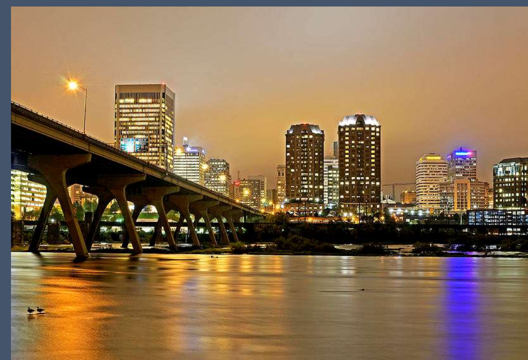

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Investigating the Links Between Richmond's Air Quality Issues and Environmental Racism

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Environmental Studies Thesis

I)Abstract

With breathable air being a resource inequitably distributed among populations based on race and socioeconomic status, this study's objective was to analyze heat and air quality distributions in Richmond, Virginia and provide recommendations for minimizing its effects throughout the city. Richmond provided an ideal subject for this analysis as it has a lengthy history of racial segregation and discrimination and is one of the worst ranking cities for Asthma sufferers. Background was given on environmental racism as a means of systemic disproportionate pollution distribution to minorities, urban air pollution(via Fine Particulate Matter/PM 2.5) and the historical housing segregation process known as redlining. These aforementioned issues contributed greatly to the environmental vulnerability of parts of many American cities, including Richmond. Later, research was done on the specific environmental racism realities within Richmond. Using heat data from the summer 2021 Virginia Heat Watch Project, the CDC's environmental vulnerability Index, historic maps of redlined neighborhoods in Richmond, and the Berkeley Environmental Justice Index, this study found that areas of Richmond with the greatest socioeconomic and environmental vulnerability to aggregate air and heat pollution were located in the poorest and most racial minority dense areas of Richmond. This analysis recommended that efforts to increase public awareness of environmental racism, continue to finetune an aggregate environmental justice index, and to create a government agency in charge of monitoring and reducing environmental vulnerability would be the best steps forward.

Key terms: Urban Heat Island, Redlining, Environmental Racism, Particulate Matter (PM 2.5), Environmental Vulnerability Index

II)Introduction and Background

Urban Air Pollution

Urban air pollution, while its effects are often most felt in disadvantaged communities can persist in a myriad of forms and spatial levels. Common forms of air pollution experienced by cities such as Richmond, VA include particulate matter, Nitrogen Oxides(NOx), Carbon Oxides(COx), and tropospheric(ground-level) Ozone.(Gao et. Al(2019), Xing and Brimblecombe 2019 and Zipprich et. Al (2002). These can be specifically harmful to minority-dense and impoverished communities, as they tend to be situated closer to pollutant sources, lack the political, social, and economic clout to remedy these conditions, and have lower ability to afford treatment for the negative health consequences of pollution. Urban areas with high pollution levels tend to see spikes in violent crime, immunodeficiencies, respiratory disease, and higher mortality rates due to excessive pollution burden(Kristiansson et. Al 2015). Air pollution exposure plays a role in divergent health outcomes across different communities in Richmond and the neighborhoods that were historically segregated to include only Black and Brown residents are similar if not identical to the neighborhoods with the most consistent pollution and heat(Vogelsong 2020). This set the stage for the later analysis of environmental racism, which was found as a driving factor in who in Richmond would be most likely to encounter air pollution. As the city suburbanized, affluent white families could move north, west, and south of the city center into more spacious, wooded, and less polluted neighborhoods, while poorer minority families became trapped in the city. This was further augmented by the development of Interstates I-95, I-195, and I-64, which severed many formerly bustling Black corridors such as Jackson Ward, and created a less, walkable, and more polluted region. With this in mind, modern Richmonders continue to opt for the cleaner and/or more manageable air quality in the Suburbs, further exacerbating the tendency to push pollutant emitting sources such as toxic waste facilities into poorer neighborhoods miles from the affluent suburbs.

Urban Heat Island Effect

The urban heat island effect occurs when the combination of lack of tree-cover and non-reflective pavement types such as asphalt, cause urban areas to experience considerably hotter temperatures, sometimes 5-15˚F hotter than their suburbs. This can be especially true in Richmond, a city with drastic variation in tree cover and asphalt-heavy streets. (Eanes et. Al 2020 and Plumer et Al. 2020). Communities vulnerable to heat in Richmond tend to be similar to the ones most vulnerable to criteria air pollutants, with Black and Brown neighborhoods seeing the worst of the heat and lowest opportunities for relief (Plumer et. Al 2020) (Hoffman et. Al 2022)(SMV 2022). With sparse access to public parks, weak or no air conditioning, and few trees, poorer neighborhoods, especially public housing projects in Richmond's East End have tended to suffer the greatest departure in maximum temperatures from cooler suburbs. Since urban heat island effects are driven by absorption of heat during the day and release of heat at night, temperatures in the most vulnerable regions of the city remain incredibly warm at night, with effects happening on a much more localized scale than commonly perceived air pollutants(Yang et. Al 2016). Thus, the local scale of the urban heat island effect makes it incredibly vulnerable to environmentally racist behaviors such as the 'Not in My Back Yard" (NIMBY) effect. Cooler, more densely forested suburban communities in Richmond, thus become more attractive, as people avoid the hotter city. With heat also being associated with increased mortality, violence, and immunodeficiency, suburbanites tend to condemn cities as naturally dangerous areas and thus do not see an incentive to improve urban pollution when they have resources to relocate(Kristiansson et. Al 2015). In a staunchly segregated city like Richmond, it became clear that urban heat was addressed as a local threat and often ignored by less affected suburban areas. Areas with the worst pollution in Richmond tended to be the ones where people of color were confined, and overtime became acceptable as the norm because of the assumption that once segregation was over cities would not suffer different temperatures based on race. However, due to the precision locality of heat islands, communities see a generational continuity of heat exposure. Heat related illness continues to be more probable in these regions, and over time this has likely accounted for the considerable changes in life expectancy between different regions of Richmond.

The stifling heat and humidity of Richmond should seemingly be ameliorated by the city's position along the James River, however most of the river access, even its public parks, are difficult to reach by foot, and in areas like the West End and Stratford Hills, restricted to private properties. The most prime areas for recreation in and along the river can be a cumbersome hike from the disadvantaged neighborhoods whose residents often have limited personal vehicle access, or public transit options that connect them directly to the river front. This added burden even further increases the inequality in heat exposure throughout the city of Richmond, as even on the hottest days of the year, affluent, White communities have a considerably easier time accessing relief from the heat, while minority communities are left sweltering within the borders of an archaic residential segregation system. This will continue to worsen in coming decades as climate change continues to increase the number of heat wave days cities like Richmond see every summer(Douglas 2020).

Redlining

This entails a process an early to mid-20th century practice in which Black and Brown people were excluded from home loans for suburban housing and condemned to the poorest and often most polluted and least wooded parts of the city(Gross 2017). From there the system could compound on itself zoning the cleaner air and abundant green spaces in Richmond's affluent West End for White residents, and the industrial freeway-laden corridors for racial minorities. This system effectively sealed the fate of neighborhoods at the lowest ranks of C and D, as heat and pollutant domes for minority residents, and neighborhoods ranked A and B, as air quality oases for affluent white communities(Plumer et. Al 2020). The A and B ranked neighborhoods became prime locations for affluent White citizens to flee the city for spacious housing in the suburbs, while minorities were forced to swelter in the crowded C and D neighborhoods, which would soon become the center of Richmond's nascent section of Interstates I-64 and I-95 and their eventual corresponding spurs and beltways. This location at the epicenter of heat trapping pavement and NOx and COx traffic pollution created a section of starkly unhealthier air compared to other areas of the city(Gao et. Al 2019, Zipprich et. Al 2002, Xing and Brimblecombe 2019). In the modern era, the racial composition of these neighborhoods remain similar to that of the 1930s and 40s, a sobering reminder of the comorbidity of race in Richmond. Aforementioned physical and mental health effects from heat and pollution such as immunodeficiencies, exacerbation of violent behaviors, and respiratory issues, continue to disproportionately affect minority communities in frequency and severity(Kristiansson et. Al 2015). With this in mind, much of the theoretical framework of this analysis revolved around the glaring health disparities that illustrated purposeful allocation of pollution to historically subjugated groups. Redlining also manifested itself as a defining symptom of environmental racism, as it functioned as an objective of an overarching system to put the health, safety, longevity, and prosperity of one race over another.

Environmental Racism

Environmental racism is best described as the process in which environmental costs and benefits are purposely distributed unevenly across racial and socioeconomic identities(Pastor et. Al 2002) (Mikati 2018 et. Al) (Buzzelli et. Al 2004) (Lercher 2007) (Vaz et Al. 2017). In Richmond, this is most visible in the city's largest minority and largest demographic, the Black community. As the former capital of the Confederacy and a staunch participant in the Massive Resistance Countermovement to the Civil Rights Movement during the 1960s and even spilling into 1970s, Richmond is no stranger to racial discrimination. Decades after the final breaths of Jim Crow legislation subsided, minorities in Richmond remain stuck in poorer, more polluted regions of the city. This arose through the process of white flight in which affluent white Richmonders, with an assist from the Redlining process that barred minorities from suburbanizing, white Richmonders could move to the more wooded and thus cooler parts of the area, while minorities were trapped in the heat island. Overtime the heat island remained, because suburbanites could use their influence to lobby to keep pollutant sources such as heavy industry, toxic waste sites, and freeways out of their backyards, while poorer communities, often the minority communities, could not. As recently as 2020 the hottest parts of Richmond, contain similar demographics and socioeconomic realties as decades prior when segregation was still upfront and explicitly legal(Eanes et. Al 2020, Plumer et. Al 2020). Ultimately, environmental racism means that in Richmond and virtually every other American city, The distribution of heat and air pollution are purposely selected to impact minority neighborhoods.(Anderson 2020, CBF, 2022)(Li et. Al 2019)(Ash et. Al 2013).

Theoretical Framework and Thesis

This analysis operated off of theoretical framework supported by several guiding axioms. First among them is the overarching tendency of poorer and majority minority neighborhoods experiencing the worst air quality and heat island effects in the city of Richmond. Using the aforementioned data, on redlining, environmental justice, urban air pollution, and urban heat islands, a correlation emerged between demographic status and heat and pollutant exposure. Next, I deduced that these pollution disparities must also have contributed to the divergent health outcomes across the city, and thus minority communities would see higher rates of pollution and heat related illness. This frame creates more urgency for mitigating pollution as it shows the life and death consequences of environmental injustice. Furthermore, this analysis aimed to give excessive heat a pollutant status as more classically defined criteria pollutants(particulate matter, COx, NOx, etc), because of the manufactured nature of heat islands and their direct threat to public health and environmental quality. Lastly, the framework culminates in the overlap of excessive heat, sparse tree cover, high minority populations, industry and freeway siting, air pollution, and environmental injustice. With that in, mind this project's purpose was to see the degree to which each of these layers would overlap, and resulted in the production of maps with considerable overlap in these categories.

III) Methodology

The complexity and interdisciplinary structure of this analysis and its goals works best under several key guiding axioms. First among them is the severity and salience of the issue of unequal consequences from air pollution in the city of Richmond. Upon confirming the severity, it became clear that pollution distribution had a relation to race. Within the definition of environmental racism, there is an axiom of intentionality, in which the effects are part of a systemic effort rather than chance. As a result of intentionally distributed pollution, the reasonable assumption is that public health consequences related to said pollution are important and relevant as well. Ultimately, each of the aforementioned foundational theories in the completion of this project can be collected tangibly in the form of qualitative and quantitative data as outlined in the subsequent paragraph. Collecting data for this project will be a challenging undertaking, due to the mix of methods needed. With the pragmatic research view lending itself best to my analysis, I will be collecting qualitative data and quantitative data to reflect the connections between Richmond's racist history and its current reality of air pollution patterns. Quantitative data was used for temperature gradients and environmental vulnerability Virginia Heat Watch, University of California Berkeley's Environmental Justice Index and

Centers for Disease Control(CDC) Environmental Vulnerability Index. Qualitative data was used to observe redlining and environmental racism.

Heat Data Collection

In order to study Richmond's urban heat island effect, I needed to establish the regional units of analysis for temperature gradients. This was done using the neighborhood blocks by the Virginia Heat Watch following existing regions known as census tracts. For each neighborhood block within the official boundaries of the city, the VA Heat Watch study took mean daily afternoon temperatures in °F on July 15, 2021. This date was picked to show a snapshot of peak summer heat in Richmond as July tends to be the hottest month and the mid to late afternoon hours tend to be the hottest parts of the day. Averaging mid to late afternoon temperatures also showed the storage capacity of the heat island effect, as urban hotspots tended to heat up faster and hold heat longer when compared with their cooler counterparts. This data was compiled into a table, and then with ArcGIS turned into a map depicting average afternoon temperatures in varying color intensity for each part of Richmond. Major highways, the Richmond City Limits, interstates, and the James River were emphasized. This showed sources of heat trapping pavement, the scope of the analysis and the moderating influence of waterways (respectively). Later two tables were compiled to show the 10 hottest and 10 coolest neighborhoods by average afternoon temperature on the day of the Heat Watch Study. This was done using the sorting function on an excel file to take the 148 neighborhoods and pick the 20 extremities.

CDC Environmental Vulnerability Index

To study the aggregate environmental burden of each census tract in the city of Richmond, toxic waste site proximity, conventional air pollutants (e.g.COx, NOx, VOCs, lead, ozone, PM 2.5), socioeconomic status, race, and education were used as components of the CDC's environmental vulnerability index. A score of 0 indicates perfect environmental justice, while 1 indicates extreme environmental injustice. The aggregate index was particularly useful in quantifying the severity of environmental racism in Richmond, as until relatively recently, environmental racism was not researched quantitatively. The multifaceted nature of this index also helped insulate against anomalies such as Scott's Addition, a heat extremity, but otherwise affluent and relatively low burden area. The CDC data was sorted within its spreadsheet and compiled into two tables with the 10 best and worst neighborhoods in Richmond by EVI. Data from this list uses 2018 indices based on 2010 Census Tract boundaries. The 2020 tract boundaries did not change the Geography enough to be relevant at the scale of heat island data.

UC Berkeley EJI Data Collection

Similar to the CDC, Berkeley's mapping for Environmental Justice Project data compiled a vulnerability index for each census tract. Zooming in this study's other dimension of air quality, PM 2.5 data for each of Richmond's 65 census tracts. This was indexed on a percentile with 1 being the best(better than 99% of the state) and 99 being the worst(worse than 99% of the state). This data was depicted in the project's interactive map, with percentiles being represented by increasingly dark blues with increasing percentile numbers.

Redlining and Race Data Collection

Finally, racial data was taken from the 2019(the closest demographic analysis to the 2018 CDC index and 2021 Berkeley index), to show the percentage of white population in each census tract. This was compared to the heat data, PM 2.5 data, and a 1940 map of redlining districts in Richmond to show the thesis of this project via overlap of conventional air pollution, burden, race, and heat.

IV)Results

Heat Island Results

The hottest sections of Richmond end up being in the northwestern corner near the junction of I-195, I-95, and I-64(locally referred to as the Bryan Park Interchange), Jackson Ward, Southern Richmond along Rt 360 and I-95, and the East End(See Figure 1). Table 3 hottest neighborhoods in Richmond falling in these areas. Mean afternoon temperatures in the hottest regions of Richmond hovered around 92˚F, with Scott's Addition, Belt Center, Monroe Ward, Jackson Ward, VCU, and Forest View representing the specific neighborhoods with the highest heat burdens. On the cooler side, mean afternoon temperatures in the 10 coolest neighborhoods in Richmond peaked at 89˚F(Table 4). These neighborhoods include densely wooded areas and parklands such as Maymont, Southampton, and Stratford hills. The latter two are especially salient as they are the polar demographic opposite of hotspot neighborhoods like predominantly Black Monroe and Jackson Wards, being the most affluent, White parts of the city of Richmond's Southside. Stratford hills also straddles the south bank of the James River, adding significant opportunity for cooling and recreation. While 3˚ appears small, this is a difference in averages which means that at any given time, temperatures could still be considerably more divergent across the hottest and coolest parts of the city. In early afternoon, the urban heat island pockets of Richmond start off warmer, because they held onto heat from the previous night due to pavement absorption. Inversely, cooler regions start off considerably cooler, due to sharper drops in temperatures from the previous night and greater shade. While 5pm temperature departures between Jackson Ward and Maymont may seem narrow, Jackson Ward will exceed and remain above 90˚ considerably longer and more often than Maymont, whose average afternoon temperature barely scrapes this threshold. Heat islands are a persistent effect by definition and are most easily spotted when taken in context of a several hour time span in which city centers are quick to heat and slow to cool. Richmond demonstrates the classic set up of an urban heat island and as was seen further in my analysis, this is heavily dependent on race.

UC Berkeley PM 2.5 Index

Unlike heat, PM 2.5 vulnerability in Richmond is relatively equally disbursed, as most of the city falls in the 70-80th percentile marked by the medium-deep blue shades(Figure 2). However, the areas closer to the 80th percentile mark(shown in deeper blue), were concentrated among Interstate and freeway interchanges. This correlated loosely with heat and vulnerability, however methods of ascertaining particulate matter vulnerability are limited as the spatial scale, and measurement of PM 2.5 over extended periods of time remains a process with considerable room to grow. With Richmond being a decentralized region with sinuous suburban sprawls, particulate matter from traffic, especially high profile, and heavy-duty vehicles, can widely spread the burden of PM 2.5. With the microscopic size of 2.5 micrometer particles, this pollution can spread through larger sections of air easier than the local domes of urban heat that depend on the nexus of low-shade high pavement conditions. More research is necessary to improve the understanding of PM 2.5 and its effects on Richmond's air quality. However, not unlike heat, raw data tells part of the story, as the burden is augmented in communities where mitigation options are limited.

CDC Aggregate Environmental Vulnerability Index

Unsurprisingly the most overall environmentally vulnerable census tracts from the CDC data mirrored the locations of the hottest neighborhoods from the Heat Watch Data with the opposite being true for the cooler neighborhoods(Table 1-4, Figure 1). The top 10 most vulnerable neighborhoods across every major demographic and pollutant exposure category fell in Richmond's East End south Richmond's impoverished and industrial Rt. 1/301(corridor(parallels I-95), and a triangular agglomeration of neighborhoods between Rt 360, and Rt 60 in south Richmond(Table 2). Census Tract 204, containing Richmond's public housing projects of Whitcomb and Mosby courts had the upper limit of environmental vulnerability at the maximum 1.000 vulnerability index. This value is not surprising as this is the most disadvantaged, stigmatized, and often underserved part of the city(Table 2). The top 10 EVIs ranged from 0.9765-1.0000 and averaged 0.9909, showing a cataclysmic disproportionate allocation of pollutants to low-income and/or majority minority communities in Richmond. On the other end of the spectrum the top 10 least vulnerable census tracts, with the exception of Census Tract 208 that covers rapidly gentrifying Libby Hill and Church Hill, were found west of Rt 1/301, in regions such as the Near West End, (Far West End is in neighboring Henrico County), the Fan, Cary Street Rd between Carytown and River Road, Maymont, Forest Hill, and Tuckahoe(Table 1). Unsurprisingly these neighborhoods were also directly on or close to the James River, the most affluent parts of Richmond, the most wooded parts of Richmond, the coolest parts of Richmond(Table 4)and home to the most abundant park space. The average EVI of the 10 least vulnerable neighborhoods was 0.0423, with a range of a 0.1038. There was a perfect score of in the Richmond section of the Tuckahoe(Census Tract 504) region encompassing the overlapping Henrico and Richmond neighborhoods around the University of Richmond(Table 1). The CDC Environmental Vulnerability index gave this analysis a wholistic insight into the distribution of toxic air across racial and other demographic geographies in Richmond.

Redlining and Race

Figures 3 and 4 show the lack of change between the 1930s-40s and present day in terms of racial demographics in the wake of redlining. This is particularly salient as these overlap incredibly symmetrically with Tables 1-4. Neighborhoods in the high-ranking A and B category mirror the census tracts that are 70-97% White according to 2019 ACS data, while neighborhoods in the low-ranking C and D categories are 70-95% racial minority inhabited(Figure 3). Such an egregious overlap demonstrates that continued upholding of decades of segregation and the clear intent in the selection of who in Richmond will be most likely to experience heat and pollution. Tables 1 and 2, further drive this point home, as the CDC vulnerability acknowledges demographic variables such as race and income as comorbidities for pollution effects. 80-year-old segregation practices are alive today, as a region's former redlining rank will likely predict its current demographics. Segregation in housing, and thus by definition, environmental damage exposure, is still an ongoing and systemic process with grave consequences for disadvantaged populations. The lens of race and socioeconomic status ties the entire project together, as it explains the purposeful distribution of environmental injustice across the city of Richmond.

V) Discussion and Conclusions

While the results were largely conclusive that minority and low-income neighborhoods were most likely to experience the brunt of the heat and pollution, there were exceptions in a few neighborhoods, as well as further complexities of PM 2.5 measurements. The discussion will evaluate the conformity to established scholarship of each section of the project, analyze and explain departures from expectations, and finally offer possible next steps to solutions for the inequitable distribution of air quality in the city of Richmond.

Heat Island Effect Analysis

Studies conducted based on Richmond's history of redlining and its current demographic trends regarding heat island distribution were confirmed by this project finding the hottest neighborhoods being the most minority dense, most impoverished, and lowest ranked under redlining(Plumer et. Al 2020)(Eanes et. Al 2020)(Mapping Inequality 2022)(American Community Survey 2019). These effects also contribute to health disparities across different areas of Richmond as heat related illness is obviously higher in urban heat islands, especially impoverished housing projects with faulty or nonexistent air conditioning(Kristiansson et. Al 2015). With the ever-escalating threat of global climate change, Richmond, alike many other cities, is seeing a precipitous increase in heat waves every summer, with 90-degree temperatures stretching deep into September and sometimes October, increasingly frequently in recent years. This burden will be felt most in heat-weary communities that barely make it through a normal summer in Richmond and will manifest itself as a catastrophic public health threat for vulnerable communities in the coming decades as summer in Richmond continues its climate change induced intrusion into autumn(Douglas 2020). Given the aforementioned findings of racialized heat burden, it is clear which communities will endure the most of Richmond's lengthening summer, and which communities will remain oases(Hoffman et. Al 2022)(SMV 2022).

Aggregate Vulnerability and Environmental Racism Analysis

The glue that held this analysis together was the Aggregate environmental and social vulnerability index calculated by the Centers for Disease Control. This multifaceted index gave synthesized a myriad of major pollution threats into an accurate predicter of the safest and most toxic air in the city of Richmond, as well as the socioeconomic power of residents to remedy these conditions. Unsurprisingly, affluent White Neighborhoods in Richmond's West End, Fan District, large park spaces, and along the flatwater portions of the James River, tended to have the lowest vulnerability indices thus affirming prior studies' findings that low-income and majority minority communities were forced to encounter the highest pollution burdens(Anderson

2020, CBF, 2022)(Li et. Al 2019)(Ash et. Al 2013). Tables 1-4 and figures 1 and 3 further support these findings by showing the highest environmental vulnerabilities are found in majority minority neighborhoods that were subject to the worst categories of segregation by redlining.(Mapping Inequality 2022)(Gross 2017). With the lack of change since the onset of said discriminatory policies, it is clear that prevailing NIMBY attitudes, lack of accurate information, and lack of political and economic power have upheld redlining in a de facto re-incarnation of Jim Crow Era realities.(Mikati 2018 et. Al) (Buzzelli et. Al 2004)(Lercher 2007)(Vaz et Al. 2017). Furthermore, Scholarship on environmental injustice remains limited and subject to immense partisan and societal pushback. This allowed minority communities to be targets for toxic waste sites, industrial corridors, and freeway expansions because of their lack of economic, political, and social agency to rectify these circumstances. Unless earnest efforts are made to educate the entirety of Richmond on these realities effective and substantial progress will not be made on improving the air quality of Richmond.

Departures

Despite expecting PM 2.5 to fall in line with other forms of pollution and their disproportionate pollution distribution to minority communities, PM 2.5 data in the city of Richmond was inconclusive, shaky, and varies at too large of a spatial level to be analyzed within the context of a single city. There is likely a link at a state level between an entire city's racial and socioeconomic composition and PM 2.5 exposure, however this measure will need more investigation and finetuning. However, this does not undermine the salience of studying air pollution and heat islands, and with further study, it could be uncovered that environmental injustice is similarly applicable across all pollutants. Even if particulate matter behaves differently, understanding the big picture of urban air pollution, will help better understand the solutions needed to ensure its distribution is not disproportionate and targeted to minority communities.

Moving onto the heat deviations, two neighborhoods broke the mold of this study's chief hypothesis. Scott's Addition, a trendy, affluent, predominantly white neighborhood built out of the skeleton of an industrial district is one of the hottest parts of the city(Figure 1). One of 10 least vulnerable areas in Richmond according to the CDC's environmental vulnerability index, was Church Hill, a historically redlined Black neighborhood(Mapping Inequality 2022)(Figure 4). Scott's Addition can be best explained by the fact that it is sparsely wooded and flanked by massive interstate interchanges and ample pavement. Despite its heat, the socioeconomic status of the relatively low residential population of this mostly commercial district is such that dwellings can afford up-to-date, powerful air conditioning systems as well as higher quality ventilation. This allows Scott's addition to avoid a high vulnerability ranking, while still experiencing excessive heat. Church Hill is best explained by the key words "historically black"(Figure 3). Once predominantly Black, the neighborhood's demographics have flipped as affluent White Richmonders are gentrifying the area due to its increasingly trendy appeal. Thus, the original Black population of Church Hill is crowded and priced out of the neighborhood by an expanding NIMBY effect forcefield caused by a sharp demographic flip. Despite the region's considerable upgrade in air quality, and relative status as an urban heat oasis, these improvements paradoxically prove a modern escalation of an environmental racism and a reverse economic redlining that skyrockets property value out of original residents' purchasing power.

Former residents of the area have likely relocated to areas still suffering from pollution as property value is obviously contingent on hazards like pollution. Despite showing the "wrong" trend Church Hill and Scott's Addition exemplify a Jim Crow 2.0 of sorts, as a new process continues the age-old trend of pollution burden being born by minority communities in disproportionate amounts. These deviations ended up telling the main story of the thesis, by illuminating the defining characteristic of environmental racism, as purposeful allocation of environmental degradation based on race.

Conclusions and Solution Frameworks

Neighborhoods in Richmond with more minorities tend to suffer the worst environmental justice scores especially in heat, hazardous material sites, and traffic pollution. While some affluent regions still see significant PM 2.5 and/or heat exposure indices, their aggregate scores remain high in environmental justice because of distance from toxic waste sites, economic opportunity to mitigate local hazards, economic clout to demand baseline environmental standards, and educational opportunity to know and claim rights to environmental justice. The use of race as a determinant for pollution exposure was purposeful at its inception. It is still at least passively upheld by affluent communities that continue to throw societal caution tape around disadvantaged areas as if they are intrinsically dirty rather than victims of systemic environmental abuse. With this in mind it is critical that we work to establish a framework for reversing the system of environmental racism and extending the right to breathable air to all Richmonders. This can be accomplished using a multipronged process that establishes clear definitions of air quality hazards, creates an entity in charge of monitoring and mitigating said hazards, setting ambitious targets for environmental justice mitigation, and by assuring symmetric distribution of information on these processes to every community in Richmond.

Initially, there needs to be a multifaceted approach, like that of the CDC Social Environmental Vulnerability Index that measures aggregate environmental vulnerability. This measure should also contain a Heat Vulnerability Index that can act as a standalone criterion as well as a factor of an aggregate index. Due to its similar negative physical and mental heath effects as classic EPA criteria pollutants, excessive heat should be considered as a form of air pollution. Everything else in the existing CDC index can stay, as it is shown to be a comprehensive environmental burden predictor in the results of this analysis.

Once pollutant criteria are agreed upon, a city-level(this can be advanced to a state and national level eventually as well) department should be created or incorporated into the existing Department of Sustainability in Richmond, whose mission is to monitor and regulate environmental vulnerability. They can also be an agency in charge of setting pollutant guidelines to inform legislation that sets limits on how high the discrepancy in environmental vulnerability index can be on average across the highest and lowest tracts, and the target for the entire city's vulnerability index. For example, there could potentially be a regulation that keeps Richmond's total EVI below 0.05, or one that prevents the top EVI from being more than 0.1 from the bottom. This would force equalization of air quality improvements and begin the necessary process of reversing decades of environmental racism.

Finally, the steps described above must be clearly and accessibly communicated to all Richmonders, including the most vulnerable communities. Suburban communities need to understand the extent of the effects of their environmental attitudes on disadvantaged urban communities, and disadvantaged communities will need clear communication on how they can find support to remedy these effects. It is imperative that there is cross-communication between the government, industry, all social classes, and racial identities, so that the entirety of Richmond can begin the complex, yet necessary process of improving the quality of air for all residents of the city of Richmond. The process will be arduous at times, and political and economic pushback will at times derail progress, however the scientific consensus is clear that these issues are of critical concern and demand attention to protect the environmental safety of all Richmonders.

Final Takeaways

What might not be one's back yard today, could have indiscriminate environmental effects down the line, especially in pollutants like PM 2.5 that are distributed at a much less local level. Furthermore, environmental destruction of cities like Richmond will be catastrophic for suburbs as economic opportunities, recreation, and centers of higher education will be compromised by increasingly frequent heatwaves, floods, and other extreme events as climate change continues to worsen. The chain reaction of the blight of disadvantaged neighborhoods will ripple its way through the economy and could cause economic hardship far beyond the borders of segregated heat and pollution domes. Additionally, as Richmond continues its suburban expansion, and neighborhoods further from the city become increasingly dense, the urban heat island effect will travel with it. Today's pollution oases could easily be the heat domes of the future. Abundant pavement in urbanized sections of Richmond will continue radiating deeper into the suburbs and exurbs as the commuting demand intensifies. The oasis of Richmond's West End will continue to move west, with property values, demographic trends, and environmental burdens shifting right behind. People just barely within their means to live in pollution oases now, won't be able to move to the next exclusive neighborhood, and thus will slide into the new class of environmentally vulnerable.

Breathable air, high life expectancy, access to green space, adequate ventilation, moderate air temperatures and working air conditioning, should not be inaccessible to large segments of the city, and definitely not on the basis of archaic means of racial segregation. With this in mind, I recommend that this analysis be used as the framework for creating a more sustainable, breathable, and equitable city of Richmond.

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VII) Figures

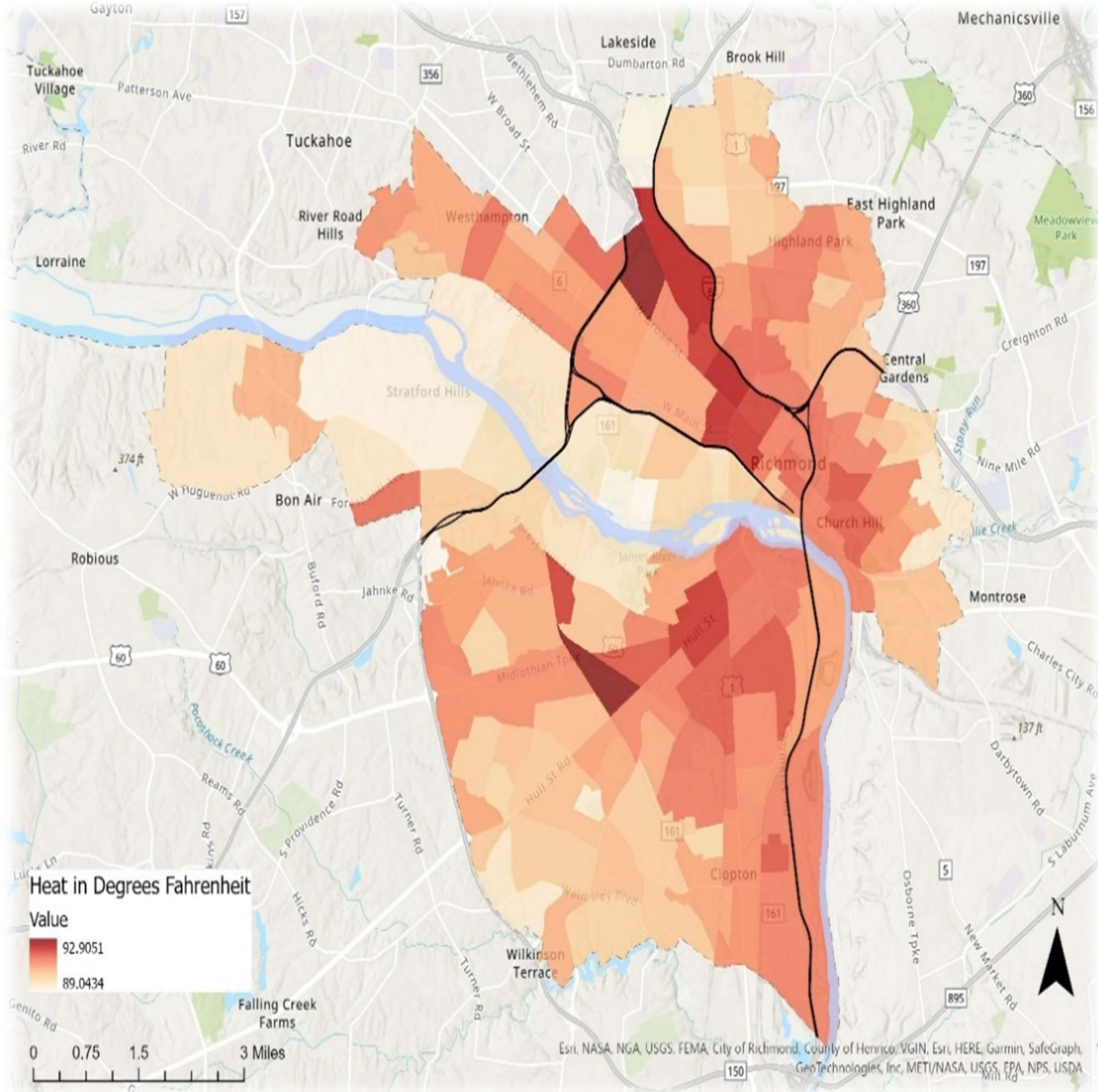

Figure 1: Mean July Afternoon Temperature(F) by census tract in Richmond, with the deeper shades of red corresponding to higher temperatures(VA Heat Watch 2021)

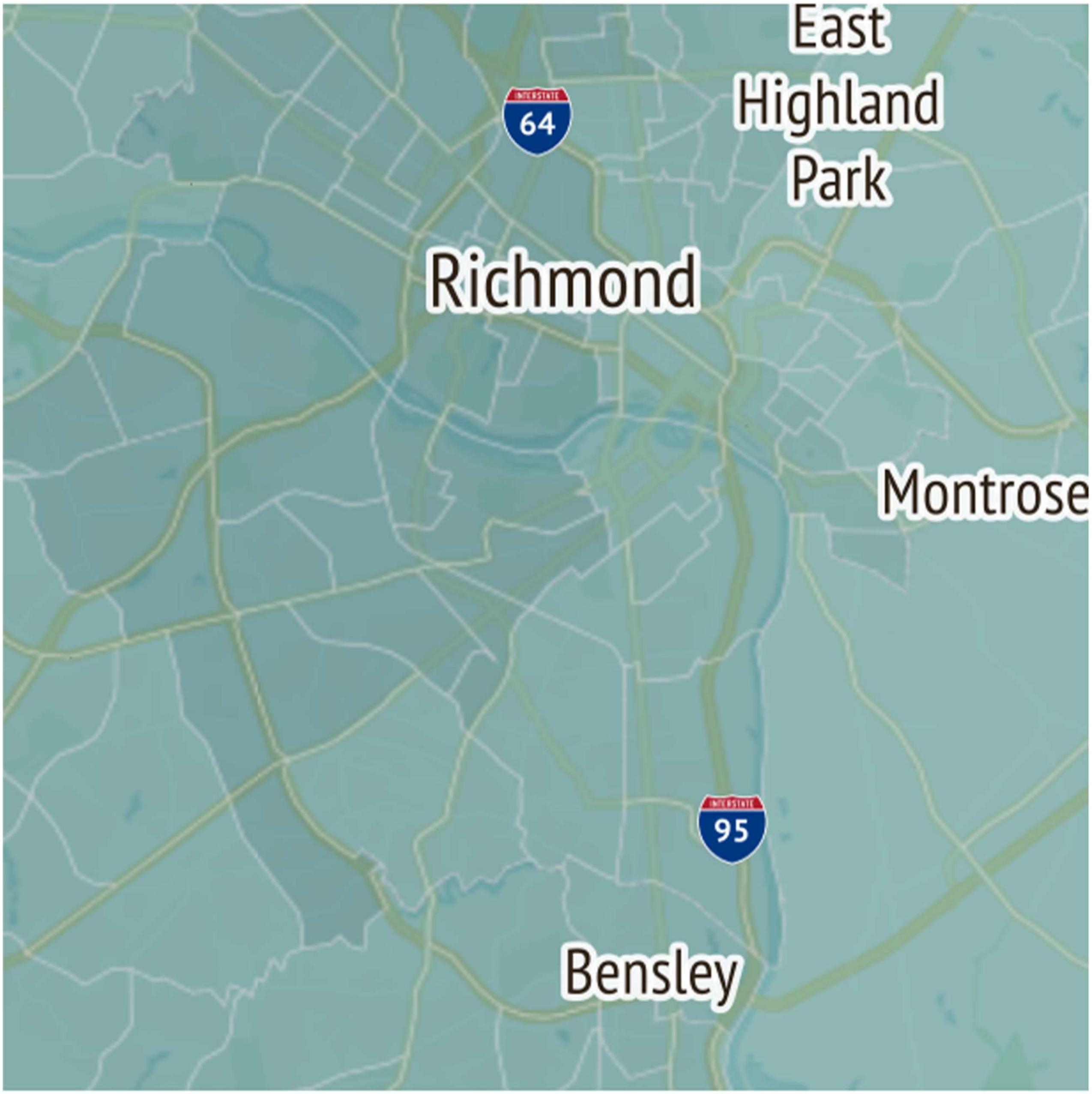

Figure 2: Distribution of PM 2.5 pollution by census tract in Richmond, VA. Darker blue indicates higher percentile and thus worse pollution. Most of the PM 2.5 is spread evenly, with only slight hotspots around the I-64, I-195, I-95, Rt. 76, and Rt 150 corridor to the north, west, and southwest of Downtown.

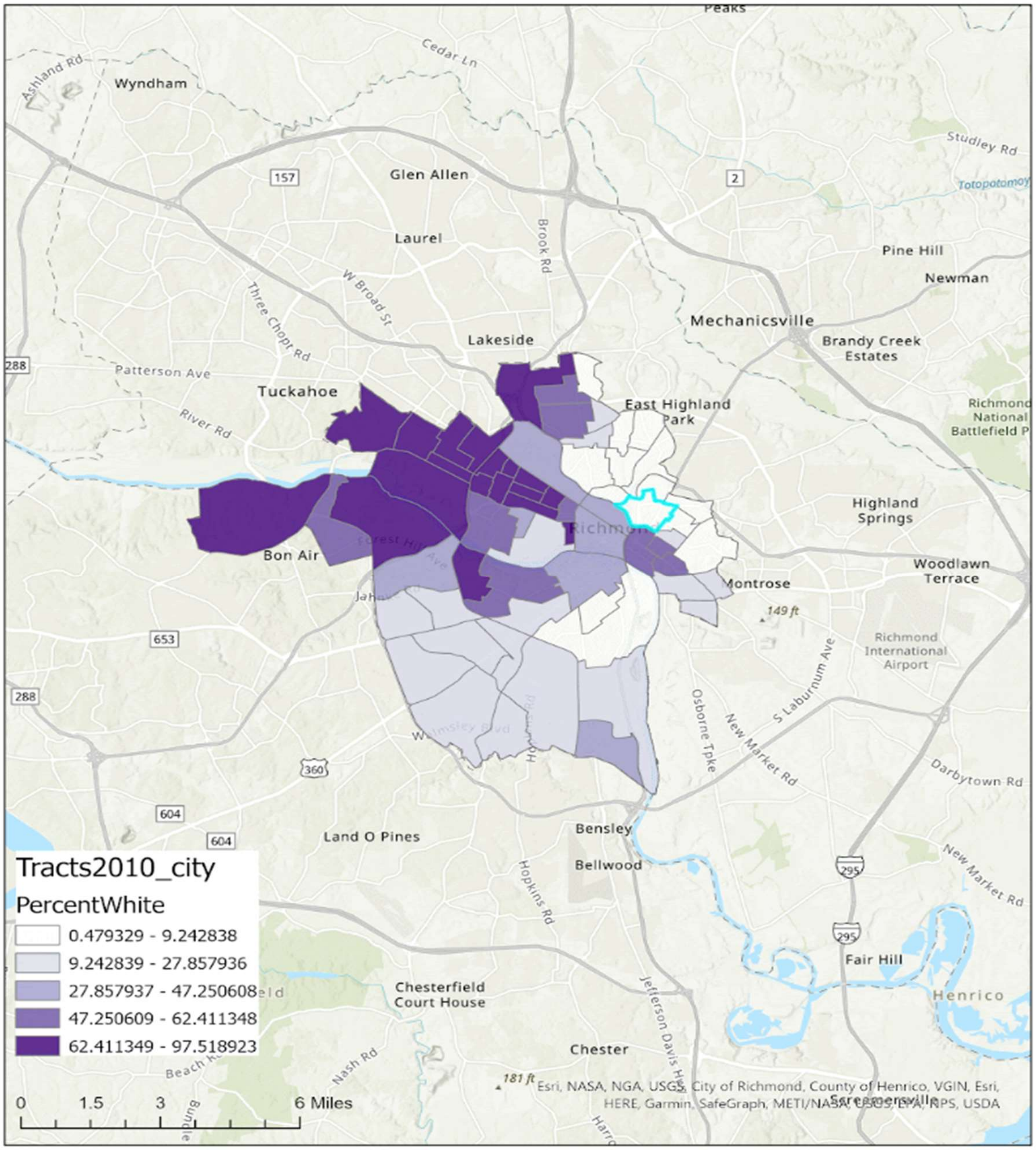

Figure 3: Percent White Population by Census Tract (American Community Survey 5-Year Estimates, 2019. Darker shades of purple indicate higher white populations.

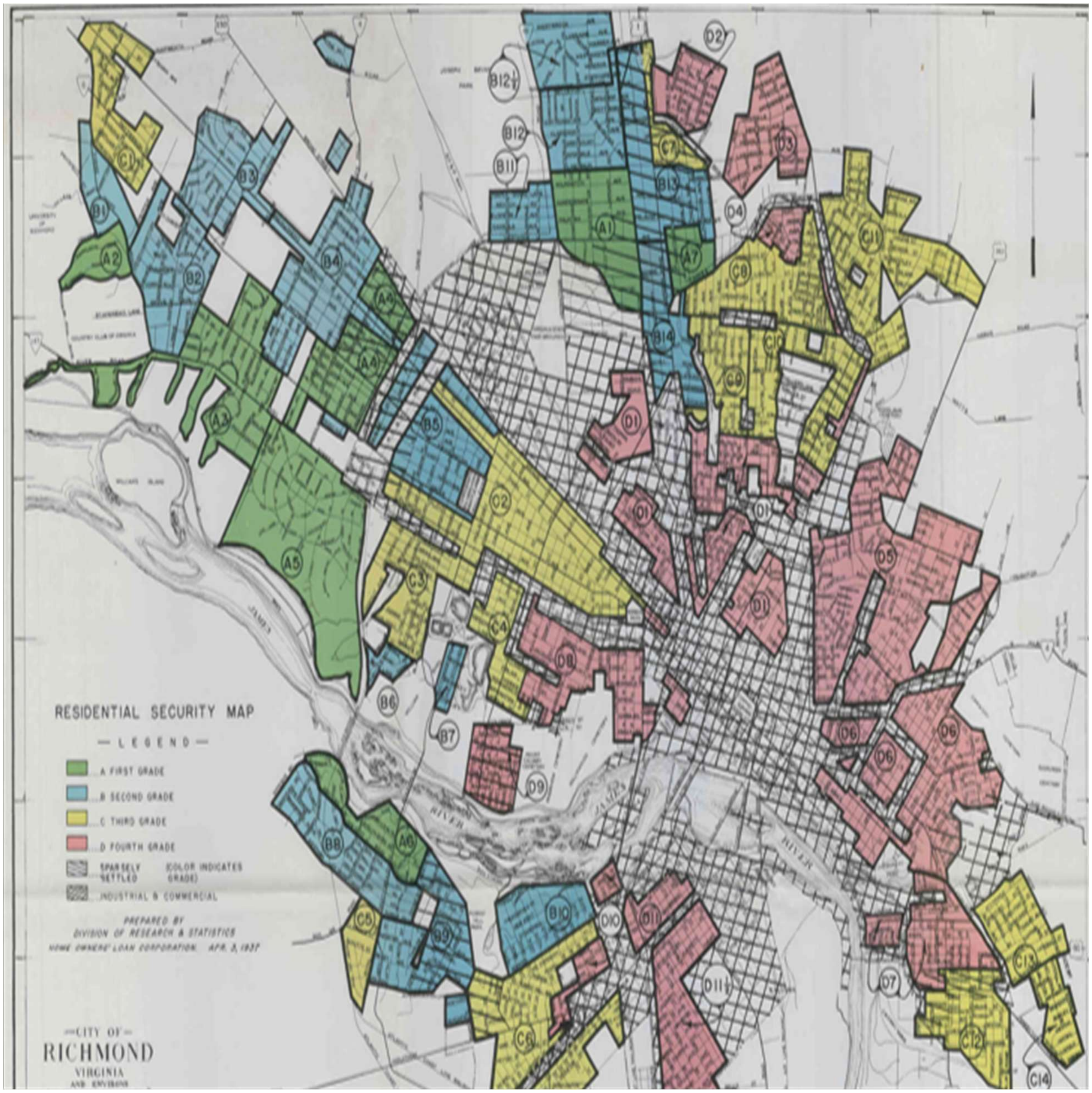

Figure 4: Map showing historical redlining categories in Richmond, VA. Rating increases based on decreasing number of minorities from D-A(.

VIII)Tables

Table 1: The CDC's environmental vulnerability index and its relevant components for each census tract in Richmond are shown for the 10 least vulnerable neighborhoods.

CDC Environmental Vulnerability Index By Region (10 Best)		
Census Tract	Region/Neighborhood	CDC EVI
Census Tract 504, Richmond city, Virginia	Tuckahoe(Richmond)	0.0000
Census Tract 502, Richmond city, Virginia	Grove Ave	0.0016
Census Tract 506, Richmond city, Virginia	Near West End	0.0171
Census Tract 416, Richmond city, Virginia	Maymont	0.0182
Census Tract 503, Richmond city, Virginia	Cary Street Rd	0.0257
Census Tract 410, Richmond city, Virginia	The Fan	0.0385
Census Tract 606, Richmond city, Virginia	Forest Hill	0.0583
Census Tract 409, Richmond city, Virginia	The Fan(West)	0.0594
Census Tract 208, Richmond city, Virginia	Libby Hill	0.1001
Census Tract 206, Richmond city, Virginia	Church Hill	0.1038
Key: 0 is high environmental justice, 1 is severe environmental injustice		

Table 2:The environmental vulnerability index and its relevant components for each census tract in Richmond are shown for the 5 most vulnerable neighborhoods.

CDC Environmental Vulnerability Index By Region(10 Worst)		
Census Tract	Region/Neighborhood	CDC EVI
Census Tract 204, Richmond city, Virginia	East End	1.0000
Census Tract 608, Richmond city, Virginia	US Route 1/301 Corridor	0.9979
Census Tract 709, Richmond city, Virginia	South Richmond	0.9973
Census Tract 706.01, Richmond city, Virginia	Warwick/Pocoshock/Woodhaven	0.9941
Census Tract 710.01, Richmond city, Virginia	Chippenham-Jahnke	0.9936
Census Tract 609, Richmond city, Virginia	South Richmond	0.9914
Census Tract 301, Richmond city, Virginia	Downtown/MCV/VCU	0.9909
Census Tract 707, Richmond city, Virginia	Hull Street	0.985
Census Tract 708.01, Richmond city, Virginia	South Richmond-Falling Creek	0.9818
Census Tract 607, Richmond city, Virginia	US Route 1/301 Corridor	0.9765
Key: 0 is high environmental justice, 1 is severe environmental injustice		

Table 3: Top 10 Hottest Mean Afternoon Temperatures in ˚F by neighborhood in Richmond, VA(VA Heat Watch July 15, 2021)

Mean Temperature(˚F) by Neighborhood	
Neighborhood	Temperature (˚F)
Belt Center	92.905
Scott's Addition	92.755
Carver	92.380
The Diamond	92.342
VCU	92.210
Monroe Ward	92.129
Swansboro	92.116
Newtowne West	92.094
Forest View	92.024
Jackson Ward	92.016

Table 4: Top 10 Coolest Mean Afternoon Temperatures in ˚F by neighborhood in Richmond, VA(VA Heat Watch July, 15, 2021)

Mean Temperature(˚F) by Neighborhood	
Neighborhood	Temperature (˚F)
Maymont	89.043408
Powhite Park	89.182523
Maymont Park	89.291116
Bryan Park	89.30312
Southampton	89.445163
Stratford Hills	89.492168
Wilton	89.649962
Broad Rock Sports Complex	89.663402
Belmont Woods	89.689901
Oakwood Cemetery	89.741366