

ENVIRONMENTAL JUSTICE AND FLOOD ADAPTATION: A SPATIAL ANALYSIS
OF FLOOD MITIGATION PROJECTS
IN HARRIS COUNTY, TEXAS

by

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THESIS ABSTRACT

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Although literature on flood risk and environmental justice investigates the link between race and ethnicity and vulnerability to floods, few studies examine the distribution of flood mitigation amenities. This study analyzes census tract proximity to flood mitigation projects (FMPs) completed between 2012 and 2016 in Harris County, Texas to determine if a) project location is biased towards economic growth and the urban core; b) areas most impacted by previous floods are prioritized for drainage assistance; and c) if low-income and Latinx populations are being neglected. A spatial error regression analysis indicates that FMPs are significantly proximate to the urban core, net of other factors. Results also indicate no significant relationship between census tract-level Latinx composition, income status, and proximity to FMPs. Finally, built environment characteristics and locations of previous flooding had no significant effect on where projects were placed.

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I. INTRODUCTION

As the U.S. experiences wealth inequality levels close to Depression-era conditions (Saez and Zucman, 2016), urban planners, policymakers, and environmental justice scholars are studying the myriad of ways that cities perpetuate impoverishment and residential segregation. These disparities in turn produce spatially heterogeneous vulnerability to floods; thus, it is important to recognize how city policies and procedures contribute to the concentration of flood risk in certain neighborhoods. One way that municipalities could unknowingly maintain inequitable conditions is the uneven distribution of funds for adaptation to flooding. Furthermore, a changing climate places disproportionately more stress on low-income communities (ironically, the groups that create the least environmental ills (Timmons Roberts, Parks, & Choucri, 2006; U.S. Census Bureau, 2005)), while seemingly benevolent adaptive policies and infrastructures can either neglect, directly harm, or displace low-income communities.

Since its founding in 1837, the city of Houston has sought to mitigate its almost annual floods. However, city officials influenced by political elites have spent state and federal dollars building levees, widening and deepening bayous and ship channels, and constructing expansive drainage systems, largely to protect capital interests and become an internationally recognized port city (Feagin, 1985). Houston's history of protecting business interests and creating a "business-friendly climate" at all costs necessitates further scrutiny into the placement of these various projects. The city historically prioritized large infrastructure projects to facilitate the shipping and transport of goods and enrich the wealthy elites that proposed them, while failing to regulate a skewed

market and provide public amenities and services for residents. Low tax rates on the wealthy resulted in a dependency on federal dollars to sustain the growth machine (Derosssett, 2015). Logan and Molotch (2007) conceptualize municipalities as “growth machines,” made up of collection of city agencies, officials, business elites, and their supporters that exist to secure land for profit. This form of development has not served all of Houston’s residents equally, especially when it comes to flood protections and public amenities. Some communities thrive from the creation of ecological havens, while others are relegated into “sacrifice zones” which make such safe areas possible (Martin, 2017).

The city’s latest efforts to address increasingly frequent and devastating floods are concentrated in Houston’s Department of Public Works program, Rebuild Houston. This program aims to improve drainage and streets in Houston through a dedicated “Pay-as-you-go” fund. The main sources for this fund are property taxes, third party funding (such as federal grants and the Texas Department of Transportation), a drainage utility charge, and a recently instated (2014) developer drainage impact fee. The program, whose slogan is “First Worst”, aims to target areas experiencing the worst flooding for the receipt of these funds and designated projects.

However, it is clear that Rebuild Houston defines worst only in engineering terms, and without taking into account the social vulnerabilities of residents that can compound the harms of flooding. A promotional video showing an idyllic residential area with cartoon cars and residents asks, “When will your street be replaced? Or what about drainage for the road you take to work? Or the school street, or an old bridge? Wouldn’t it be great if a Superbrain could figure out which is more important?” The narrator then asserts that such an infallible algorithm does in fact exist: the City of Houston

Infrastructure Analytics. The emphasis on a mathematical determination of who receives prioritization of these funds and designated projects is a typical characteristic of the utilitarian framework that guides policy and planning decisions, as opposed to that of an equity framework which prioritizes those most who are most vulnerable.

These projects technically fall under the jurisdiction of the Public Works Department. However, their locations are planning decisions. Urban planning does not typically address climate change adaptation, and recent political ecology studies documenting the inequalities of city-led climate adaptation urge that we look more closely into the spatial nature of these programs (Meerow and Mitchell, 2017). Additionally, distributional outcomes of adaptation efforts are rarely studied, leading to a lack of understanding as to whether projects are equitable or not (Shi, 2016).

The use of multivariate spatial regression methods to determine the distribution of publicly financed amenities is well documented in recent Environmental Justice (EJ) literature on street trees, parks, waterfront access, and other forms of green/blue space (Landry & Chakraborty, 2009; Smoyer-Tomic et al., 2004; Montgomery et al., 2015). The present study seeks to add to this body of knowledge by examining the distribution of flood mitigation projects. Using census tract data, I estimate the effects of a neighborhood's socio-economic makeup and built environment characteristics on proximity to Rebuild Houston's drainage projects. Other environmental justice scholars have used spatial econometrics to examine inequitable exposure to flood hazards and map areas of increased vulnerability (Maldonado et al., 2016; Maantay & Maroko, 2009). This is the first study that I know of which conceptualizes flood mitigation projects (FMPs) as a public amenity, and examines proximity to FMPs as a measure of inequity.

II. LITERATURE REVIEW

Flooding in Houston

In 2017, Hurricane Harvey hit Houston and became one of the costliest hurricanes in U.S. history, second only to Hurricane Katrina (NOAA, 2018). This event prompted many to demand that we better prepare our cities for increasingly frequent and more intense hurricanes as expected under climate change (Satija et. al., 2014), as well as inquire into the social conditions under which disasters occur. Up until recently in scholarly literature, natural hazards have inappropriately been termed “natural disasters,” a dangerous misnomer as it effaces the human systems that create vulnerabilities in society which allow a hazard to become a disaster.

In Houston, it is clear that the boom and sprawl of suburbs and complementary destruction of wetlands and prairie grasslands played a role in Hurricane Harvey’s devastation. These new developments place people that often do not know that they have bought a flood-prone property in harm’s way (National Resources Defense Council, 2018). New development also exacerbates issues of drainage through the paving over of important grasslands, wetlands, and soils that drain storm water. A 2005 study examined the relationship between land cover change in Houston and precipitation and runoff data and found a significant increase in runoff between 1994 and 2003 for 17 out of 23 study sites (Khan, 2005).

Another study from Brody, Kim, & Gunn (2013) examined flood losses for five different development patterns in the Gulf of Mexico. It found that low-intensity development occurring in sprawling patches across a landscape significantly increases

National Floodplain Insurance Program-based losses. Low-intensity development is most commonly characterized by single-family housing units and is defined by the National Land Cover Database as a mixture of constructed materials and vegetation with impervious surfaces making up 20-49% of total cover. Tellingly, Brody, Kim, & Gunn (2013) identified Harris County, out of 144 counties bordering the Gulf of Mexico, as containing (by far) the greatest area of patchy, low intensity development in the 227 square mile study area.

Uneven Vulnerability to Flood Risks

This destruction of wetlands, construction of housing in flood plains, continued contribution to climate change, and concurrent impoverishment of marginalized residents leads to heightened flood risk for many Houston residents. Wisner et. al. (2004) define flood risk as both the severity of the event and the vulnerability of those exposed to it. Flood vulnerability is the inability to anticipate, cope with, and recover from hazards due to socio-economic, environmental, or political conditions (Wisner et. al., 2004).

Anticipation of hazards is influenced by a person's financial status. In a capitalist system, a low income is a barrier to accessing opportunities and consumer goods which enable quality of life, and becomes a form of oppression. Low-income status is also embedded within and intersects with other forms of oppression, such as race, ethnicity, sexuality, and gender.

Eisenman et al. (2006) found that inability to anticipate Hurricane Katrina in 2005 was a primary reason for people not heeding evacuation warnings. In a series of 58 interviews with people living in Houston's evacuation centers, the authors identified a

number of factors that contribute to this particular aspect of vulnerability. These include a lack of community-specific information, mistrust of public officials, inability to take time off from work and employment, lack of resources to seek shelter elsewhere, and inaccessibility to transportation for evacuation. The authors confirmed that evacuation patterns during Katrina reflect previous studies on environmental hazard anticipation, which found that minority communities are much less likely to evacuate than affluent whites.

Additionally, income has a large effect on the ability and speed with which a neighborhood recuperates and returns to pre-flood conditions (Fussell, 2015). Fussell noted how the neighborhoods least damaged by Hurricane Katrina (and therefore those that recovered the quickest) were also those located on high ground near the Mississippi River where property values are high and socially-privileged residents are concentrated. Fothergill and Peek (2004) further reviewed the many ways that low-income households experience difficulty in accessing public and private resources that aid recovery including housing, flood insurance, and mental and physical health care.

These findings directly contradict the myth perpetuated by city officials that floods are “equal levelers”. Urban planner Patrick Walsh insists that Hurricane Harvey “was an equal-opportunity disruptor. Harvey hit a lot of areas of significant wealth, and it hit disadvantaged areas” (Stephens, 2017). This statement effaces the reality that one’s built environment, socio-economic status and political power all influence one’s ability to access vital resources and information. When Walsh and other officials insist that Harvey was not, in fact, disproportionately impactful in low-income neighborhoods, they ignore literature that shows the many ways in which underserved and marginalized groups are

often placed in harm's way. For example, a study using Google API elevation data and American Community Survey data found that poverty, high concentrations of racial-ethnic minorities, and immigration status are associated with lower elevations, and therefore could be more vulnerable to flooding (Lu, 2017). These findings are supported by an earlier study of 146 cities in the U.S. South, which found that African Americans have historically been forced into lower-lying marsh and swamp areas, while whites have occupied the higher elevations (Ueland and Warf, 2006).

The worsening reality of floods

These unequal social and economic conditions are projected to only get worse as climate change continues to alter weather patterns. Flooding, while already the most common natural hazard, is expected to increase in both frequency and severity as sea level rises and storm surges reach further and further inland (Buchanan, Oppenheimer, & Kopp, 2017). Additionally, the National Climate Assessment's 2014 Report, compiled by more than 300 scientists using climatological modeling and an independent review board, predicts a future in which heavy downpours become the norm (Kunkel et. al., 2013). Not only are these kinds of rain events predicted by these models, but observational data backs up the claim that intense, one day precipitation events are becoming more and more frequent (Perica et. al., 2018).

While inland cities may face these deadly deluges in the future, coastal cities are at risk of sea-level rise and higher storm surge during extreme weather events. The politicized nature of regulated growth prevents cities from quickly and efficiently incorporating sea level rise projections into development plans (and some are in fact

banned from doing so (H.B. 819, 2012)), and continue to develop coastlines and areas within the floodplain. Due to this additional development of (mostly) high-end, luxury units, the amount of damages due to flooding is projected to increase (Hallegatte, Green, Nicholls, Corfee-Morlot, 2013). Tellingly, National Floodplain Insurance Program (NFIP) data shows that both the number of claims and average amount of damages claimed has increased, just from 1980 to 2012 (Kousky & Michel-Kerjan, 2015).

However, research on flooding aftermath demonstrates how insurance programs and federal aid effectively result in an upward redistribution of wealth (Pralle, 2017; Logue and Ben-Shahar, 2016; Munoz & Tate, 2016). A study on wealth concentration following flood hazards from 1999-2013 found that whites tend to gain wealth while Blacks, Latinxs, and other people of color lose wealth, even after controlling for education, homeownership, county population, and a number of other factors. On average, whites in counties with \$10 billion in hazard damages gained \$126,000 from federal aid and subsequent neighborhood investments by the city. Blacks, on the other hand, lost \$27,000, while Latinxs lost \$29,000. Other people of color, mostly Asians, lost \$10,000 (Howell and Elliot, 2018). Such disparities in the recovery process require an enquiry into the placement of flood risk management infrastructure and its benefits to the most affected and vulnerable communities.

Houston's Growth Machine

The sprawl that Brody, Kim, and Gunn examine in their study is largely a result of the post-war economic boom of the 1950s. Yet despite the skyrocketing costs to the public sector of these suburban areas, Harris County continues to see the conversion of

open space into residential areas (Jacob et al., 2014). Urban planner Patrick Walsh notes that it will take “tremendous political will” to see through smarter planning, better building restrictions, and impervious cover mitigation. Unfortunately, Houston’s history indicates that this political will evaporates as soon as developers become involved. In “free-enterprise” cities such as Houston, urban development prioritizes the needs of businessmen and their “free market”. As per growth machine theory, this intensification of land use in order to promote growth and development is enabled and actualized by powerful growth coalitions (Logan & Molotch, 2007). These growth coalitions include government agencies, the media, and city elites that endeavor to create a good business climate and reduce corporate overheads through the use of “favorable taxation, vocational training, law enforcement, and ‘good’ labor relations” (Molotch, 1976, p. 312).

The effort to keep taxation low and spend tax dollars on growth infrastructure (as opposed to social programs) is evident from historical tax data. In 1997, a Houston family with an income of \$25,000 was paying taxes at a rate of 5.3% of income, while a family of similar income was paying 8.5% in New York City and 10.2% in Detroit. Even worse, wealthy Houston residents making more than \$150,000 in income were paying taxes at a rate of 4.7% as compared to a fourteen-city average of 10.2% (Vojnovic, 2003). True to the pro-growth agenda, in 1996, the city of Houston spent all of \$32.19 and \$6.70 per capita on Housing/Community Development and Public Welfare respectively, as opposed to \$139.62 per capita on highways (Vojnovic, 2003). As “violent class and ethnic conflict” detracts from a good business climate (Logan & Molotch, 2007), the city invested \$259.27 per capita on police protection, an organization historically dedicated to protecting propertied interests and repressing social movements.

The excess spending of taxpayer money on highways and other growth infrastructure is only the tip of the iceberg. Houston has always garnered large checks from the federal government to develop transport routes for the benefit of its huge cotton, mineral, oil, and gas industries. After oil was discovered east of the swamp city, a delegation was sent to Washington DC to secure federal funds for a 25-foot deep shipping channel that would allow the petroleum industry to be significantly expanded. Congress approved the Houston Plan, making this the first instance in which the federal government split the cost of a project with a municipality. The \$1.25 million grant was also the largest that Congress had approved for a local initiative. Port improvement projects continued, and by 1963, the federal government had covered about \$60.9 million, or 95.6% of the bill, while state and local taxpayers made up the rest. The use of lobbyists and powerful elites to accrue funds to stimulate development is a central tenet of growth machine theory, and has been shown to result in more robust growth rates (Logan & Molotch, 2007). As a result of the Houston Delegation's "entrepreneurship", by 1983, 34 out of the 35 largest oil companies had offices and plant facilities in the Houston area in order to benefit from low taxes and cheap labor (Vojnovic, 2003).

Growth machine theory also navigates the push and pull of agents seeking to accumulate capital by increasing the exchange value of land (i.e. property values) and social groups that push back against these schemes in order to build place and community and maintain use values. This dynamic is especially clear in the way that Houston identifies certain areas of the city for urban renewal and redevelopment. These programs assume that these areas, or "zones of transition," would naturally welcome the next and supposedly better use of land which cities and growth coalitions have planned. To carry

out these paternalistic and top-down changes, statutes such as eminent domain are used with abandon to maximize exchange values.

Environmental destruction is another direct effect of land use intensification and exchange value enhancement at the hands of growth coalitions. Logan and Molotch (2007) point out that places with rapid growth experience the most environmental decline, many examples of which can be seen in Houston (Feagin, 1988). Most relevant to this study is the paving, dredging, and filling of various wetlands. As a swamp, Houston relies on these kinds of land cover to drain and filter polluted stormwater (Bullock and Acreman, 2003). These natural stormwater filters have little exchange value and are thus constantly endangered by development, which has boomed in the Sunbelt due to lax regulations. From 1992-2010, Harris County lost 15,853 acres, or 29.1%, of their remaining wetlands due to development (Jacob et al., 2014), earning itself a place among the top ten jurisdictions in the US from 1996–2001 who converted land specifically for development (NOAA, 2008). Of this, 14% of the wetlands developed over were in the 100-year floodplains (areas that have a 1% risk of flooding annually), and thus some of the most vital areas.

Distribution of Flood Risk Management

Many coastal cities have been managing flood risks since their founding, Houston included. However, as climate change increases the frequency and intensity of flooding, environmental justice activists, scholars, and policymakers are asking what entails a “fair” way to manage flood risks (Johnson et al., 2007). Often, this includes a discussion on procedural justice – as cities plan to “live with the water”, it is crucial to ask questions

around how decisions are made, who is included in the process, and this participation is limited. As O'Hare and White (2017) argued, current approaches involve engaging affluent and educated people in the process, as well as political elites, while those in more deprived areas with more specialized needs are excluded.

When participation around flood mitigation projects is limited in this way, distributional effects can further impoverish and deteriorate living conditions in lower-income areas through neglect, while mitigating an environmental disamenity and creating various ecological enclaves in areas deemed more "valuable". Scholars studying periods as far back as the post-Bellum Progressive era (1890-1930) have noted this. Colten (2002) studied the New Orleans' ambitious public works project that first sought to exclude poor Blacks living in the lowest sections of the city from levee improvements. These areas eventually were included in public drainage works, but largely because of the nature of urban flooding – to protect affluent, high grounds, levees must be built in the lowest sections as well.

Flood risk management can also result in the relocation of certain groups of people for their own safety, or for the construction of flood protection infrastructure. However, upon examination of who benefits and who loses in these situations, cases in both coastal Louisiana and Houston show that resettlement strategies by public administrators can disadvantage socially and economically vulnerable communities. Colten et al. (2018) found that engineering projects meant to supplement levees on the banks of the Mississippi caused conflicts with coastal communities, largely comprised of Native Americans, African Americans, Asians, Acadians, and Isleños, who were forced

to leave homes and livelihoods, only to be relocated in areas just as flood-prone, if not more.

Lynn (2017) discussed how disadvantaged groups are most vulnerable to forced relocation because the homes are relatively inexpensive for the city to acquire. Additionally, low-income minorities generally lack the political power and financial resources to negotiate or fight relocation. Over the course of 53 interviews with residents from Kashmere Gardens, Lynn examined public agency claims that the relocation process in Houston, Texas will render residents “whole”. “Whole” as defined by Harris County Flood Control District, means relocating residents to housing that is no more expensive than vacated homes. Since the neighborhood is largely comprised of Blacks (77%), Latinxs (22%), and low-income residents, the relocation process is difficult to resist. The interviews document the physical and mental stress experienced by residents throughout the process, as well the non-monetary concerns held by residents slated for relocation. Residents clearly expressed concerns over use-value factors, such as informal support networks, feelings of belonging and familiarity, and proximity to family, as opposed to the exchange-value factors that drive growth coalitions to invade these neighborhoods with promises of renewal and reinvestment. Lynn argued that public agencies need to re-examine how “whole” is defined and expand the definition beyond a purely economic and financial one.

Impacts of the Growth Machine on Flood Risk Distribution

While relocation is touted as a move that results in safer conditions for residents, relocation is also a strategy employed by growth coalitions to acquire desirable property.

Anguelovski et. al. (2016) explored how this ulterior agenda has the potential to result in further injustices. The study documents the efforts of public agencies in charge of relocation in Medellin, Columbia and Manila, Phillipines. The authors found that these programs sometimes force low-income residents or informal settlements to move in the name of “flood mitigation”, only to expand high-value luxury properties in their stead. This is a clear example of city officials acting as growth advocates to enable the enhancement of exchange values. This entanglement of the private sector with flood protective measures, and the unevenness in resiliency that results, is well-documented by Dawson (2017) everywhere from Jakarta to Miami to Holland. Each of these places, under the guise of flood mitigation, has initiated huge real estate projects to act as capital sinks that enrich profiteering developers.

It should come as no surprise that real estate is a major focus of growth coalitions and urban elites that have an interest in investing capital. According to David Harvey, the overproduction of manufactured goods renders further investment into the primary circuit of capital (the means of production) as redundant. Instead, capitalists find a secondary circuit of capital in real estate (Harvey, 1978). Because these investments are concerned with the maximization of exchange values, the real estate market has the potential to spur uneven development. Such development, as Henri Lefebvre (1974) argued, is a process that benefits some areas of the city, while disinvesting in and abandoning others. This is demonstrated by a study from the Kinder Institute for Urban Research at Rice University, which found that Houston is becoming more and more economically polarized (O’Connell, n.d.). There is a lack of economic diversity within the region’s most affluent areas, indicating that neighborhoods are continuing to concentrate wealth and resources.

Additionally, high poverty areas are supplanting tracts considered middle class in 1980. The segregation of low-income neighborhoods not only has implications for the quality of amenities in the area, such as schools, parks, and hospitals, but it can also invite disamenities, such as higher risks to hazards such as flooding.

To an extent, the real estate market has focused on selling Houston's core as a sink for the secondary circuit of capital. Urban sociologists note the reversal of "white flight" in some cities, in which affluent whites are moving back into the urban core to take advantage of transportation systems, employment opportunities, social networks, and other amenities. As city centers gentrify, poorer communities are pushed to urban fringes, where infrastructure and services are not extended. This "core versus periphery" pattern appears in many low-income suburban neighborhoods in which public amenities such as transportation (mostly concentrated within the Sam Houston Tollway loop) appear sparse. In cities that follow this pattern, capital investment is often directed into the city's core (DeOliveira and Roberts 1996). This could likely result in the clustered distribution of flood mitigation projects (FMPs) in Houston's core, leaving large, fringe tracts to fend for themselves. Since urban centers receive the lion's share of funding for storm drainage infrastructure from the city, suburban and rural communities are often responsible for their own drainage systems, and may not be able to afford the cost.

Hypotheses

I hypothesize that, due to this urban core bias, Rebuild Houston will be more concerned with pouring funds and resources into the urban core as opposed to distributing them throughout flood prone areas of Houston. Census tracts that are closer

to the urban core will also be closer to flood mitigation projects. This bias for areas that attract growth and development could also extend to other areas of the city that developers are eyeing. Therefore, I further hypothesize that Rebuild Houston will place FMPs closer to areas slated for redevelopment and reinvestment, such as Houston's Tax Increment Reinvestment Zones.

I also hypothesize that a neighborhood's built environment will play a role in determining where FMPs are built. Considering what a measurable and significant impact land cover is shown to have on flooding outcomes, a utilitarian decision-making framework like Infrastructure Analytics should take into account the built environment to determine flood risk. I hypothesize that areas with less impervious cover, or open space areas, will be further from flood mitigation projects. I also hypothesize that areas with a great deal of low-intensity development will be closer to flood mitigation projects.

I also propose an institutional bias hypothesis which predicts that areas with lower median household income and higher percentages of Latinx residents will be sited further from flood mitigation projects. The institutional bias perspective is used in previous distributional justice studies to highlight how bureaucratic decision-making can be a factor in producing unequal resilience to environmental hazards and events (Liévanos & Horne, 2017). Research on institutional bias and flood risk further found that an engineering approach to managing flood risks does not result in equitable outcomes (Harries & Penning-Rowsell, 2011). These utilitarian approaches fail to discriminate between those who choose to live in a floodplain and with the resources to rebuild, and those who are unaware of the risks or unable to leave. I hypothesize that the vulnerability of areas with lower median household income and higher percentages of Latinx residents

is obscured by a utilitarian framework. Furthermore, neighborhoods primarily composed of people of color or low-income households are seen as incapable of contributing to accumulation and growth, and are subsequently subjected to disinvestment (Pulido, 2016).

Finally, I hypothesize that Rebuild Houston will prioritize areas that were flooded during Hurricane Allison as a result of their “Worst First” philosophy. I hypothesize this for two reasons: 1) Hurricane Allison was the most catastrophic flood event in Houston’s recent history (at the time of the project’s planning period; Harvey exceeded Allison in both rainfall and number of homes flooded); and 2) Hurricane Allison’s effects spurred a number of initiatives at the city agency level to mitigate flooding. These initiatives use data and information from the Tropical Storm Allison Recovery Project.

IV. METHODOLOGY

Study Area and Unit of Analysis

Houston is generally regarded as one of the more diverse cities in America. White residents total just 59.2% of Harris County, while the national average is close to 72% (U.S. Census Bureau, 2010). Demographic and land cover aggregate statistics for Harris County are summarized in Table 1.

Table 1. Descriptive Statistics for Harris County, Texas

	N	%
Total Population	4,092,459	100%
Non-white Latinx residents	702,930	17.1%
White residents	2,318,256	59.2%
Square Area	1,777 sq. miles	100%
Area within .2% chance of annual flood	209 sq. miles	11.8%
Area within floodway	122 sq. miles	6.9%
Open space	372 sq. miles	12.5%
Low-intensity development	400 sq. miles	13.5%

Note: Data is take from 2010 Decennial Census, Houston-Galveston Area Council, and FEMA.

Nearly 20% of all land in Harris County lies within a FEMA defined flood zone, the most high-risk area to live in and develop. The units of analysis for this study are census tracts that lay at least partially in the FEMA 2015 delineated flood hazard zone. While many have criticized FEMA maps for being outdated and obsolete with a changing climate, the Harris County Flood Control district relies on these maps to build the mapping tools that they release for public knowledge. It is likely that they use these same

maps to determine where to place flood mitigation projects (FMPs) so as to not plan FMPs outside of the areas with the highest level of danger. This also serves to eliminate the consideration of elevation in my model. The flood plain maps are constructed using elevation, therefore I know that census tracts lying in the flood plain will be located in depressions, and are more likely to benefit from the proposed FMPs. I excluded 114 census tracts that did not intersect the flood hazard zones as well as 18 census tracts with missing data. The remaining sample size is 654 tracts. All of the data used for this analysis are cross-sectional data collected by a variety of public agencies. Table 2 summarizes the variables, gives a brief description, and reports their source.

Table 2. Variable summaries and data sources

Variable	Description	Data Source
Distance to completed projects (m)	Distance from the center of each census tract to the closest flood mitigation project	Rebuild Houston 2016 Report
Percent open space	Percent of tract covered by open space (large-lot single-family housing units, parks, golf courses, and planted vegetation)	National Land Class Dataset 2016
Percent low-intensity development	Percent of tract covered by LID (single-family housing units, 20%-49% impervious cover)	National Land Class Dataset 2016
Proximity to urban core (km)	Distance from the center of each census tract to the center of Houston's commercial district	Houston Galveston Area Council GIS Datasets
Percent TIRZ	Percent of census tract lying within a Tax Increment Reinvestment Zone	City of Houston GIS Portal
Proximity to flooded areas (km)	Distance from center of census tract to closest stream gauge flagged as flooded or cautionary	Harris County Flood Warning System Historical Data 6/9/2001
Percent Latinx population	Proportion of census tract residents that identify as non-white Hispanic on the census	Decennial Census 2010
Median household income (thousands of dollars)	Average income of census tract	ACS 2012-2016

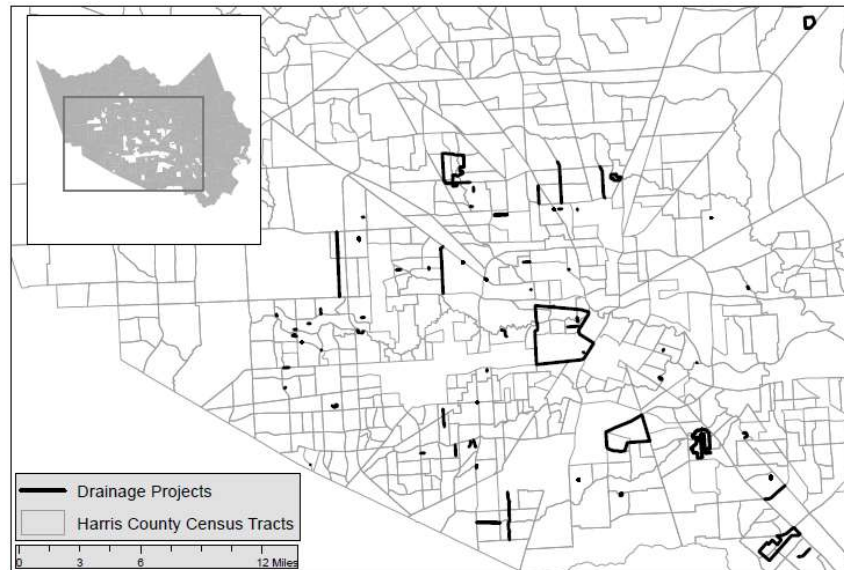
Dependent Variables

To build my dependent variable, I used a 2016 Rebuild Houston report, “Look Back/Look Forward”. The program, managed by the Department of Public Works, is framed as an investment in the street and drainage infrastructure to reduce flooding and “improve mobility” (although it is not specified if this is for cars or pedestrians or bicycles). I therefore focused on the projects that explicitly aimed to improve drainage and were labelled as Drainage and Pavement Improvement (DPI) and Local Drainage Projects (LDP).

Using ArcMap, I created a shapefile of the projects described in the 2016 report. Map 1 below shows all 81 DPI and LDP projects that were included in the report, with the exception of three projects whose location descriptors were too vague to conclusively mark. After mapping these projects, I used the Near Table Generator tool to calculate the distance between each census tract centroid and the closest flood mitigation project.

The dependent variable did not initially exhibit a normal distribution and thus had to be transformed. I considered both a log-10 transformation and a square root transformation and examined their skew and kurtosis test scores using Stata, and found that the log transformation of the variable creates the most normal distribution of the three transformations. The untransformed and transformed variables are described in Table 3 below.

Map 1. Rebuild Houston Project Locations



Independent Variables

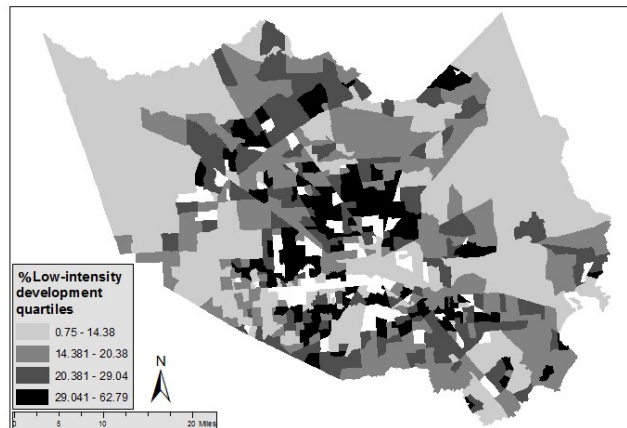
To inform my built environment characteristics variables, I used the 2011 National Land Cover Database. This dataset, produced by the Multi-Resolution Land Characteristics consortium, is a collaboration between a number of federal agencies, including the Department of the Interior, the US Geological Survey, the Environmental Protection Agency, the US Forest Service, and quite a few others. The dataset is a compilation of primarily Landsat data, as well as census, wetlands, topographical, agricultural statistics, and other land cover maps. The NLCD 2011 Land Cover dataset is available for download as a raster dataset and describes the whole of the conterminous United States. Land is classified based on level of development, type of forest or grassland, as pastured or cultivated land, as woody or herbaceous wetlands, or as water. This analysis focuses on two types of land use: low-intensity developed areas and developed open space.

Because this data is only available in raster format, I used ArcGIS tools to create a table that could then be appended to my main dataset on Harris County. I first converted the raster data into shapefile data using the Raster to Polygon tool, resulting in 738,290,738,290 polygons throughout Harris County. These were all polygons of various land cover types, so I had to aggregate them based on type of land cover using the Dissolve tool. Once I had a multi-part polygon shapefile aggregated by various land cover types defined by the NLCD, I used the Intersect tool to clip these large polygons into polygons divided up by census tracts. I could then create the table that listed percent of each land cover type in each census tract.

Maps 2 and 3 below show the distribution of tracts with a high percentage of open space and low-intensity development throughout Harris County. High amounts of low-intensity development were close to the urban core in south Houston, as well as in more suburban tracts further from the core in the north and northwest. This contrasts with high amounts of open space, which can be seen clustering in the northern tracts as well as some south to southwest tracts.

Low-intensity Development

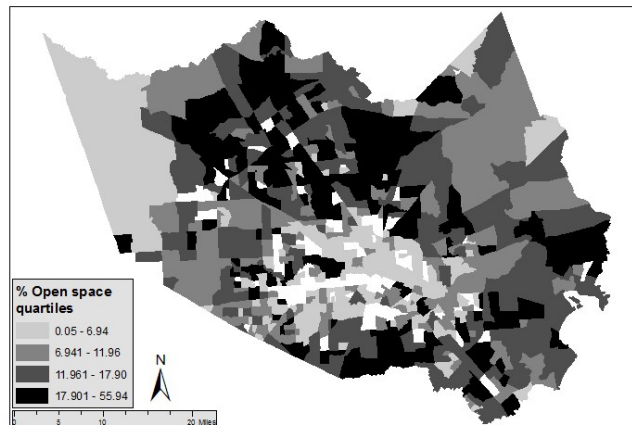
Low-intensity development (LID) is defined by the NLCD as areas with 20%-49% impervious cover and is characterized by single family housing units and lawn grasses. LID areas are a good indicator of where flood damages are highest and necessitate improved drainage systems (Brody, Kim, & Gunn, 2013). Thus, if Rebuild Houston is placing these projects in areas hit by the worst flooding, tracts with higher percentages of low-intensity development should be closer to these projects.



Map 2: Percent of census tract covered by low-intensity development in Harris County, Texas, 2011.

Developed Open Space

Developed open space (referred to as open space throughout this study) is characterized by parks, vegetation in the form of lawn grasses, golf courses, urban green spaces, and very large single family lots. Open space areas have less than 20% impervious surfaces. Brody, Blessing, and Sebastian (2014) identify this type of land use and maintaining drainage fairly well and appropriate capturing precipitation runoff. Other research finds that under certain conditions, green space can reduce surface run-off (Gill, 2007).

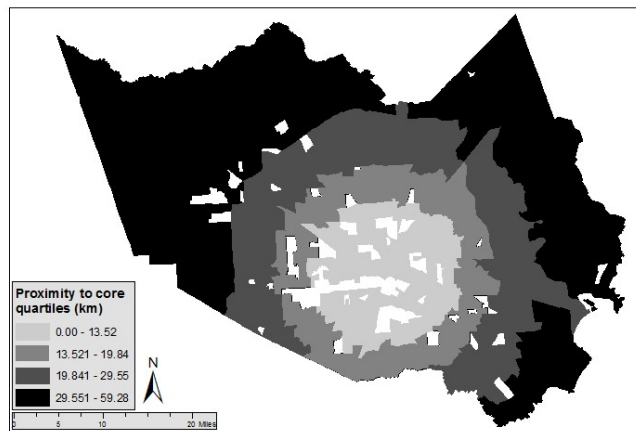


Map 3: Percent of census tract covered by developed open space in Harris County, Texas, 2011.

Proximity to Core

My “urban bias” hypothesis is represented using two variables: proximity to urban core and percent TIRZ. Proximity to core was created using the Houston Galveston Area Council GIS Datasets. I then created a point at the center of Houston’s main commercial area and oldest business district. Next, I used Near Table Generator to calculate the distance from each census tract centroid to the center of Houston’s core. I

hypothesize that this variable will have a positive relationship with my dependent variable – as distance from the core increases, a census tract will experience a simultaneous increase in distance from the closest flood mitigation project.

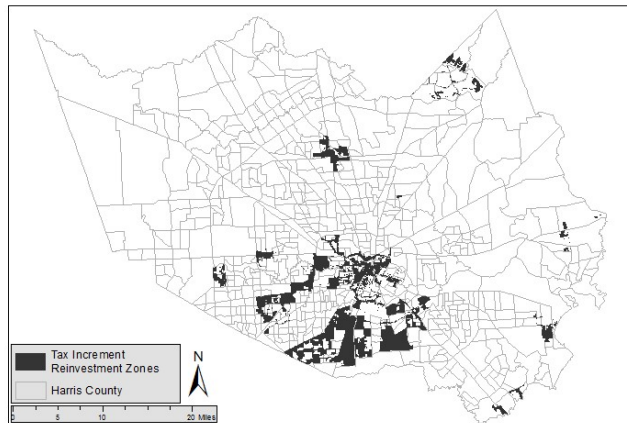


Map 4: Proximity of census tracts to urban core in Harris County, Texas.

Percent TIRZ

Percent TIRZ is a variable that describes the amount of census tract that lies within a Tax Increment Reinvestment Zone (TIRZ). Houston is actively involved in creating zones of transition in low-income neighborhoods. The city identifies a number of Tax Increment Reinvestment Zones (TIRZ), in which redevelopment costs are financed in order to “promote growth in areas that would otherwise not attract sufficient market development in a timely manner” (City of Houston, n.d.), a clear example of the growth doctrine which drives space production in cities. I hypothesize that, in order to protect

areas and enhance the exchange values of such areas, Rebuild Houston will place projects closer to these tracts. Thus, this variable will have a negative relationship with my dependent variable – a census tract further away from a FMP will have a lower percentage of TIRZ.



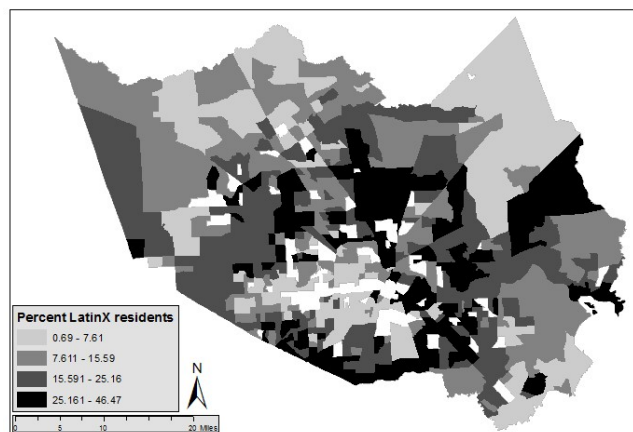
Map 5: Tax Increment Reinvestment Zones as delineated by the city of Houston.

Percent Latinx and Median Income

The 2010 Decennial Census (DC) and the American Community Survey (ACS) inform the two socio-economic variables, percent Latinx and median household income.

Both of these groups are chosen due to the way that they can be disadvantaged by institutional decision making processes.

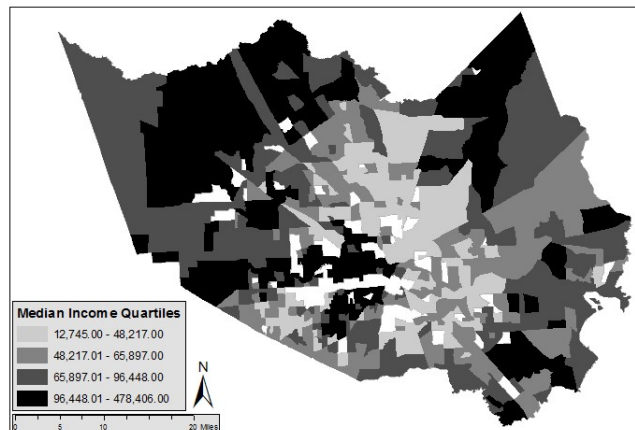
Additionally, the Latinx community is the largest demographic after white residents (Census Bureau, 2010).



Map 6: Percent of Latinx residents in each census tract in Harris County, Texas, 2010.

The ACS has specific benefits and limitations when it comes to sampling that must be mentioned. The ACS is collected and compiled every year on a rolling basis and is therefore more up-to-date than the Decennial short-form survey. However, the DC is distributed to every resident while the ACS samples one in six residents in an area and extrapolates the results (Census Bureau, 2014). While the ACS provides a margin of error for each statistic provided, which allows researchers to identify less-than-optimal data, these margins can be extremely high and spatially heterogeneous. Research on the spatial variation of uncertainty estimates finds that measurement error is neither low nor uniformly distributed, as is assumed in regression analysis (Folch et. al., 2016). To address some of this variation in the median household income variable, tracts had a

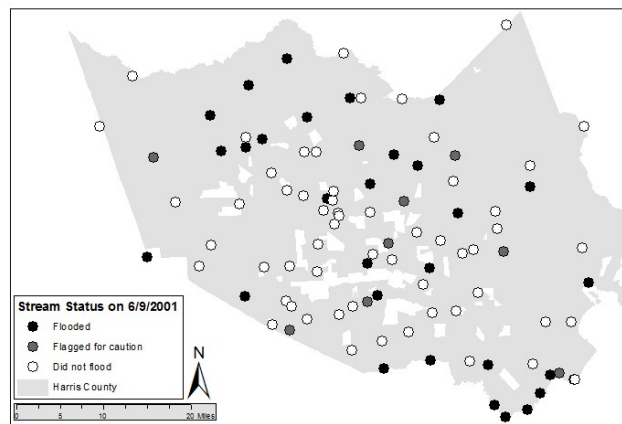
coefficient of variation (CV) of .5 or lower. The coefficient of variation is derived by dividing a figure's margin of error by the figure. Therefore, a figure whose margin of error is greater than half of its value would be considered too erroneous to include in the dataset.



Map 7: Median household income of census tracts, Harris County, Texas, 2012-2016.

Proximity to Flooded Areas

The variable proximity to flooded areas, was created using data from the Harris County Flood Control District (HCFCD), which has a number of mapping tools on their website available for public use. One of these is the Harris County Flood Warning System, which maps and reports the status of all stream and bayou gauge stations in Harris County. Each gauge station also reports the daily channel status, and users can view historical data for as far back as February 1, 1986. I mapped these flood gauge stations and their channel status during Tropical Storm Allison's worst day of flooding, June 9th, 2001. Using ArcMaps' Near Table Generator tool, I created a table that reports the distance from the centroid of each census tract to the closest overtopped or cautionary-status flood gauge station. This data then informed the variable, proximity to flooded areas, which was incorporated into the final model.



Map 8: Map of flood gauge statuses on the worst day of flooding during Hurricane Allison in Harris County, Texas, 2001.

Analytic Strategy

This analysis goes through multiple stages. First, I use descriptive statistics to examine the level of clustering of each variable, including the dependent and independent variables. Next, I conduct Pearson correlation between all my independent variables and

my dependent variables. Table 4 summarizes these results. Bivariate correlations are useful for assessing patterns in the data, as well as identifying independent variables that are strongly and significantly correlated with the dependent variable. However, bivariate correlation results often suffer from omitted variable bias, since there are usually multiple factors influencing a certain phenomenon. Therefore the third stage of this analysis implements an OLS model to estimate the effects of the explanatory variables on the dependent variable simultaneously.

In the final stage of the analysis, I develop a spatial error regression model to eliminate the spatial autocorrelation that would otherwise reduce the efficiency of my multivariate model. In a spatial error model, neighboring units share similar behaviors, even when there may not be behavioral interactions. Instead, these similar behaviors are a result of their sources being geographically clustered. When incorrectly using an OLS model for data that exhibits a high level of spatial autocorrelation, researchers may find biased and understated standard errors, due to the clustering of similar standard errors in certain places. Instead of the traditional OLS model which assumes a random distribution of standard error values, standard errors can be higher in some areas than others. If spatial dependence is not fully modelled in the data generating process with a spatially weighted error term, this may result in Type I errors, or the rejection of a null hypothesis when in fact, no relationship between the independent and dependent variable exists (Darmofal, 2015). To determine that this was the most efficient model to use, I began with the following OLS regression model, in which y is the dependent variable, β_0 represents the constant, $\beta_k X$ represents the explanatory variables, and ε signifies the random error term.

$$y = \beta_0 + \beta_1pct_openspace + \beta_2pct_LID + \beta_3distance_to_core + \beta_4pct_TIRZ + \beta_5distance_to_floodgauge + \beta_6median_income + \beta_7pct_Latinx + \varepsilon$$

The Lagrange Multiplier error and Robust Lagrange Multiplier error statistics were both higher than the Lagrange Multiplier lag and Robust Lagrange Multiplier lag statistics, indicating that a spatial error term is necessary to capture the spatial autocorrelation in the model (Darmofal, 2015). After adding the spatially weighted error term the final model appears as below. The error term is composed of the spatial autoregressive coefficient λ , the spatial weights matrix W , the random error term ε from the OLS model, and the spatially independent error term u .

$$y = \beta_0 + \beta_1pct_openspace + \beta_2pct_LID + \beta_3distance_to_core + \beta_4pct_TIRZ + \beta_5distance_to_floodgauge + \beta_6median_income + \beta_7pct_Latinx + \lambda W\varepsilon + u$$

The parameters on this model are estimated using a Maximum Likelihood Function, as opposed to the Best Linear Unbiased Estimates method used for OLS models. I used a 5,000 meter distance-band, row-standardized weights matrix. As Tobler's First Law of Geography states (Tobler, 1970), "Everything is related to everything else, but near things are more related than distant things." A weights matrix defines which locations are more proximate and gives these locations more importance in

calculating local values, than other locations. A neighbor definition is assigned for each location i . All census tracts within a 5,000 meter radius of i are given a “neighbor status” and are thus given more importance in the model than locations outside the threshold. When incorporated into the model, the matrix identifies this pattern in the error terms that are influenced by spatial proximity to one another. The error term captures this “noise” and ensures that the model is an efficient estimator of the parameters (Darmofal, 2015).

I chose a distance-band matrix for three reasons. First, EJ literature in the past has noted that queen and rook matrices are usually more appropriate for data appearing in a gridded fashion, while census tracts, which vary greatly in shape, perform better with a distance-band matrix (Chakraborty, 2009). Second, a distance-band matrix allows for large variation in the size of census tracts, which is the case in Harris County. With a queen or rook matrix, neighbor definitions might span hugely varying distances, creating a fluctuating definition of influence. However, a distance-band matrix will define a radius of influence consistently throughout the study area. And finally, the 5,000 meter distance-band managed to eliminate the spatial autocorrelation from the model, while queen matrices were unable to do so.

V. RESULTS

Descriptive Statistics

Table 3 below summarizes both the log transformed and untransformed versions of these variables. Using univariate Moran's I scatterplots, I tested for the presence of spatial autocorrelation in the absence of covariates. My dependent variable returned a highly significant value of 0.6349 indicating high clustering of tracts with similar proximities to FMP. The Moran's I value for the proximity to urban core variable reflects the highest clustering, while the moderately-high Moran's I for percent Latinx variable characterizes the highly segregated nature of Houston neighborhoods. This can also be seen in maps 3 and 7 respectively. Proximity to flooded areas is weakly clustered, indicating that there are some flooding hotspots, and can be viewed on map 5. However, it is important to note that this clustering could be by virtue of where flood gauges are placed, rather than where flooding is occurring. All of these were highly significant at the $p < 0.0001$ level, except low-intensity development (LID), which is significant at the $p < 0.01$ level.

Table 3. Descriptive statistics for dependent and explanatory variables

Variable	Mean	St. Dev	Min	Max	Moran's I
Distance to completed projects (m)	6, 298.78	6, 789.86	7.83	38, 664.26	0.736***
Log-transformed distance variable	3.52	0.55	0.89	4.59	0.503***
Percent open space	13.00	0.33	0.05	55.94	0.129***
Percent low-intensity development	22.28	11.30	0.75	62.78	0.021 *
Proximity to urban core (km)	21.34	0.41	0.00	59.28	0.781***
Percent TIRZ area	8.07	20.14	0.00	100	0.093***
Proximity to flooded areas (km)	5.23	2.80	0.41	16.54	0.230***
Percent Latinx population	40.59	25.20	3.50	97.20	0.405***
Median tract income (thousands of dollars)	80, 362.07	50, 802.52	12,745	478,406,000	0.133***

Note: *** $p < .0001$ level, * $p < .01$ using a second order queen matrix. $N = 654$ tracts.

Bivariate Correlations

These results indicate that only proximity to urban core is strongly (and positively) correlated with proximity to closest FMP. As hypothesized, this indicates that flood mitigation projects are located closer to tracts that are closer to the urban core.

My built environment variables are both consistent with my original hypotheses. Percent open space exhibits a moderate positive correlation, indicating that tracts further away from FMPs also contain a great deal of open-space. Percent low-intensity development shows a very weak and negative correlation with my dependent variable. Thus, tracts with a high percentage of low-intensity development are closer to FMPs.

Percent TIRZ exhibits a moderate, negative, and significant correlation, and is consistent with my growth bias hypothesis. The bivariate correlation indicates that tracts with less area designated as TIRZ are further from FMPs.

Neither institutional bias variables, percent Latinx and median household income, are highly correlated with distance to nearest FMP. Percent Latinx shows a weakly negative and highly significant correlation and is inconsistent with my hypothesis. Tracts with high percentages of Latinx residents are actually located closer to FMPs. The Pearson's correlate for median household income is positive, and also contradicts my hypothesis. Tracts that are further away from FMPs may actually have higher median household incomes than those close to FMPs.

Proximity to flooded areas, my control variable, was positive and insignificant, and is consistent with my hypothesis. Tracts closer to FMPs are also closer to previously flooded areas.

Multivariate Analysis

After using Geoda to run both the OLS regression and the spatial error regression, model fit appears to have improved. The Akaike Information Criterion drops from 615.819 in the OLS model to 239.959 in the spatial error model, while the log likelihood increases from -299.909 to -111.979. The added spatial autoregressive coefficient is highly significant. Additionally, the Moran's I is close to zero with a value of -.00947 and is highly significant, leading me to believe that the spatial dependence displayed in the OLS model has been largely eliminated.

The model variables, including the constant, all experience a slight drop in value, as is expected with the addition of the error term. Proximity to flooded areas is rendered an insignificant variable. The other variables, summarized in Table 5 below, also experience similar decreases in probability. The urban core variable is the only variable

which remains significant in the spatial error model. Proximity to urban core is positive, confirming my original hypothesis that areas close to the urban core are also close to FMPs.

Table 4. Bivariate correlations between all variables

	Logged Distance to completed project	Percent open space	Percent low intensity development	Proximity to urban core	Percent TIRZ area	Proximity to flooded areas	Percent Latinx population	Median household income
Logged Distance to completed project	1							
Percent open space	0.231***	1						
Percent low intensity development	-0.149***	0.189***	1					
Proximity to urban core	0.705***	0.292***	-0.158***	1				
Percent TIRZ area	-0.213***	-0.086*	-0.182***	-0.272***	1			
Proximity to flooded areas	0.0326	-0.009	0.054	0.188***	-0.057	1		
Percent Latinx population	-0.155***	0.018	0.011	-0.215***	-0.001	-0.053	1	
Median household income	0.032	-0.037	0.174***	0.128***	-0.106*	0.084*	-0.349***	1

Note: *** p < 0.00001 level using a second order queen matrix, ** p < 0.01, and * p < 0.05. N = 654.

The other “urban bias” variable, percent TIRZ area, was found insignificant and negative, which also confirms the original hypothesis; a census tract with less area designated as TIRZ will be further from an FMP. However, the 95% confidence interval of this variable overlaps with 0; therefore, it’s possible the variable is actually positive and not signed as expected.

Both built environment variables, percent open space and percent low-intensity development, are insignificant. Open space is signed positively, while low-intensity development is signed negatively; both of these findings would support the original hypothesis if their confidence intervals didn’t overlap with zero. It is still possible that these variables are signed differently and do not support the original hypothesis.

The institutional bias variables, percent Latinx population and median household income, are both negative and insignificant. As with the other insignificant variables, the 95% confidence level intervals overlap with values of the opposite sign. Thus, while percent Latinx is not signed as hypothesized, and median household income is signed as expected, the results are unclear.

Finally, proximity to flooded areas is negative, insignificant and not signed as expected; a tract further away from an FMP is actually closer to a previously flooded area. As with the other insignificant variables, the confidence interval overlaps with values of the opposite sign and cannot be conclusively interpreted.

Table 5. OLS and spatial error model output

	OLS model	Spatial Error model
Percent open space	0.00183 (0.0020)	0.00022 (0.0015)
Percent low intensity development	-0.00171 (0.0015)	-0.00112 (0.0012)
Proximity to urban core	0.03707 (0.0017) ***	0.03187 (0.0040)***
Percent TIRZ area	-0.00102 (0.0008)	-0.00026 (0.0007)
Proximity to flooded areas	-0.01874 (0.0055) ***	-0.01033 (0.0076)
Percent Latinx population	-0.00140 (0.0015)	-0.00081 (0.0013)
Median household income	-0.00061 (0.0003)	-0.00017 (0.0003)
Constant	2.9288 (.0724) ***	2.9314 (0.1476)***
Lagged error variable		0.86742 (0.0250)***
Multicollinearity Condition Number	13.011	
Pseudo R ²	0.5130	0.7523
Moran's I	0.4136 **	-0.00947
Log likelihood	-299.909	-111.979
Akaike Information Criterion	615.819	239.959

Note: Standardized coefficients with SE values in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ ¹

¹ The Jarque-Bera test on the OLS model, which reports on the non-normality of residuals, is highly significant at the $p < 0.00001$ level, indicating that residuals are non-normally distributed.

The Breusch-Pagan test has a relatively low test statistic (164.6234) and is statistically significant at the $p < .00001$ threshold, indicating that heteroscedasticity must be rejected.

VI. DISCUSSION

This research sought to add the consideration of flood mitigation projects as a public amenity to the current literature. Although other environmental amenities like parks, waterfront access, clean air, soil, and water resources, street trees, and community gardens have been widely studied and considered, flood mitigation sponsored by city and municipal governments have not undergone quantitative analysis to examine the fairness of distributional outcomes. This is important for two reasons: first, climate change is altering the frequency and severity of floods in urban environments and second, lax development regulations in Houston continue to invite the sinking of over-accumulated capital into real estate. This means that development will continue to eclipse other priorities of city governments, such as mitigating flooding, diminishing the wealth gap, and environmental justice for underserved residents, which only puts more property, infrastructure, and people in harm's way.

The objective of this study was to determine whether flood mitigation projects were cited closer to or further from low-income, Latinx tracts. It also aimed to determine whether built environment characteristics of tracts, urban bias, and economic development plans factored into planning decisions, considering Rebuild Houston's slogan "Worst First".

First of all, we can infer that suburban and rural fringe tracts are receiving less public investment than core city tracts— as the results indicate, when distance from the core increases (or the area gets more and more suburban or rural), distance to FMPs increases. As Brody et al. (2013) suggest in a review of Gulf Coast state development

patterns, suburban subdivisions are often left to implement their own drainage programs. While some of these tracts are highly affluent and can afford to bear the financial burden of risk, many others are not. Low-income suburban and rural tracts at the edge of Harris County are not included in any municipal plans to mitigate flooding, as acknowledged by H-GAC (Houston-Galveston Area Council, 2013).

Second, the spatial error model does not determine whether built-environment characteristics of neighborhoods had an effect on the placement of these projects, as both the open space and low-intensity development variables are insignificant. However, it is important to note that the variable “open space” does not accurately capture the concept behind the variable. The purpose of including “open space” was to incorporate the area of a tract that is not covered by impervious surface and can still absorb floodwaters, and are likely to be rural and suburban fringe tracts. After examining Map 2, one can see that tracts with high levels of open-space are dispersed throughout Harris County, as opposed to on the outer fringes of Harris County, as I had expected. Since I measured this variable only using the NLCD classification of “open space”, areas such as pastures, fields, prairie and grasslands, wetlands, and forests are not included. In order to properly measure the variable “open space” as I’m conceptualizing, I would have to build an index that incorporates all land classes that are not characterized by impervious surface.

The spatial error model does not conclusively find whether tracts with higher percentages of Latinx residents are located closer to FMPs. As the Moran’s I for percent Latinx indicates, tracts with high percentages of Latinx residents are fairly clustered. Map 6 indicates that this clustering occurs relatively close to the urban core. This is consistent with the settlement patterns of Houston, where affluent, white, commuter class

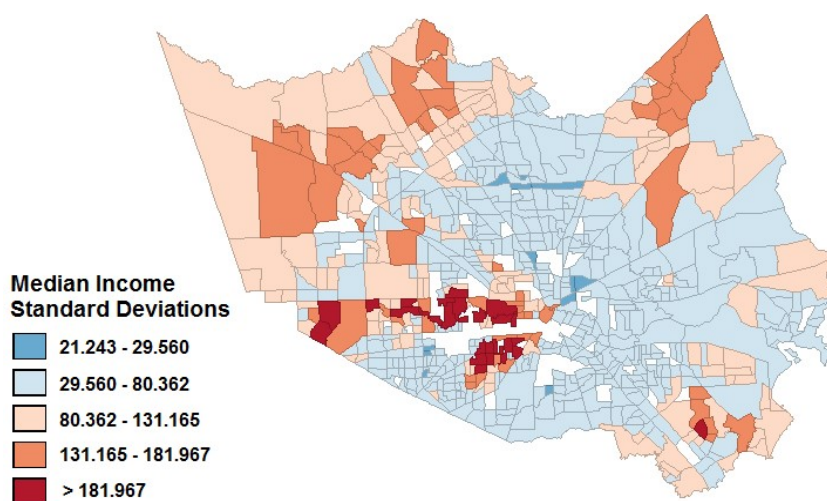
neighborhoods self-select to be located at the urban periphery, while those who must be close to work opportunities or public transport live near the core. However, median tract income was not signed as expected by my hypothesis, indicating that FMPs are sited further away from areas of low-income. A change in sign is possibly due to the addition of variables that control for certain effects, or could be due to a missing explanatory variable. Since the only strongly correlated variable was proximity to core, it is very possible that an added variable that explains more of the dependent variable would improve the model. This is further supported by the Jarque-Bera test on the OLS model, indicating that residuals are non-normally distributed, which could be a result of the weak correlations between the explanatory variables and the dependent variable.

As the percent TIRZ variable is insignificant, it is difficult to conclude whether this measure of economic development plays a role in siting flood mitigation infrastructure. However, it is important to note the locations of these areas. Several of the TIRZ areas are located in largely minority and low-income areas, such as Greenspoint, Fifth Ward, Sunnyside, Gulfgate, and Harrisburg. This program, like others driven by the growth coalition, assumes that “these zones of transition are crying out for the same sort of ‘higher and better uses’ of the next transition.” (Logan & Molotch, 2007). Like many American cities, this may drive up property values and rent and push historically Black and brown neighborhoods out of the urban core, away from these now completed FMPs. Should the urban core transition to mostly affluent tracts with plenty of street drainage investment, it is possible that displacement of low-income and non-white communities might result in increased flood risk.

Proximity to flooded areas was signed negatively in the spatial error model, contradicting its sign in the bivariate correlation matrix. However, since the variable was insignificant in the spatial error model, it is difficult to conclude whether this particular measure of flooded areas has an impact on distance to FMPs. Since there are some limitations in the way that this data and variable were measured, this variable could benefit from being re-conceptualized. These limitations are discussed below.

The Breusch-Pagan test is still significant at the $p < .00001$ threshold, which could be a sign that relationships between the explanatory variables and the dependent variables are non-stationary. This tentative hypothesis is supported by Map 9 below which shows the way that high income tracts (as defined by tracts two standard deviations above the mean), although clustered, exist both in the city center and the urban periphery. In this case, income could have a much greater impact on proximity to FMPs on the fringe of Harris County, and less of an impact at the core, where race and ethnicity may play a greater role.

Map 9. Median Income Standard Deviations



Limitations

There are specific limitations with the methodology that must be mentioned. First, the data used to inform previously flooded areas may not be theoretically consistent with the data used to inform the Rebuild Houston projects. Rebuild Houston cites the floods resulting from Hurricane Allison as a major motivator to remap the flood plain, determine current flood risks, and ultimately reduce flood damages. Tropical Storm Allison Recovery Project is mentioned throughout the website. However, the data I used to map previously flooded areas is all stream gauge data and describes flooding due to bayou and stream flooding. A great deal of flooding during hurricanes and tropical storms is also from rainfall and may not have anything to do with nearby bayous and streams. The Rebuild Houston projects may not be intended to address this kind of flooding (which is typically dealt with using levees) and may instead be intended to address flooding that occurs as a result of rainfall away from bayou and channel networks. In order to address this source of measurement error, I would need a map of flooded areas, both due to bayou bank overtopping and stagnant water from rainfall.

Second, others measures of “investment” from the city should be considered. While the TIRZ variable sought to identify areas that are considered economic investments, there are a number of other ways to identify such areas – for example, office spaces in Houston tend to be important real estate, especially for foreign investors (Feagin, 1987), and could be an indicator of areas that generate a great deal of exchange value. I also tested a “hospital proximity” variable to account for institutional bias towards previous investments; Rebuild Houston is likely to prioritize infrastructure that is particularly important in post-flood conditions. Unfortunately, I was unable to verify if all

the hospitals were built before Rebuild Houston began construction on the FMPs and ensure the data would still be cross-sectional. Therefore, it is quite probable that an additional explanatory variable with a higher correlation to my dependent variable would both improve model fit and cease confounding the median household income variable.

VII. CONCLUSION

Future Directions

In considering improvements for the model, it might be beneficial to consider the urban core and the urban periphery as two separate models. This might address some of the nonstationarity as well as identify differences in the way that race, ethnicity, and socio-economic status impact a neighborhood's proximity to publicly-financed flood mitigation projects.

One could also improve the model by stratifying the dataset by distance to urban core. When examining maps 2, 3, 7, and 8, it seems as though certain built environment characteristics, racial and ethnic neighborhood makeup, and income is influenced by proximity to core. By creating strata, the confounding influence of the core on these characteristics could be removed and core data would be examined separately from periphery data. There are some limitations to using stratifications, such as the great increase in degrees of freedom. To avoid using stratifications, one could also use interaction terms in the model that capture the variable being tested as well as its proximity to core.

Recommendations

While this study focused on the way that public amenities are distributed around flood-prone Houston, it is important to remember that FMPs are only one part of the equation to building a resilient city. As Fu (2016) points out, mitigation only serves to lessen the direct impact of catastrophes. These innovations do not necessarily help cities

withstand disaster and recuperate quickly; resiliency is a result of redistributive justice before disasters hit, better infrastructural and planning decisions, and compassionate policies that aid the most vulnerable groups first following disasters.

Drainage programs are a way to continue building without adapting in any meaningful way. As Molotch (1976) points out, while people do tend to support “good planning principles” in theory, in practice this rarely means limited growth or conservation. In fact, public administration officials’ idea of good planning often entails planning for “sound growth”.

Disturbingly, Harris County Flood District (HCFD) officials insist that built flood retention areas to replace these valuable natural prairie and grasslands are just as, if not more beneficial. Mike Talbott, former head of the HCFD argues that new development is rigorously mitigated with widened channels and stormwater detention (Collier and Satija, 2017). However, these claims overlook the fact that wetlands are not just beneficial for retaining stormwater – they come with a host of other benefits, such as reducing the Urban Heat Island effect, serving as recreational areas when dry, and filtering toxins from the water that ultimately ends up in the Gulf. The remarks of Talbott reflect the sentiment that Molotch warns us of – HCFD is but a growth statesman, an advocate for a certain kind of development, and certainly not the defenders of a sound environmental policy.

Furthermore, extensively engineered drainage systems are a sign of the eco-modernist approach that has largely led the environmental programs of city government. The belief that Houston can engineer and build its way out of risk is reflected in the Urban Houston Framework: A Case Study for the H-GAC Regional Plan for Sustainable Development report released by the Houston-Galveston Area Council (H-GAC) in 2013.

The report is dominated by a discussion of how sustainability and flood improvements can be economically beneficial and improve exchange values of land: greenspaces raise adjacent property values, parking garages waste usable flood area (UFA) and do not generate income, and requiring low-impact development standards for all new construction would inhibit beneficial development. The hesitancy to acknowledge the problems caused by development is a sign that city planners and councilors have pinned all their hopes on drainage projects as being the technological solution to flooding.

A singled-minded focus on exchange values effaces the reality that the real estate market contributes to segregation in America. As the history of New Orleans illustrates, Progressive Era flood drainage engineering actually further segregated and worsened conditions for the Black population because of the way that they were barred from accessing better neighborhoods. As drainage systems lowered the water table and opened up new areas for settlement, real estate practices and policies catered to white populations and contributed to the racial geographies that we see today (Colten, 2002). Today, areas with subpar drainage and more frequent flooding have lower values on the property market and are often the only areas that a low-income family can afford to rent or buy housing. A study from the NYU Furman Center found that 80% of the rental units in the 100- and 500-year floodplain are affordable housing — either public, subsidized, or rent-stabilized housing (Findlan et. al., 2014). Only building affordable housing units in less-desirable areas sends the message that one’s quality of life should be determined by income. It is imperative that the City of Houston, in the process of rebuilding public housing units that were previously built in a flood plain and subsequently devastated by

Hurricane Harvey (Popkin, 2017), reconsider the way affordable housing sites are chosen.

Of course, affordable housing is not the only development that takes place within flood zones. A market which devalues flood prone land actually incentivizes developers to buy up this cheap land, build multiple residential units, and make windfall profits. Although H-GAC conveys the council's commitment to infill and densifying the urban core, this can result in higher land values, which may further pressure developers to buy up cheap, flood-prone lots. Without a proper acquisition fund to buy up these lots and stringent regulations on where development can occur (as well as the updating of outdated flood maps), Houston will continue to see more development happening in risky areas of the floodplain. Already, a developer named Meritage Homes is looking to build 800 houses within a 100-year flood plain and a watershed in which more than 2,300 housing units were damaged by Harvey (Morris, 2018).

The report also suffers from a lack of discussion around what would constitute a fair outcome for Houston's residents. While the report does mention a goal to "Enhance community stability, accessibility, and equity", there is no meaningful discussion of what equity means and what kind of outcomes would be considered equitable. Furthermore, the report notes that drainage projects take a "Worst First" approach, in which monies are directed towards Urban Centers, yet it is not clear if "worst" refers to the level of flooding, the social vulnerability of the area, or a combination of the two. This also ignores the fact that many low-income tracts outside the urban core have suffered greatly in past floods.

Rebuild Houston's use of Infrastructure Analytics also ignores literature which finds that one's experience following flooding events is highly impacted by gender. The act of rebuilding and recuperating is significantly more difficult for women-identifying persons, as they are typically the primary caregivers for children and elderly family members, and leads to additional mental and financial stress (Walker, 2011; Fothergill & Peek, 2004).

Other groups limited by their mobility, such as those living with disabilities, the elderly, female-headed households (who are less likely to own cars), and the incarcerated, are often neglected by public officials in evacuation plans. Harvey raged for four days before officials evacuated 6,000 inmates from five prisons, largely due to pressure from the media and concerned families of the inmates. Harris County Jail was still not evacuated during that time, despite being located directly next to a flooded portion of the Buffalo Bayou. (Goodman, 2017). Media presence also prompted the evacuation of 18 residents left in waist deep water at La Vita Bella living facility in Dickinson, Texas. The inability to escape rising floodwaters should be incorporated into Rebuild Houston's plans to mitigate flooding.

In order to build the resilient, green, and prepared city that Rebuild Houston asserts is possible, the city must examine assumptions around equitable flood management. Harris County officials must dispel the myth of the rising tide lifting all boats and recognize the disparate effects that flooding has on marginalized residents.

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