not only include the importance of moving away from gray infrastructure, but also provide plans for implementing green systems. From the multitude of studies, it is evident that regions that revolutionized industrialization such as the United States or Germany via gray methods are now set on redevelopment in order to address concerns of environmental health and safety.

Emerging countries:history of industrialization and infrastructure in India

Like western countries, emerging countries have also had a history of implementing gray infrastructure. Much of this implementation has been the result of colonization, such as in India, where the heavy usage of gray infrastructure for urbanization was a direct result of British rule. The use of reinforced concrete, made of Portland cement and steel, grew substantially with the establishment of manufacturing plants for both cement and steel starting in 1914, making importation from Europe no longer necessary. Early on, engineers were aware of the technical challenges of building with concrete in India, especially given the effects high temperatures have on curing time and cracks formation (Tappin, S. 2002). However, these challenges didn't hinder the development of large infrastructure projects. Engineers continued to impose European design principles and standards without modifications to Indian landscapes (Broich, J. 2007). In the context of water management and storage, several water towers were built as a means of supplying water to the growing population (Tappin, S. 2002). Thus, a colonization-influenced blueprint for expansion was created at the expense of proper research and development of

strategies to build in India, leading to not only gray infrastructure, but poorly designed infrastructure.

Key themes

Addressing differences in the implementation of green systems of water management

The principle of mitigating floods and pollution can be reduced to reestablishing much of the same natural infrastructure needed to control nutrient uptake and pollution reduction in the environment. This 'green' infrastructure mostly occurs in wetlands and estuaries, where nitrogen-fixing bacteria uptake much of the excess nitrogen in streams, where natural flood pans hold and retain water, and where the soil is rich with nutrients that make the environment ripe for biodiversity (Benedict et. al 2002). This initial green infrastructure is what drew civilizations to form near river beds with these natural flooding cycles, such as in Mesopotamia and Egypt (Mabrouk 2013).

Due to current geo-politics, many of these same regions are now in favor of gray infrastructure. Brazil, Russia, India, and China, or what the IMF defines as BRIC countries, have had significant growth in economic development in the last few years, which has contributed to rapid urbanization (Duttagupta, R., and C. Pazarbasioglu 2021). This urbanization has led to an even larger investment in water infrastructure. Due to the establishment of infrastructure to produce 'gray' materials, a large portion of this new water infrastructure in India is gray. As of 2021, India's national government had 21 dams undergoing the appraisal process by the Central Water Commission (Press Information Bureau 2021). But these systems do not tend to provide sustainable, long-term solutions, and the reduction of wetlands due to urbanization is single-handedly leading to more urban flooding. (Vazquez-Gonzalez, C. et. al. 2019).

There are generally fewer case studies done regarding the implementation of green infrastructure in cities in emerging countries. And as for the case studies that do aim to address this gray vs. green debate, they often cite governmental challenges as running opposition to implementing more sustainable growth strategies. One article that aims to point out these challenges is a case study done on the political implications of creating sustainable systems for water management. In a case study of Santo Domingo, Dominican Republic, implementing

greener systems of water management was difficult due to the lack of an effective institutional push for responsible stormwater management, along with the lack of communication between infrastructure departments, planning institutions, communities, and social organizations (Sletto et. al 2019). Another case study done in Alexandria City, Egypt indicates that although there is public interest for green infrastructure practices, there are no political motivations (Nasr et. al 2020). These studies, along with several others, all seem to cite the same struggles of motivating a government so hard set on economic prosperity to move towards green infrastructure development. Yet in reality, much of the new innovations of green infrastructure are already present in these same regions and a plan to develop sustainably could be a viable option for development.

Methodology

A study of Tamil Nadu, India

While many studies regarding water management technology in cities in predominantly western countries exist, there aren't as many case studies done in cities from emerging countries. India boasts several urbanizing cities and regions, but is currently undergoing water crises in these same regions (Indira Devi, P. 2022). Furthermore, due to geographical differences, cultural barriers, and the general diversity of the country, each region can be assessed in its own case study. I decided to focus my review on Tamil Nadu, South India, as several cities in this particular state in India have grown since the boom of the IT industry (Murali 2021). Currently, Tamil Nadu has the highest proportion of urban population in the country at about 9.3% (Krishnan, N 2022). Its climate and situation next to the coast makes it suitable for swamp and marshlands. Some prominent natural wetlands in this region are the Pallikaranai wetland and the Sholinganallur Marsh Lands. Although the Pallikaranai wetland was about 8000 hectares in size in the 20th century, it has been reduced to smaller discontinuous patches of green space (Jagadisan 2019).

This reduction in wetlands, mostly due to urbanization and poor land management practices (Satish, H. and Satish K. 2021), has gained some attention in academia. In my research, I found one GIS study, whose primary focus was on soil and water quality reduction, that aimed

to assess the damage due to poor land management practices on the wetlands (Mageswari, S. et al 2017). I also found one study addressing green infrastructure and urban design by illustrating the potential to interconnect waterways in order to mitigate the damage of floods. This study hinged on a graphical schematic of water systems in Chennai (Bedford, N. E. 2021). Thus, currently available research considers the possibility of this region becoming more "green" and emphasizes the importance of wetland restoration.

While current studies provide analyses on wetland importance and groundwater pollution, there are some fundamental gaps in research. In my review I found fewer than five case studies that specifically mention green infrastructure practices. This is quite a stark contrast to the number of studies of cities in western regions, especially given that Tamil Nadu holds almost 10% of the total urban population of India, a population of over 35 million (Envis Center Tamil Nadu 2022). Of the case studies I read, none mentioned the current usage of gray infrastructure vs. green infrastructure specifically (Jagadisan 2019, Bedford et. al 2021). In the GIS study I found, there was no mention of infrastructural concerns. And finally, the graphical approach to green infrastructure, while innovative, had a delivery that was difficult to follow, and didn't include the same degree of detail that case studies in western cities include. Additionally, this study does not address the current context of urbanization as it relates to the loss of green infrastructure, and the motivations behind pursuing the implementation of green vs. gray infrastructure in this region.

All of these factors only illustrate the necessity for a significant increase in research on not only the region, but also regarding green infrastructure and wetland preservation in order to mitigate this damage before it becomes too extensive. This minimal research also draws to attention a very common issue with implementation of green infrastructure in regions such as Chennai, or Alexandria City, or Santo Domingo: a general lack of support and resources despite the growing needs of an urbanizing area. Based on the qualitative analysis of case studies where green infrastructure was implemented over current industrial gray systems, it is clear that most of these studies are done in cities in predominantly white, European, and wealthier countries. Typically, these case studies cite governmental motivations for the betterment of populations as a motivating factor for the implementation of such green initiatives to manage stormwater, as well as several citations linking health, both human and environmental, as being a proponent of change to combat internal issues of oppressive systems. The same, however, cannot be said for

less wealthy cities in non-white regions, where designing for green spaces is seen as a financial burden and a hindrance to economic growth. In cities such as Alexandria City, Egypt and Santo Domingo, Dominican Republic, the government operates in direct opposition to green infrastructural changes, instead choosing to focus on ways to escape the title of "emerging" by trying to develop fast and economically favorable gray systems to manage water (e.g dams, canals).

METHODS

Study site description

In order to understand the potential barriers in motivating certain regions to adopt green infrastructure, this research will focus on conducting a case study of Perungudi, a suburb in Tamil Nadu. Once a small village, Perungudi is now a growing suburb south of Chennai, and its urbanization has been part of the greater urbanization trend in South India due to the steady growth of the IT industry (Vaddiraju, A. K. 2022). Perungudi's climate and situation along the coast makes the region home to natural waterways and marshlands, most prominently of which are the Pallikaranai wetland and the Sholinganallur Marsh Lands. The Pallikaranai wetland, as of the 20th century, was about 8000 hectares in size, but now has been reduced to smaller discontinuous patches of green space (Jagadisan 2019). Rapid urbanization has also promoted uneven development in the region, with smaller clusters of makeshift homes sandwiched between larger subdivisions (Murali 2021). This expansion has allotted for a need for more enhanced water management, yet instead has consequently led to an exponential reduction in preexisting green infrastructure (Jagadisan 2019).

The issues of urbanization, water management, and infrastructure were exacerbated in December 2015, when strong El Niño conditions, bolstered by the warm air of the Bay of Bengal, led to record levels of rainfall (Sriram, P. and S. Shekhar 2016). The remaining natural waterways and drainage systems were overwhelmed, and the gray systems of retention walls and storage tanks were unable to handle the sudden increase of water. A primary example of this occurred at Chembarambakkam Lake, a rain-fed reservoir and a large source of Chennai's water. Record levels of rain threatened lake overflow, forcing the government to release water to avoid

damage to the lake's dam and retention walls (Rajendran, D. 2021). What resulted was a positive feedback system where already overwhelmed natural waterways flooded, causing destruction.

Besides flooding, this region has become an emerging concern in the last decade due to its major landfill, situated directly in one of the largest swamps in Chennai (Satish, H. and Satish K. 2021). However, while available papers consider the necessity of becoming more 'green' due to groundwater contamination and pollution concerns (Rajendran, G., Rooby, J., & Govindan, V. 2023), there are few studies that address implementing environmental policies to reduce the current green infrastructural destruction. Furthermore, of the case studies I read, none mentioned any prioritization of specifically gray or green infrastructure (Jagadisan 2019, Bedford et. al 2021).

Geospatial data analysis

Given the limited amount of research available for the Perungudi region, I approached my case study through multiple methods of inquiries and analysis. First, I conducted a qualitative analysis of available USGS data over time to contextualize the wetland destruction in Perungudi. This analysis took a similar approach to the concentric ring and grid analysis methods used for characterizing urbanization in Latin American cities, in which the density of urban landmass was calculated by finding the area of urban land and dividing it by the area of buildable land [$Dens=S_{(urban\ land)}/S_{(buildable\ land)}$] (Wu, S. et. al 2021). In my study, I observed the density of wetland by dividing the wetland area by the total area, which was consistently set to 20 square kilometers.

I also conducted a quantitative analysis of the fluctuation of vegetation by analyzing MODIS NDVI data at 16 day intervals of a distance of 500m each month between 2013-2023. This data range was chosen based on available data and prioritization of recent data. Here, NDVI refers to the Normalized Difference Vegetation Index, used to quantify the vegetation greenness by observing the visible and near-infrared light that is reflected by plants containing chlorophyll (NASA). The NDVI is calculated as a ratio between red (R) and near infrared (NIR) values as (NIR - R) / (NIR + R), and valid values range from 0.0 - 1.0. It is important to note that the lack of studies in the region placed limitations on the available data for both aspects of geospatial study.

Policy analysis

Next, to assess what current strategies have been employed addressing the loss of green infrastructure and the implementation of gray infrastructure, I conducted a brief review of policies enacted within the last twenty years. This review analyzed local and state policies passed that tackle addressing environmental concerns in the region. The goal of this policy review was to assess the motivations at the local and state level to address issues specific to infrastructure, and to understand the priorities of the local government.

Media analysis through Google search trends

I also conducted a review of the level of interest in the floods through Google search trends. I did this to assess the local, state, and national levels of attention to this flooding crisis and attitudes to infrastructural revival in and after 2015.

Surveying local residents

Finally, I conducted a survey of local residents in order to understand their personal motivations and concerns with the current green infrastructural loss, tied to the sentiments specifically surrounding the green vs. gray infrastructural debate. I surveyed residents of Green Acres, a development next to Perungudi Lake, which was hit very hard by the lack of proper infrastructure in 2015 when the entire subdivision flooded. This survey gathered responses on sentiments regarding the 2015 floods and lack of infrastructure.

RESULTS

Geospatial data analysis

In my review of 'green-ness' of landmass, I analyzed the earliest available imagery. I observed that without any calculation, there was a significant loss in 'green-ness' from the year

2000 to 2019, the most significant loss occurring between the years 2000 and 2005. I set my area of study to 20 km^2 in order to standardize my approach.

Figure 1. Landsat ETM+ C2 L1 images of October 2000, March 2005, April 2011, February 2015, January 2018, and May 2019

In my analysis of aerial imagery, I overlayed concentric circles of equidistant spacing over the Landsat ETM+ C2 L1 imagery taken from USGS's GloVis feature. I then divided the

circles into squares by drawing lines from the centroid of the land mass and counted the total number of squares in each image that were green. The specific images I chose for this analysis were one from October 2000 since this was the earliest available image whose pixels were small enough to be zoomed into and February 2015 since this image was most close in time to the flooding incident of December 2015. The results of this analysis are below:

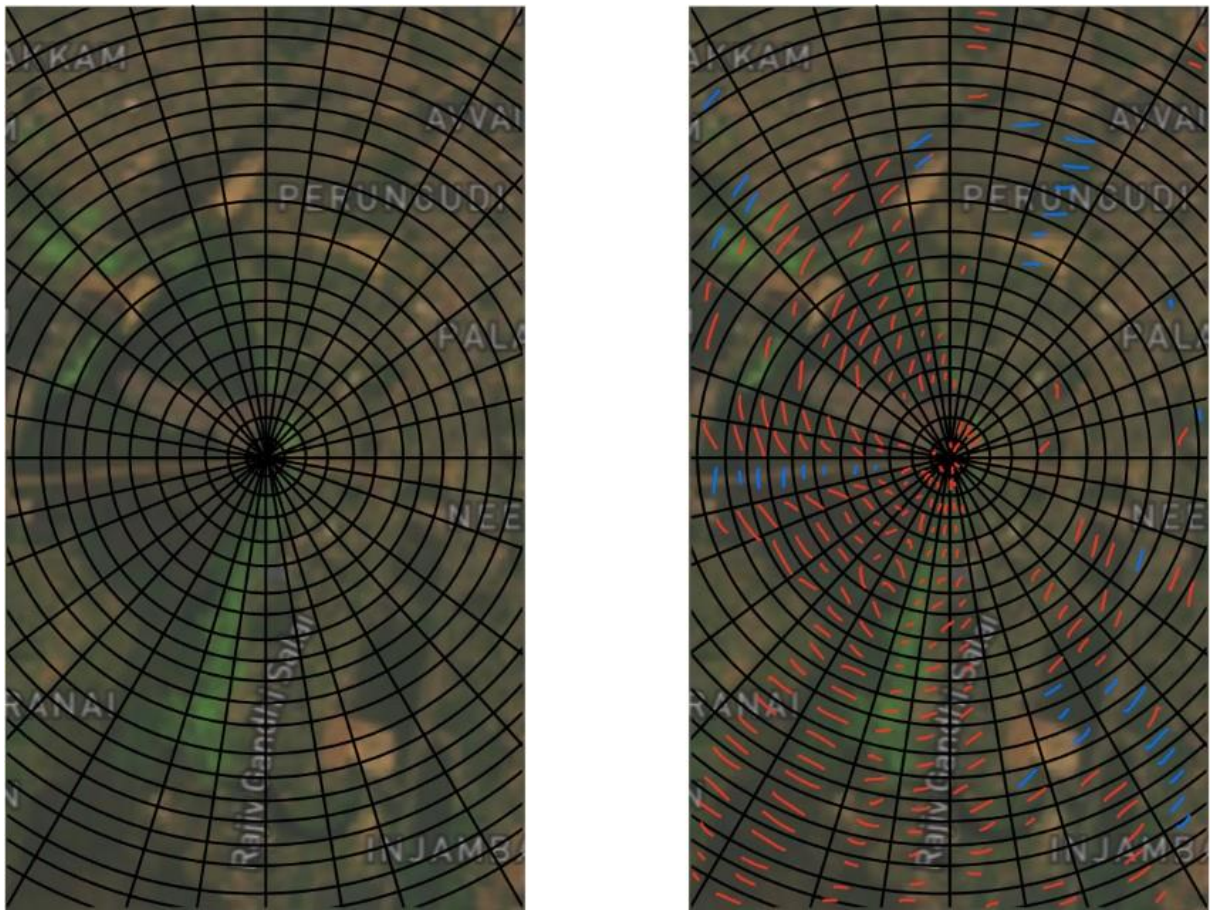

Figure 2A. Wetland density for October 2000 calculated from $Dens=S_{(wetland)}/S_{(total\ land)}$

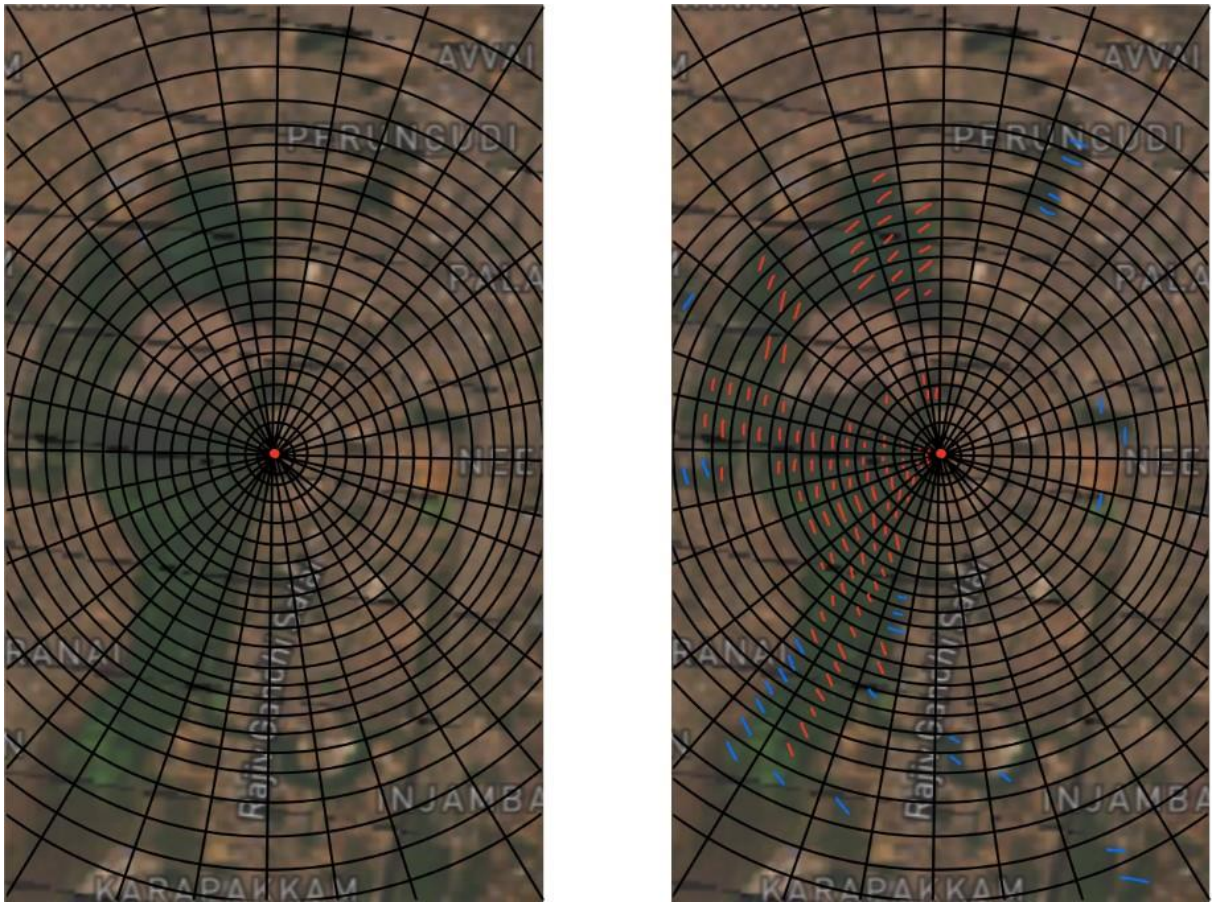

Figure 2B. Wetland density for February 2015 calculated from Dens=$S_{(wetland)}/S_{(total\ land)}$

For both images, there were a total of 556 squares which each corresponded to 0.036 km^2 of area per square. The red lines represent squares where the entire square was a darker green, and the blue lines represent squares where only half of the area was green. In order to standardize this approach, the only green that was counted was the darker shade. For October 2000, there were 240.5 green squares, and the density was calculated to be $240.5 \div 556 = 0.43$ or 43%. For February 2015, there were 124 green squares, and the density was calculated to be $124 \div 556 = 0.223$ or 22.3%. The percentages indicate that of the total land area in 2000 and 2015, 43% and 22.3% of the land respectively was covered by 'green-ness.'

Available NDVI data was used to quantify the changes in 'green-ness' over time. I focused on trends in the last decade from 2013 to 2023 because this was the only available data in the database and also to track recent changes in vegetation. Below are the results overlaid onto one graph:

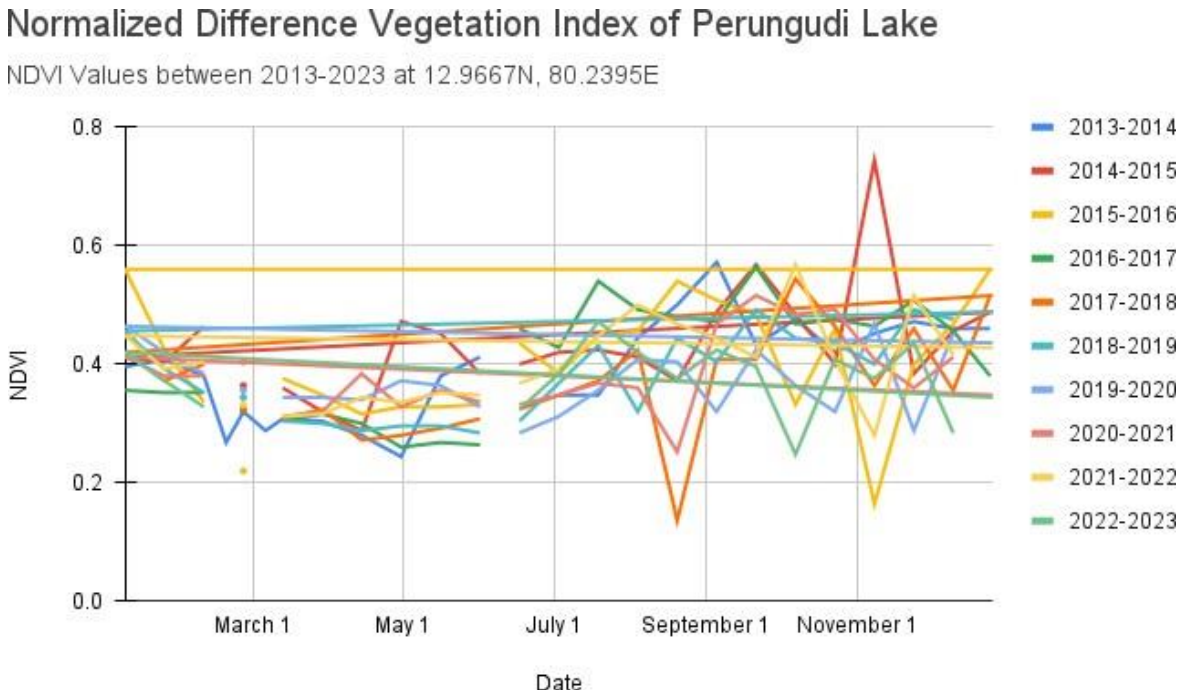

Figure 3. Normalized Vegetation Density Index (NDVI) 2013-2023 of Perungudi Lake

The peak of this data occurred in November 2014 with an NDVI value of approximately 0.77. The lowest amounts of vegetation occurred in September 2020 and November 2021 with NDVI values of 0.16 and 0.18 respectively. No data was available for most years during March or June.

Policy analysis

I looked at water and infrastructural policy passed at the governmental level to understand current political motivations in passing large infrastructural legislation. I narrowed my search to policies passed in the state of Tamil Nadu from 2013-2023, similar to the time range set for NDVI data in my geospatial analysis. In these years, there were a total of eight policy notes that were written by different departments, three of which were from the Public Works Department (Irrigation), three from the Municipal Administration and Water Supply Division, and the others from the Environment and Water Resources Departments. The contents of these notes all include various levels of environmental concern and wetland conservation. In a

2014 policy note from the Environment and Forests Department, Minister of Environment Thoppu N.D. Venkatachala writes:

> "Environmental preservation would encompass the entire ecological footprint of human activity and it would include increasing forest cover, protection of wetlands, conserving groundwater…in general maintaining the ecological balance across the entire State" (Policy Note Demand No. 15).

More sustainability objectives were mentioned, including in a 2022-2023 policy note that refers to the 2030 Sustainable Development Goals set at the UN General Assembly. Target 6.6 states that restoration and protection of "water-related ecosystems" such as wetlands should occur by 2020 (Sustainable development goals: United Nations Development Programme).

Several investments in gray infrastructure were also made in this ten year period. In a policy note from 2017-2018, the Public Works Department discusses the construction of several new dams and retention walls, totalling millions of Rs. One such project is the Tamil Nadu Irrigated Agricultural Modernisation Project, proposed in 2017 and funded by the World Bank, which included the investment and construction of new gray methods of managing water. In this project proposed by the Water Resources Department, the rehabilitation of 4,778 tanks, construction of check-dams and artificial recharge wells, and the improvement of irrigation channels summed to a total Rs. 2,195 crore investment (Policy Note 2017-2018, Demand No. 40).

Media analysis through Google search trends

To contextualize media coverage and public interest in the 2015 floods, I used Google search trends data of terms such as "Chennai Floods" in a two month span. Since the flooding occurred during the first week of December 2015, my search was limited to trends between November 30 and January 30. I also researched the same search term one year and five years after the flooding to assess relative relevance. Down below are the results of this search:

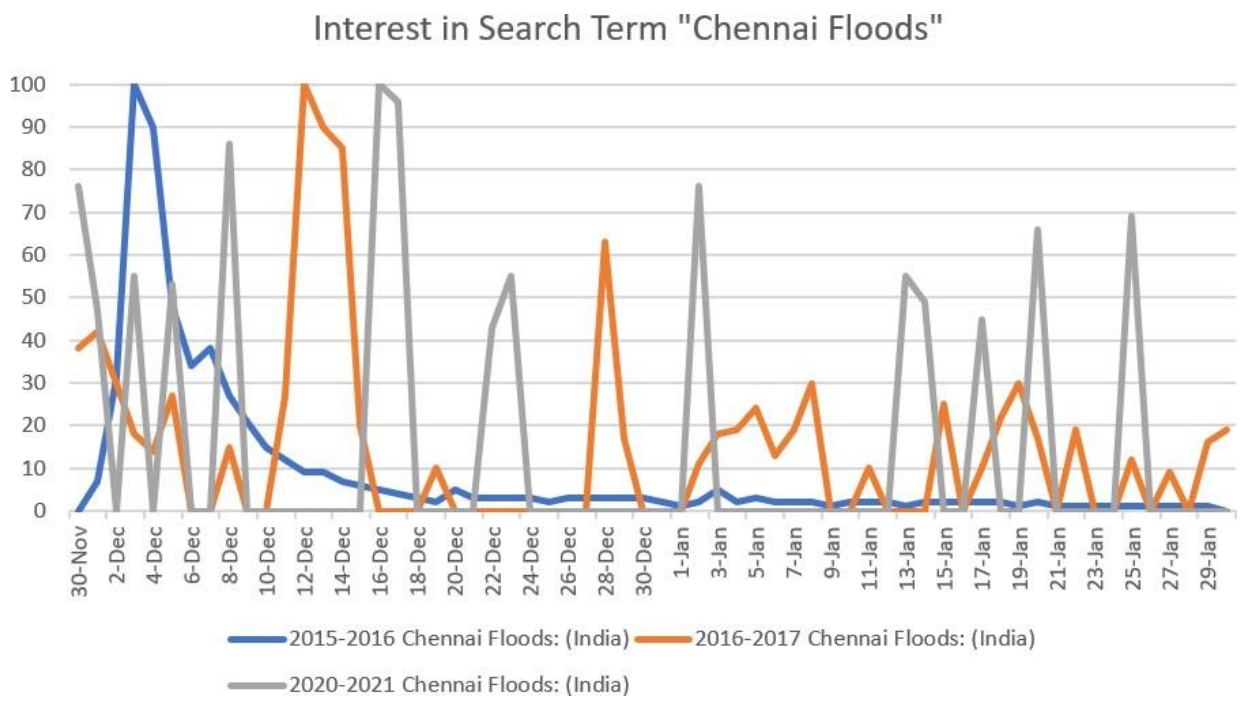

Figure 4A. Frequency of Search Term "Chennai Floods" Between November 30 and January 30

Interest was scored on a scale of 0 to 100 where 100 indicated that the search term reached its peak popularity. Peak popularity was reached on December 3, 2015, December 12, 2016, and December 16, 2020. The average popularity scores for 2015-16, 2016-17 and 2020-21 were 9.217, 14.823. And 15.661 respectively.

I then looked at the popularity of the search term "Chennai Floods" by region in a two month span surrounding the flooding from November 30, 2015 to January 30, 2015 to assess the popularity at a national level. Each region was provided a popularity score out of 100 where 100 indicates that the search term analyzed was the most popular searched term in the specified region.

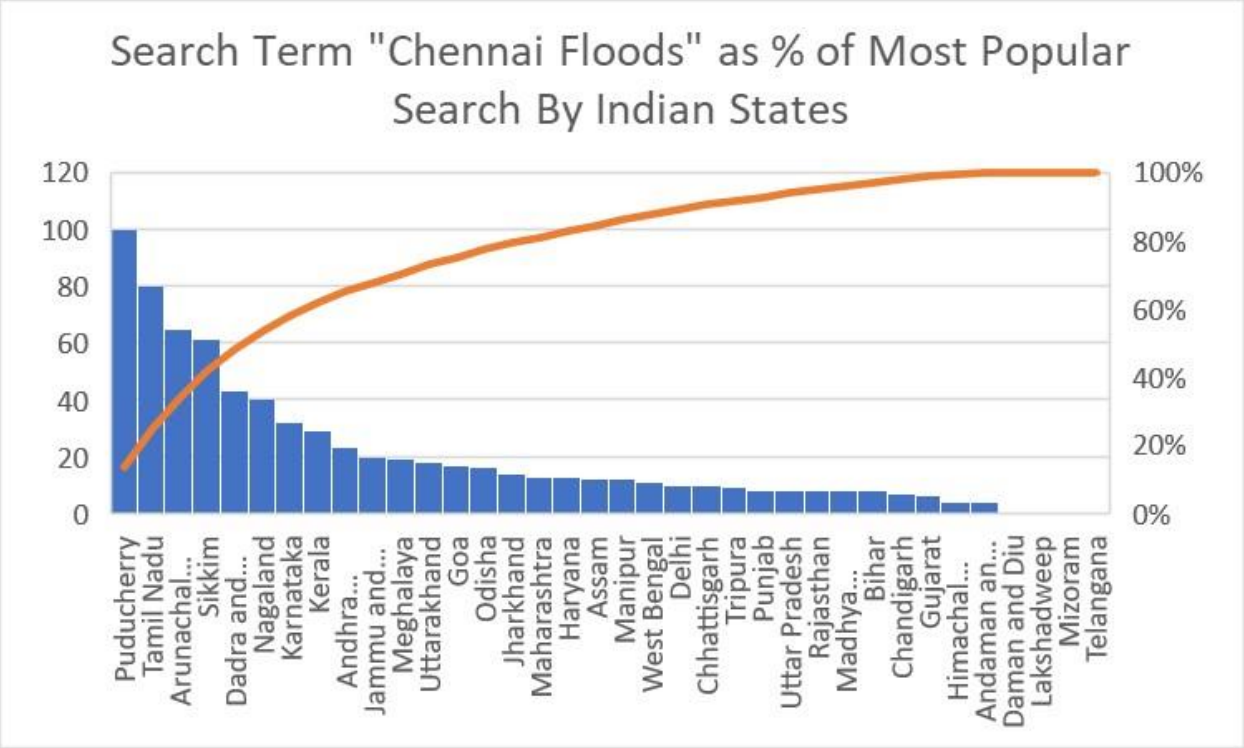

Figure 4B. Search History of "Chennai Floods" as Total % of Most Popular Searched Term, By Indian State, November 30, 2015 to January 30, 2016

The search term gained most popularity in Puducherry and Tamil Nadu, which were the states most affected by record high levels of rain, with each state scoring a maximum popularity score of 100 and 80 for the term.

Surveying local residents

In my survey of residents of Green Acres, I managed to get a total of eight responses from different residents of the total community. Questions that were asked included summarizing experiences with the 2015 floods, as well as sentiments on the level of government support that was provided regarding infrastructure. The results of this survey are shown in Table 1 and Figure 5. When asked about experiences during the 2015 floods, residents generally reported having no electricity or access to clean drinking water.

Table 1. Results of survey of Green Acres residents. Residents were asked to briefly describe their experience with the 2015 Chennai Floods.

Survey Responses
During the floods water had started collecting in our house after a week of rain because we lived in a low rise property. So we had to move away for weeks. Current was always out during that time. The Perungudi Lake and the sewage water started overflowing and getting mixed together which made the water unsanitary and unsafe to be around. Due to the strong winds, a large tree fell on top of our garage.
The 2015 floods were nothing like I have experienced in my lifetime living in Chennai city for 42 years of my life.
We were flooded in saligramam chennai 93
Had to survive without electricity and connectivity for more than 3 days which was challenging
Was unexpected and was deeply upsetting to see what people were going through. Grateful to God for keeping family members safe.
Water water everywhere but no drinking water
Was a surprising black swan event. Rains flooded and blocked many schools, parks, homes, etc. Many reported seeing dead fish on roads in the weeks after, which was disturbing.
Vacated our home due to rising flood waters, disconnection of power and water.

Five of the eight respondents reported some degree of frustration with the government's assistance during the 2015 floods, with some saying that the government's lack of preparedness was the main reason for the long recovery period following the floods. These results are summarized in Figure 5.

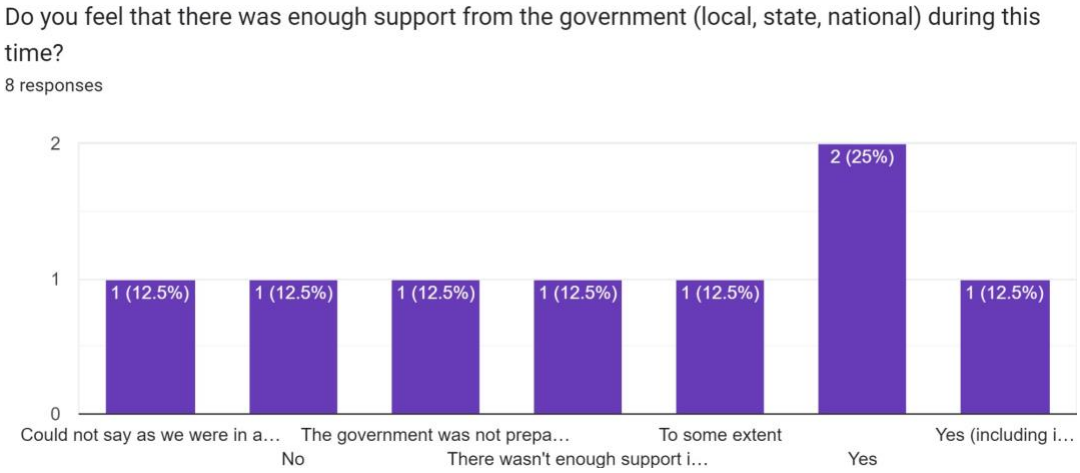

Figure 5: Survey results of Green Acres residents on if there was adequate support from the government during the 2015 floods.

DISCUSSION

Introduction

Modern water management in India was heavily influenced by British colonial rule in the 1900s, when engineers created large concrete storage tanks to store water for growing populations. This sparked the beginning of 'gray' industrial development, with steel and concrete manufacturing skyrocketing (Broich, J. 2007). Reinforced concrete became the primary building material of everything by the 1930s, and with the boom of the IT industry came a need for more infrastructure due to urbanization (Krishnan, N 2022). Chennai, the largest city of Tamil Nadu, grew rapidly, and so did its suburbs. What once was a small village, Perungudi grew to accommodate, and with this growth came a new system of dams, walls, and canals all made of primarily concrete. Yet simultaneously came the reduction of wetlands, which due to poor land management, were reduced to make room for subdivisions and landfills (Jagadisan 2019). This combined reduction of natural infrastructure and creation of poorly-planned infrastructure led to a crisis in 2015, when record-high rains caused major urban flooding. All systems, gray and

green, were overwhelmed, calling into question the government's responsibility to protect people and the environment.

Are there similarities between cities that are currently implementing green infrastructure over gray infrastructure?

Most countries currently implementing green infrastructure are western countries. This encompasses most of the countries that industrialized during a time where innovative infrastructure involved building with steel and concrete, such as the United States (Rosenbloom, J. 2018). There are not only similarities between countries that implement green infrastructure, but there are also similarities in countries that are currently exponentially implementing gray infrastructure. The main similarities found came from the designation of a country's economy as either being developed or emerging.

What factors affect implementation of types of infrastructure? Are there potential barriers to implementation?

A large influence factor of the implementation of any infrastructure stems from the effects of flooding on the economic prosperity of a respective country, and furthermore the risk of flood in general. In fact, China, followed by the United States and India, suffers from the largest economic losses due to flooding specifically (Li, L. Collins et. al 2020). Urbanizing countries, specifically in Asia, have all followed a very similar path. In more recent years, these regions are experiencing transformations in their economies, and with this, their environments are starting to suffer. Large economic gains and exponentially growing populations stand in the way of the implementation of different, and more green, methodologies for water management. In fact, while most of these emerging nations particularly in Asia are concerned about economic development, this also is the pitfall of environmental protection, thus leading to the potential for further environmental degradation (Chikezie Ekwueme, D., Lasisi, T. T., & Eluwole, K. K. 2022). This is congruent with the results of my own research, where industrialization due to the IT industry in Chennai led to immediate urbanization with lack of proper infrastructural

planning, leading to pockets and patches of green space and a degradation of natural flood protection.

Another potential barrier to the implementation of green technologies and green space preservation is politics at a local, state, and national level. From my review of policies, I found that while government documents referred to new environmental goals and policies to increase stormwater management and flood resilience, there were also several requests and funds for new gray infrastructure. Furthermore, most of these gray infrastructural demands were at an inter-state level, which requires support at the national level (Policy Note 2017-2018, Demand No. 40). These barriers are not necessarily unique to Perungudi, but are two major factors that seemingly have determined the current trajectory of infrastructure development unless further government involvement is involved, or if economic interests were affected by natural phenomena, such as the case in 2015.

Finally, somewhat tangential to political and economic motivations, is the monetary aspect of funding green projects. Using China as an example, whose flood risk and population is similar to India's, we could assume that we could extrapolate that these countries face similar struggles to implementation. Yet while China falls under the BRIC countries list, it has begun to implement green infrastructure. When conducting my research, there were several case studies done regarding green infrastructure implementation in China, including comparative analyses between China and other countries. One such study was done of the United Kingdom and China, which found that while both countries set aside government funding for green infrastructure projects, monetary restraints were the biggest barriers to implementation (Li, L. Collins et. al 2020). This is different from my study, where I found that India had already set aside thousands of rupees towards gray infrastructural projects (Policy Note 2017-2018, Demand No. 40). Thus, while money is a concern in India, it is moreso the allocation of funding and the lack of prioritization of green infrastructure that stands in the way of innovations to stormwater management in Perungudi.

Implementing green infrastructure in place of gray infrastructure for proper stormwater management and flood mitigation: is it possible?

While there are many challenges to implementing green infrastructure from political and cultural fronts, it is clear that this "modernization" of a process so natural is part of a much greater systemic oppressive cycle of western countries dictating what technologies are "in." Countries and regions with these natural systems, where much of modern society originally stemmed from, are now following the same practices that western countries took to industrialize, such as the implementation of concrete and waterways and dams. And these countries are incentivized to follow the western path to success while doing away from the natural processes simply due to economic successes. It is important to recognize the influence and impact of these western-ideologies as we move forward with designing for a more sustainable and equitable world, especially with regards to the conservation and management of one of the most scarce natural resources in the world: water.

This being said, large natural disasters have illuminated the issues with following these methods of urbanizing. Following 2015, the Indian government, specifically the state of Tamil Nadu, began to take a new approach to legislature, creating new bills that were inspired by the UN's Sustainability Goals, inspired by wetland preservation, and most importantly, inspired by the need to innovate water management and technology in a way that was more sustainable (Tamil Nadu Government Portal). Local residents, after being impacted by this, are also asking more from a government who they felt failed them in 2015 (Table 1), as well as a government that has failed in protecting natural systems like the Pallikaranai wetlands (Murali, J. 2021). Thus, with collaboration and across several fronts, it is very possible to see the emergence of new greener systems of water management in Perungudi.

Limitations and further directions

My case study of Perungudi was designed in an attempt to understand and contextualize green and gray infrastructure implementation in regions that are still developing. There were some limitations in the general design of the study. While I was able to survey a few residents from Perungudi, I was unable to set up interviews with residents and connect in person. Visiting Perungudi in person may have been able to illuminate some of the nuances in this discussion of governmental interference with infrastructure and personal connections to land and water. This study also highlighted how diverse India is as a country in that no two states can entirely be

compared due to language barriers, state-to-state political differences, and even economic backgrounds. My study was of a specific area in Chennai, which cannot be extrapolated to other cities in other states that differ from Tamil Nadu such as Northern Indian states that have different economic, social, and political backgrounds despite being from the same country. The other limitation was in available data. Since Perungudi is a smaller community compared to other more studied regions in India, it was harder to acquire data such as Landsat images that were not heavily pixelated, or NDVI data.

For further study, I would like to survey and interview residents of other subdivisions surrounding Perungudi Lake for more perspectives on flood management, government involvement, and social implications. Expanding my sample size would also allow me to ask demographic questions that would highlight how backgrounds such as socioeconomic status and gender may have impacted experiences. I also think asking more specific questions regarding infrastructure would lead to more discussion on the differences in green and gray infrastructure and attitudes towards flood management in higher risk areas. For my qualitative analysis of land area and vegetation, I would like to recompute a concentric circle analysis using different radii on GIS in order to have a quantitative approach to this more qualitative analysis.

Conclusions

From the results of my study, it was clear that large changes to infrastructure are being made regardless of country status (developed vs. emerging). This was especially the case in parts of India, where growing populations make it necessary to develop large systems to both conserve water and also manage water resources. It is also more necessary, due to the rapid changes in climate, to become climate resilient and build out infrastructure, which is currently still highly gray (Indira Devi, P., Sam, A. S., & Sathyan, A. R. 2022). Perungudi, Chennai, and Tamil Nadu as a whole have made clear attempts to prioritize environmental health, yet there seems to still be a discrepancy between policy and execution. “Gray” systems of dams, levees, canals, and retention walls are still being placed, and green infrastructure is being replaced out of a need to grow out urban areas to accommodate for exponential growth. This study explores the need for more studies to be done in similar urbanizing regions like Perungudi, especially those that fall under the BRIC category, to promote sustainable growth in cities. This study also calls to

attention the importance of considering various variables before making decisions regarding infrastructure for water management, including both human and environmental health. In Perungudi's case, by shifting into a multidimensional expansion approach considering wetland preservation, water infrastructure, and urbanization, it may be possible for the state of Tamil Nadu to change the narrative on urbanization and land management in India.

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