The Case of Digital Redlining: Evaluating whether Broadband Internet Speeds are Disproportionately Accessible in Metro Atlanta

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Abstract

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This thesis aims to explore the probable effects of disproportionate access to internet capabilities across census tracts in Atlanta to understand the phenomenon of digital redlining. Defined by *Governing*, Digital Redlining refers to the "underinvestment in providing adequate broadband services to low-income areas and/or communities of color" (Quaintance, 2022). Often, these practices result in plans that issue low internet speeds disproportionately, and capabilities that are less affordable in low-income areas. At least 18 million American households lack broadband subscriptions, and a majority of these disconnected homes reside in metropolitan areas. As broadband is becoming an essential public commodity, assessing the modes of barriers to accessibility and the delivery of infrastructure is pivotal to uncovering possible broadband adoption and network gaps and expanding digital equity. To investigate this objective, internet performance data was collected through the Measurement Lab (M-LAB) from 2010 to 2022 and was mapped and aggregated across census tracts in Atlanta. In order to account for changes over this period, a component of time was analyzed with evolving internet usage to scope the effects of gentrification in shifting populations within these areas. Further, aggregated upload and download speeds were evaluated among demographic variables to estimate the internet performance across the population of households in Atlanta. From the results of this study, there is circumstantial variation in internet speed coverage which signifies inconsistencies in broadband capabilities across Metro Atlanta.

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Table of Contents

Introduction

The rise of the digital age has contributed to the rapid transformation of the internet in creating groundbreaking changes for every industry and sector. As internet usage has become integral to our lives, we have become codependent on the internet for everyday activities and functions. Approximately 93% of Americans use the internet, a proportion that will continue to increase in the near future (Pew Research Center, 2023). The expansion of the internet has enabled individuals to engage in the digital world, providing them with the means to foster social connections and better meaningful communication (Stansberry, 2019). While these advancements have disrupted many industries and nations, the benefits of the internet have increased access to opportunities, skills, and services further improving human outcomes (Stansberry, 2019). Despite the promising nature of the internet, the effects of internet capabilities have been disparate across populations. Internet connectivity and infrastructure has been unevenly distributed throughout the United States, creating consequential barriers to participation in the digital world (Stansberry, 2019).

Technological dependence has made society more reliant on digital capabilities, with the internet becoming a necessity for households in the U.S. Many experts believe that the internet will fundamentally lead to the hybridization of humanity and technology in the next fifty years, as constant developments in the internet will reimagine the way individuals experience and utilize this platform (Stansberry, 2019). Experts are tangentially skeptical of the imposition of technology as it has become far more developed than "our understanding of the human implications" (Stansberry, 2019). As consequences of the distribution of technology have raised significant ethical concerns, these implications largely threaten the ability to participate in the digital world.

In the case of the internet, at least 120 million Americans do not possess high-speed and reliant internet service, or broadband (CNET, 2023). As internet speed coverage largely defines the parameters for what types of activities can be performed by users digitally, slow or unreliable internet speed coverage impedes individuals from accessing quality services or knowledge ("Advertised vs actual internet speeds: What's the difference?", 2023). Existing systemic barriers and structural disparities have exacerbated disproportionate access to internet capabilities. Former institutional practices such as redlining, which historically neglected essential investments in communities of color, have extended into digital forms, largely prevailing in metropolitan cities such as Atlanta. The city of Atlanta has been long deprived of investments in historically redlined areas, but rapid gentrification has shifted population outcomes over time. Since Internet Service Providers largely invest in areas coinciding with the inclusion of large-scale investments, many previously redlined areas may lack consistent broadband capabilities. In order to understand discrepancies in network delivery and infrastructure, assessing internet speed coverage in Atlanta may be pertinent in understanding the firsthand effects of digital redlining. Based on this premise, evaluating network performance data from the Measurement Lab will provide greater details in recognizing current gaps among Atlanta's minority population. If the proportion of non-white individuals increases confounding income and educational attainment, then internet speeds should decrease. By testing this claim, I was able to evaluate whether communities of color in Atlanta are underserved in internet capabilities, further challenging their abilities to access quality services, opportunities, and knowledge to improve their life outcomes.

Literature Review

Broadband Internet

Broadband refers to the "transmission of data over a high-speed internet connection" which encompasses the following modes of delivery: Digital Subscriber Line (DSL), Cable, Fiber, Wireless, and Satellite ("Understanding the Urban Digital Divide", n.d.). Digital Subscriber Line (DSL) enables data to be transmitted over traditional copper lines ("Understanding the Urban Digital Divide", n.d.). Cable modems provide connections from the same line causing internet speeds to vary based on the number of users of that service at a given period of time ("Understanding the Urban Digital Divide", n.d.). Fiber optic cables by using pulses of light to transmit data through fiber strands ("Understanding the Urban Digital Divide", n.d.). Fiber cables provide faster internet speeds but are less available for the complexity of fastening cables. Wireless connections are used for the last mile of cable and DSL capabilities to provide internet coverage for larger, densely populated settings ("Understanding the Urban Digital Divide", n.d.). Satellite broadband provides internet via orbiting satellites, mostly in rural or less sparsely populated areas ("Understanding the Urban Digital Divide", n.d.).

Broadband subscription differs across demographic groups, uncovering adoption gaps based on race, income, education, and community (Pew Research Center, 2023). A report on Broadband adoption by Pew Research reveals that "63% of Black adults compared with 49% of white adults report not having high-speed internet," leading to major disadvantages in connecting with essential services and resources (Atske et al, 2021). Since 2018, at least 18 million American households appear to live without a broadband subscription (Fishbane, 2022). Further, a majority of these disconnected households reside in metro areas revealing adoption gaps to be larger in neighborhoods of the same area. In spite of urban and suburban areas experiencing the highest median broadband adoption rates, there is persistent variation in broadband subscription and accessibility among residents (Fishbane, 2022).

Digital Redlining and Internet Service Providers

The phenomenon of redlining refers to the "discriminatory practice in which lenders actively denied loans to individuals from communities of color, further classifying them as risky investments" (Mcall et al, 2022). The former practices of redlining continue to hold lingering effects on low-income and racialized communities. Because redlining enabled institutions and corporations to historically deny investments and services to these areas, these systemic conventions have created racial poverty which significantly harms the livelihoods and prosperity of households in these communities (Mcall et al, 2022). Despite the outlawing of redlining practices, its effects continue to devastate many communities that have endured these disinvestments. As studied by the Greenlining Institute, analyzing the lingering impacts of redlining on Oakland, California revealed how previously redlined areas lack adequate broadband access. From this study, it is evident that redlining practices still have traces in areas deprived of large-scale investments and development (Mcall et al, 2022).

Innovative broadband capabilities such as fiber are expensive, and Internet Service Providers (ISPs) are reluctant in expanding these networks without a return on their investments (Tibken, 2021). Thereby, poorer communities often demonstrate limited internet access or lack high-speed coverage as their conditions are not considered to be suitable for investments for ISPs (Tibken, 2021). Even if a single provider may deliver broadband speeds, users are left without cost-effective options (Stewart, 2020). Currently, in the United States, the internet is considered to be a free-market service where ISPs establish broadband capabilities and networks and set prices based on their financial decisions and investments (Tibken, 2021). Because providers invest in areas with returns on profits, these providers concentrate on upgrading networks within wealthier parts of cities. In spite of these providers facing price caps, coverage requirements, and other regulations to expand accessibility, previously redlined areas still experience challenges in receiving broadband.

Essentially, existing broadband coverage gaps in poorer neighborhoods reveal a “digital form of redlining” (Tibken, 2021). The lack of broadband infrastructure and adoption may diminish educational and labor market opportunities, further limiting access to privatized or government-provided services. About 4 in 10 adults from low-income households do not have home broadband services. Currently, 6 in 10 adults from households earning 100,000 or more report having home broadband services (Vogels, 2021). The difference between those having access to high-speed internet at home compared to those who lack the same capabilities is perpetuating digital obstacles for certain groups (Vogels, 2021). Further, broadband accessibility promotes economic prosperity, as it increases access to markets and the availability of quality information (Tomer et al, 2020). Researchers have found that “higher levels of broadband adoption led to economic growth, higher incomes, and lower unemployment”, largely improving economic outcomes (Tomer et al, 2020). As broadband infrastructure expands internet connectivity, individuals have greater capabilities to build actionable skills which may be driving forces in collectively enhancing productivity (Tomer et al, 2020). By standardizing access to broadband, it will not only eliminate shortcomings of digital poverty but also foresee economic mobility in impoverished areas.

The Significance of Digital Equity

The absence of broadband displaces people in the overly technological-dependent society where its long-term impacts are damaging to their existence. By redefining broadband as a public utility, the FCC may regulate broadband similarly to other utilities in mandating consistent broadband speeds across all areas (Fishbane, 2022). Foremost, discrepancies in broadband deployment have been creating adverse effects for disadvantaged populations and widening social and economic disparities. The implications of the pandemic underline these persistent inequities in regard to access to quality education, employment, healthcare, etc (Mcall et al, 2022).

Nearly 15 million students lacked broadband internet which created a “homework gap” between those students in households with high-speed internet capabilities and those with limited to no internet connection (Vogels, 2021). This distinction has garnered significant attention as students with limited broadband connections were left behind. This revelation indicated how students were unable to engage in remote learning due to the absence of broadband (Vogels, 2021). These educational disparities have widened achievement gaps as those with broadband internet access were more likely to transition seamlessly to remote learning (Vogels, 2021). Further, a majority of students were at a disadvantage as they were unable to continue their education in the same manner as other students, displacing students’ education attainment (Mcall et al, 2022).

Tangentially, limited access to quality education and economic opportunities enables individuals to assume occupations based on their skill levels. At the height of the pandemic, access to adequate broadband capabilities allowed individuals of high-paying and “low exposure risk” jobs to resume work remotely. While those who had assumed positions of “high exposure risk” such as essential and service workers could not pivot towards remote work, individuals were able to shift their occupations based on their access to reliant broadband services (Mcall et al, 2022). Because a majority of service workers were people of color, current systemic inequities had complemented broadband discrepancies as individuals with limited digital capabilities were unable to change their occupations and minimize their contact with COVID-19 (Mcall et al, 2022).

The adoption of digital health tools became essential at the height of the pandemic for individuals to safely consult medical professionals. Despite telehealth services flourishing, Black, Hispanic, and low-income populations were less likely to utilize these services because of limited access to broadband (Mcall et al, 2022). At large, insufficient broadband access has deterred communities of color from seeking medical care because of network interferences during consultations or visits. Therefore, individuals with limited internet access may have become more negligible in maintaining their health and further dissuading them from pursuing additional support (Mcall et al, 2022).

The issue of urban connectivity also poses a strong concern as three times as many households in urban areas do not possess broadband (Campbell et al, 2022). Poor internet quality limits a user from accessing services and participating in activities. Interferences such as low-quality audio and video capabilities may disrupt the quality of service of care received virtually and further disconnect users from accessing essential services, education, and healthcare (Mcall et al, 2022). Because the U.S. Department of Housing and Urban Development does not allow organizations to compensate for internet costs, the additional expenses may impose financial burdens on households prioritizing payments for other essential amenities and necessities (Tibken, 2021). For this reason, households facing financial hardships may need to ration internet usage. The interesting case of broadband access in urban areas reveals greater challenges beyond the availability of infrastructure. While some forms of broadband infrastructure are constructed and available in urban areas, affordability, and digital literacy are deciding factors in whether households adopt broadband. Further availability of the internet in housing infrastructure challenges a household's positionality in adopting broadband services. As low-income households are closely assimilated with "higher rates of unaffordable housing", these groups may experience severe housing deficiencies which limit their internet accessibility (Corallo, 2021). High-income households or affordable housing with complete amenities enables families to assume internet capabilities without any hindrances (Corallo, 2021).

In recent years, the internet has been becoming an essential service, conducive to everyday functions and access to resources. If ISPs continue to upgrade networks or provide maintenance in wealthier areas rather than extending broadband infrastructure, then the broadband system will remain exclusive to high-income areas, composed of predominantly homogenous communities (Tibken, 2021). When the FCC adopted net neutrality, it facilitated the regulation of broadband to establish it as a "common carrier" (Tibken, 2021). Further, it provided them with the means to protect consumers and ensure the quality of service by employing affordable and accessible plans. However, the reversal of net neutrality laws enables ISPs to take advantage of their unbounded control to make investments in high-income areas (Tibken, 2021).

The Digital Divide

Access to resources and services is increasingly shifting to digital modes, and the case for broadband as a public utility is becoming more convincing to guarantee universal access and delivery for all households (Campbell et al, 2022). The physical availability of broadband infrastructure does not entirely resolve the issue of digital inequity. Low adoption rates in certain areas may also be a result of a lack of knowledge or disinterest in broadband services (Campbell et al, 2022). In spite of these reasons, we must reconcile the social benefits of the internet to outweigh profits for private interests. Consolidating decisions based on investments will further perpetuate digital inequities, leading to practices of digital redlining and phenomena such as the "Digital Divide" (Campbell et al, 2022). As defined by the Greenlining Institute, the "Digital Divide" refers to the "inequalities in access and the use of information and communication technologies, including the internet" (The Greenlining Institute, 2023). Hindrances in internet usage impede the ability to access quality services and knowledge. Further, lack of internet access displaces one from participating in the digital world and further exacerbates racial and social inequities.

Closing the digital divide is an insurmountable problem as it requires large-scale measures to overcome. Extending infrastructure does not solely resolve the Digital Divide as it entails wide-reaching components including “inclusivity, institutions, and digital proficiency” (Chakravorti, 2021). Subsidizing the affordability of broadband access will ensure the inclusive use of the internet across all income groups (Chakravorti, 2021). Further institutions may prevent restrictions on ISPs and impose regulations on alternative solutions such as municipal broadband which limits internet access (Chakravorti, 2021). Broadband adoption may also be dependent on digital proficiency which is shaped by “demographic profile, education levels, political tolerance, and degree of skepticism of news” (Chakravorti, 2021). Foremost, recognizing the importance of universal internet access is inherent to narrowing the magnitude of this issue. Bridging the Digital Divide will expand household wealth and generate economic opportunities for underserved communities by advancing educational opportunities and academic outcomes, increasing wages, and remote work opportunities, increasing access to online financial services and banking, building infrastructure for entrepreneurial ventures, and promoting small business growth, and generating economic benefits (The Greenlining Institute, 2023). Further, closing the digital divide is essential to eliminating racial poverty and minimizing systemic barriers to opportunity. In order to utilize broadband to create equitable opportunities and provide equal access to information in employment, education, housing, credit, healthcare, financial services, etc., it is important to address infrastructure gaps, inclusivity of internet access, institutional barriers, and advance digital proficiency (The Greenlining Institute, 2023).

FCC Broadband Definition

As of 2015, the Federal Communications Commission (FCC) has established a benchmark for broadband to be at least a download speed of 25 Mbps and an upload speed of 3 Mbps. Subscribers that meet this criterion are considered to be “served” with broadband. The FCC requires ISPs to report their broadband speeds delivered to subscribers by each census block. This causes broadband to be overstated, as an entire census block is considered to be served even if a small portion of the block is only provided with broadband. Because the FCC relies on self-reported coverage from ISPS, maximum or advertised speeds are more inclined to be reported. On account of this, advertised speeds may diverge from actual internet speeds delivered to subscribers which are fundamentally biased in measuring broadband coverage (Benton Foundation, 2019). Retrospectively, this data collection methods further question the validity of the FCC Broadband data. For this reason, speed tests completed by third-party organizations such as the Measurement Lab are better ways to understand network coverage.

Moreover, the definition of “high-speed” and “access to broadband” is controversial since FCC internet data is constructed by self-reported coverage from ISPs (Liu, 2023). Because ISPs have the incentive to report higher speeds than actual speeds, FCC network performance data is inherently biased. The most recent FCC US Broadband Data Map further demonstrates an overt dependence on ISPs to report the availability and quality of their service (Liu, 2023). Because ISPs are not legally required to provide accurate speeds, they tend to overreport misleading internet speeds which mark underserved areas as served (Liu, 2023). By doing so, the FCC Broadband maps fail to correct for deep inequities that disproportionately affect minority groups. In turn, this data is exploited by ISPs to exclude competitors and/or challenge plans in implementing broadband infrastructure in underserved areas, further impeding their access to adequate broadband capabilities (Liu, 2023). Even if ISPs or other private corporations intend to advance internet accessibility, these same entities thwart any potential competition which may diminish their profit margins or jeopardize their business models (Stewart, 2020). While it may be difficult to engage in extreme government intervention to change internet coverage immediately, issues of digital inequity are becoming more urgent (Stewart, 2020)

The City of Atlanta

In the last decade, Atlanta has been projected to be one of the fastest-growing cities, becoming an epicenter in the Southeast U.S. Far from other major areas, Atlanta is one of the most prominent Black cities, being referred to as the "Black Mecca" since the 1970s (Leigh, 2020). The presence of prestigious Black institutions: Spelman University, Morehouse College, and Clark-Atlanta University created an "elite Black community with access to education and wealth" (Leigh, 2020). Over time, their elevated status allowed them to invest in their communities, establishing prosperous businesses and developments including the first Black-owned insurance company (Leigh, 2020). However, legislation disrupted the flourishing of these communities by increasing investments to dismantle their eminence. A form of this legislation, included redlining which coerced Black people to move into low-income, underdeveloped neighborhoods, further leaving white people to assume "residential control" of a large portion of the city (Leigh, 2020). These shifts are consistent with present-day conditions of Atlanta, as Northeast Atlanta is predominantly white and Southwest Atlanta is predominantly Black (Leigh, 2020). Despite the effects of redlining fundamentally changing the layout of Atlanta, Southwest Atlanta continues to represent "Black Excellence," consisting of prominent Black figures (Leigh, 2020). In recent times, wealthy Black individuals have migrated to affluent white neighborhoods in Northeast Atlanta, remotely diversifying these areas (Leigh, 2020). Because Atlanta encompasses both affluent Black and white groups, evaluating broadband deployment in the city may disclose greater knowledge of whether the proportion of the non-white population is indicative of internet coverage.

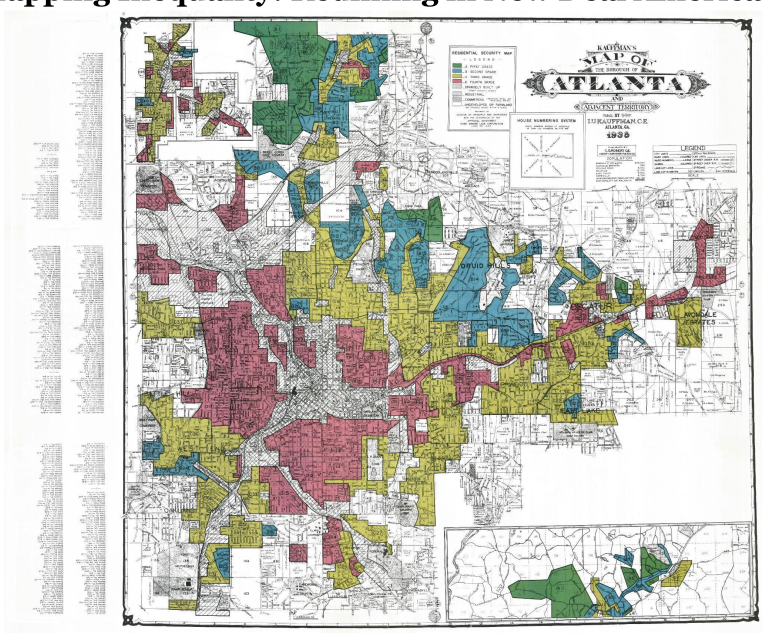
In many previously redlined areas, the gentrification of predominantly Black neighborhoods continues to threaten the displacement of Black people due to unaffordable housing. An excerpt from Dan Immergluck's "*Red Hot City: Housing, Race, and Exclusion in Twenty-First-Century Atlanta,"* characterizes the trajectory of racialized gentrification in Atlanta shifting the population to be "less-Black, more affluent, and more college-educated" (Immergluck, 2022). Although gentrification became prevalent in the 1990s, this phenomenon only escalated post-2012 as a result of the transformative changes in the urban housing and financial markets. Further, Immergluck pinpoints three statistics to argue for the drastic gentrification that had occurred including the sharp decline of the city's Black population from 67% to 48% over the last three decades, shifting the population from "majority to minority Black" (Immergluck, 2022). Further, the number of young adults with a college education had essentially doubled in population growing from 29% to 56% (Immergluck, 2022). And from 2012 to 2019, the "city-to-metro income ratio increased from 0.87 to 1.10," causing the city population to predominantly encompass high-income households (Immergluck, 2022).

The last three decades sparked a significant transformation called the "great inversion" with a rapid inclusion of higher-income households and displacement of lower-income, racialized households (Immergluck, 2022). Further, the cost of living has become more expensive leading to many lower-income households finding new living accommodations as public housing facilities have been dismantled. In retrospect, the exponential growth that reaped economic benefits was disproportionately shared across the public. Because many homeowners and property owners from higher-income backgrounds had experienced a majority of these gains, almost little of these profits were shared in revamping public commodities or developing new capabilities for low-income households or communities of color (Immergluck, 2022).

Immergluck's analysis of Atlanta's "great inversion" further sheds light on the rapid displacement of low-income households, fundamentally changing the composition of the population. Further, these revelations contribute to the larger phenomenon of racial poverty persistent in Atlanta, as the city is becoming more homogenous. Further, the impact of Black investments has led to varying effects of gentrification in Atlanta, as some Black neighborhoods are experiencing a substantial decline, and other areas are being revitalized for their cultural significance (Leigh, 2020). Despite these conflicting changes, Black legislation has led to little to no structural and system changes in advancing Black progress and building Black neighborhoods (Leigh, 2020). Because radical changes have led to the migration of low-income and minority communities, there have been minimal external investments and economic opportunities in these newly established communities (Immergluck, 2022). Further, changes to affluent white communities in recent times have enabled wealthy and elite Black people to assimilate into these neighborhoods (Leigh, 2020). Overall, the city of Atlanta has undergone many transformative changes that have shaped it in ways unlike other cities (Leigh, 2020).

In the context of this research setting, investments including broadband infrastructure have garnered little consideration in historically declining areas and low-income neighborhoods. To further expand on these circumstances, examining broadband coverage and delivery among homogenous and racially diverse communities may facilitate a greater understanding of existing digital inequities within Atlanta's intrinsic geography. As shown in Figure 1.1, this map acquired by the *Mapping Inequality: Redlining in New Deal America* outlines previously historically redlined areas in present-day Atlanta (Nelson et al, 2023). By assessing whether internet speeds are consistently delivered and compliant with FCC standards within the red-marked areas, this study will unveil greater knowledge of the lingering effects of redlining in predominantly non-white communities.

Figure 1.1: Mapping Inequality: Redlining in New Deal America, Atlanta, GA



Measurement

The Brookings Institution measures digital poverty to demonstrate low broadband connection by flagging neighborhoods where at least half of the tenant-occupied households do not possess broadband subscriptions (Fishbane et al, 2022). Currently, eight metro areas of the Southeast United States have more than 20% of census tracts in digital poverty (Fishbane et al, 2022). Even though broadband subscriptions may be widely available throughout neighborhoods, actual internet speeds may not be accordant with reported or advertised speeds. In the case of Atlanta, rapid neighborhood changes have continuously shifted and changed populations, indicating the dispersant effects of digital poverty on the city.

To complete speed tests, clients will determine a subscriber's location and their closest test server. A speed test will send a signal to the test server that responds back with the signal. The roundtrip of this ping will be measured in milliseconds (Hendrickson, 2019). After the ping is completed, then the client will complete a download test by opening connections to the server and downloading a piece of the data (Hendrickson, 2019). In this process, the client will measure the amount of time it took to download the data and the number of network resources utilized to present a download speed. Whereas a client will complete an upload test by uploading data from the PC to the server and assessing the amount of time to upload the data and the number of network resources utilized (Hendrickson, 2019).

The M-Lab Server infrastructure in Atlanta consists of a cluster of 5 server pods that test for upload and download speeds. For every server pod, there are 3 to 4 server sites which are all connected to upstream providers. In Atlanta, there are 5 server pods to ensure the inclusion of multiple paths. An M-Lab server conducts speed tests by measuring the speed at which the ping reaches an IP address and returns to the server site. The ping refers to the reaction to the internet connection (Isberto, 2023). Servers are placed strategically such that any individual can make requests for speed tests to the closest server. M-Lab servers are hosted at data centers in which ISPs are interconnected. M-Lab's network test uses a single stream of data to provide build transport capacity or "data delivery rate of a single transport connection" (Isberto, 2023). While a single stream is prone to packet loss and reordering, they may help identify performance issues that impact the reliability of a broadband connection and impact overall network performance (Isberto, 2023).

Internet speeds define the parameters for what types of activities can be performed by users digitally ("Advertised vs actual internet speeds: What's the difference?", 2023). Further, examining internet speeds among previously redlined and/or gentrified may uncover public disparities and broadband gaps. By determining the frequency of speed tests, understanding whether speed tests concentrate in specific areas than others may suggest a lack of delivery of infrastructure. Evaluating internet performance data from 2010 to 2021 will enable a more nuanced analysis of internet coverage as rapid neighborhood changes have shifted the conditions of these areas. Considering a time component, this may facilitate a detailed explanation in discovering whether homogeneous, higher-income communities experience consistently higher internet speeds than racialized, lower-income communities. By scoping the internet performance data across geographical barriers and demographic variables of interest, we will be able to measure whether specific census tracts are adequately served with consistent broadband speeds.

Methods

Data Acquisition

In the context of this research, Measurement Lab (M-Lab), which provides an open, verifiable measurement platform for network performance, sourced data was collected and visualized to clarify the usage of broadband in Atlanta (M-Lab, n.d.). Their network tests enable any subscriber on the internet to determine the speed of their network with one click in any particular area (M-Lab, n.d.). Because M-Lab speed tests are used to understand overall internet performance rather than the last-mile delivery, network data from M-Lab's data reserves publicly located in Google BigQuery was considered the most appropriate data source. NDT is a type of diagnostic test that measures how well the single TCP stream can take advantage of its link capacity. A TCP stream positions a connection to the receiver and sends segmented data which is carried by IP packets (M-Lab, n.d.). This process yields a complete M-Lab speed test which is measured at a speed of Megabits per second.

From M-Lab data reserves, I consolidated monthly datasets of NDT network performance from 2010 to 2021 in Atlanta for upload and download speeds. At first, I wrote a SQL query in M-Lab's Google BigQuery open-sourced notebook to call and collect NDT performance metric statistics filtered to a server site in 'Atlanta'. Then, I downloaded separate datasets for download and upload speeds for every month from 2010 to 2021. After, these monthly datasets were unioned to form year-long datasets for both download and upload performance metrics. Each dataset is composed of the following key variables: [*MeanThroughoutMbps, ServerSite, Latitude, Longitude*]. *MeanThroughoutMbps* refers to the average rate determined by the server, calculated in 'megabits per second'. *MeanThroughoutMbps* serves as the measurement for both upload and download speed. *ServerSite* refers to the location of the M-Lab server that conducts the measurement. M-Lab speed test automatically selects a server to collect the measurement of an IP address. *Latitude* and *longitude* refer to the geolocation of the IP address that initiates a speed test.

Further, each observation in the dataset represents a completed speed test from a given location with assigned spatial coordinates. In order to better visualize the frequency of these points, I jittered these spatial coordinates by adding a randomly generated threshold between [-0.01, 0.01] and stored as *lat_jitter* and *long_jitter*. Because these datasets contain a certain degree of granularity, all observations were jittered to add noise and create comprehensible visualizations. Afterward, network performance data was overlaid on Atlanta census tract shapefiles. The census tract shapefiles were called from a Census API and were based on the Census Bureau's American Community Survey 5-Year estimates (ACS5). The American Community Survey provides detailed data to understand changes in places and communities (citation). Further, ACS5 data was filtered to encompass the following counties "Fulton, Dekalb, Cobb, Forsyth, and Gwinnett" which accounted for changes in boundaries for census tracts over time. In regard to the ACS5 estimates, demographics of race, income, and educational attainment were of primary interest. For further context in evaluating the demographics of Atlanta census tracts, race, income, and educational attainment were determined accordingly:

- Race: Percent of Non-white population
- Income: Median Household Income
- Educational Attainment: Percent of Population with a Bachelor's degree or higher

MapBox Visualizations

In order to visualize the large collection of M-Lab's NDT performance data, a total of 72 maps were created through MapBox Open Street Maps. From 2010 to 2021, separate download and upload speed data maps were conceptualized for each individual demographic variable at the census tract level. These maps aggregate download and upload speeds measured in

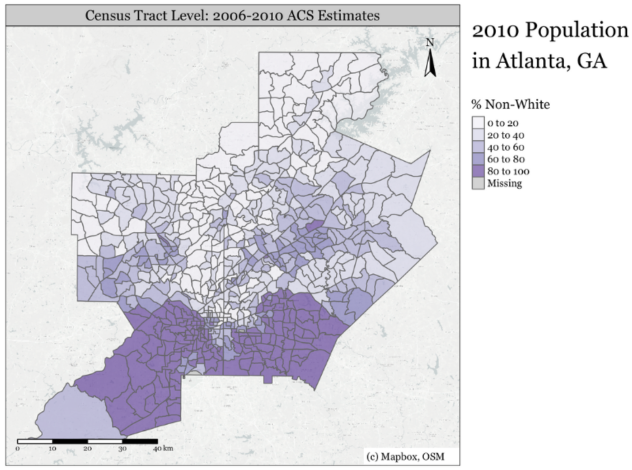
MeanThroughMbps to demonstrate the variability of internet speeds against the following demographics: race, income, and educational attainment. Mostly, these demographic variables were assessed to better understand the influence of these characteristics on the magnitude of internet speeds and frequency of speed tests.

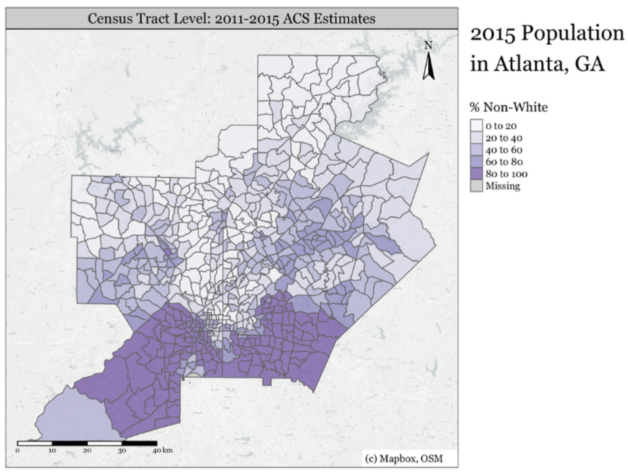
Atlanta Census Tract Maps

The results in **Figures 2.1, 2.2, and 2.3** specifically examine ACS5 data for the following years: 2010, 2015, and 2020 in regard to race, income, and educational attainment. (**To see all supplementary materials from 2010-2021, please check Appendix to see all Atlanta census tract maps based on ACS5 estimates*)

From 2010 to 2020, the annual rate of population growth for Atlanta was 1.5%. This rate reflects with the shifts in population as the job market and investments in the city have expanded (Pascual, n.d.). Based on the census tract maps from 2010, 2015, and 2020, the data is corresponding to the changes in the Atlanta population due to transformative changes and developments in the city. In the last decade, northern and central Atlanta shifted towards a more homogenous population, comprising individuals having a median income of $75,000 or above and at least a 60% chance of possessing a bachelor's degree or higher degree. Further, southwest Atlanta remained relatively unchanged, consisting of a predominantly non-white population, having a median income of $75,000 or below and a less than 45% chance of holding a bachelor's degree or higher. Moreover, **Figures 2.1, 2.2, and 2.3** provide a basis for understanding where Internet Service Providers (ISPs) may distribute investments or establish broadband infrastructure. Because ISPs are interested in securing large profits, they are most likely to deploy broadband capabilities in areas of high income and high educational attainment rates which are made up of predominantly white households.

Figure 2.1: Atlanta Census Tract Maps: Race





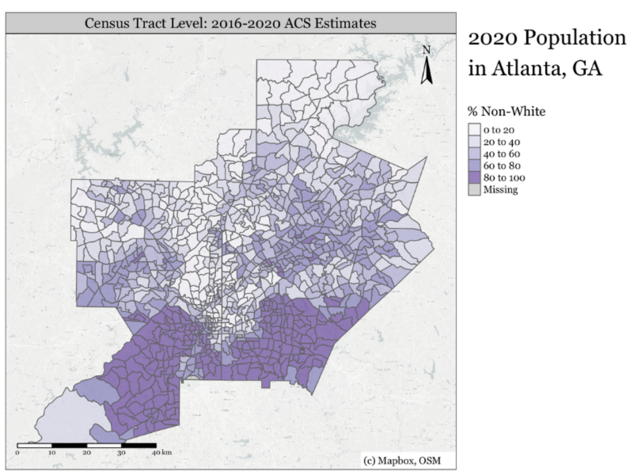


Figure 2.2: Atlanta Census Tract Maps: Median Household Income

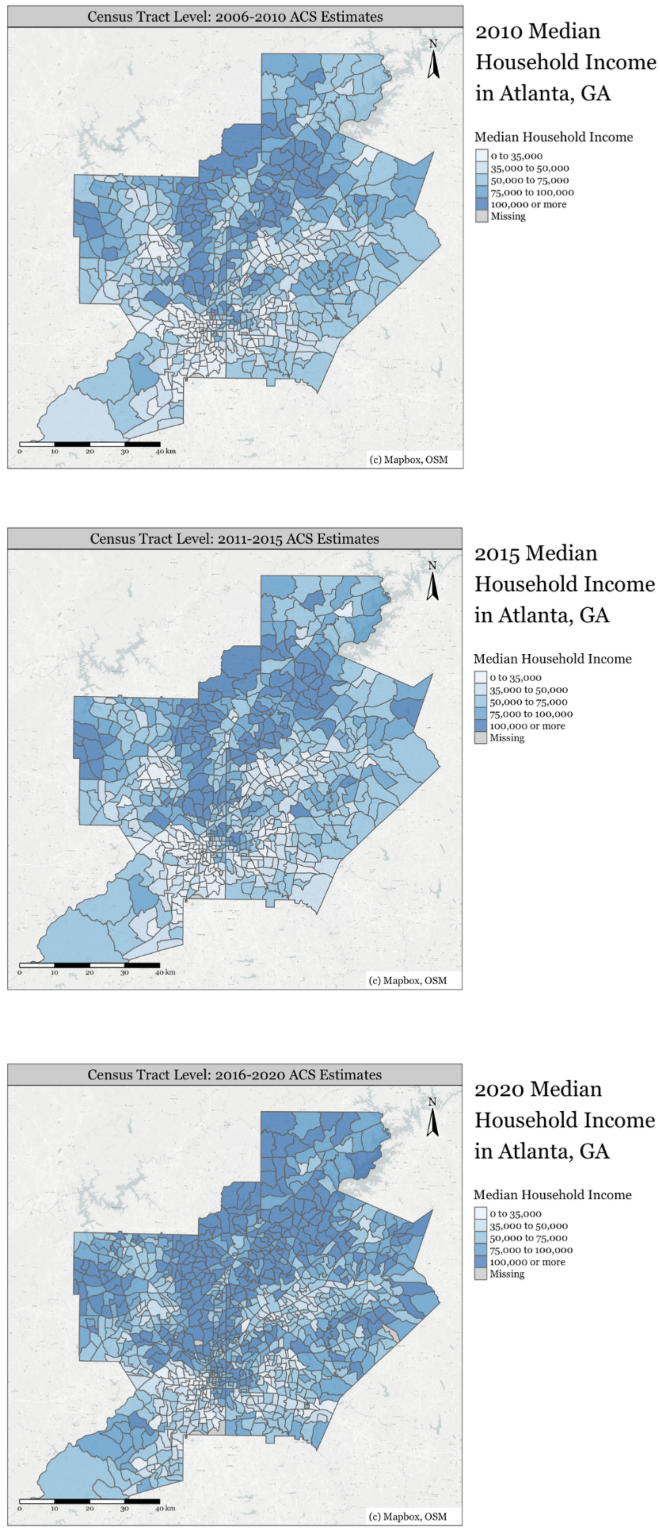
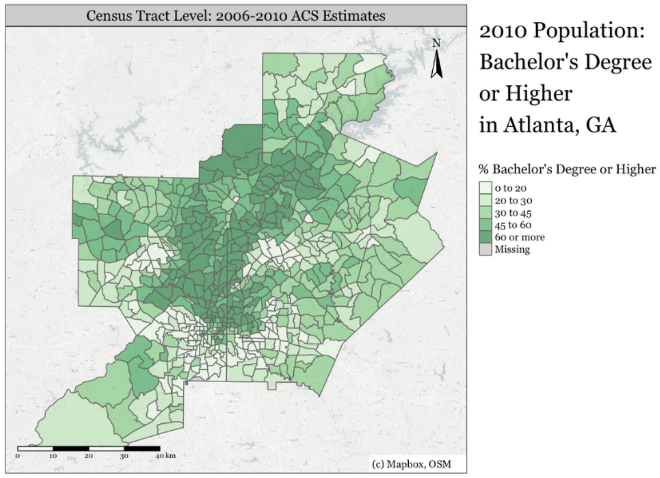
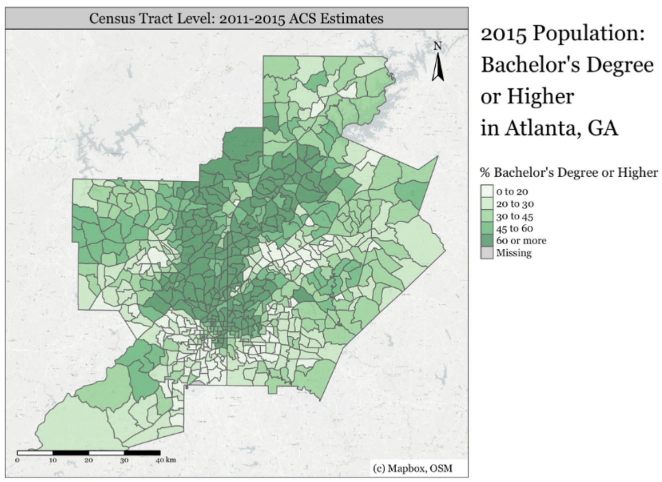
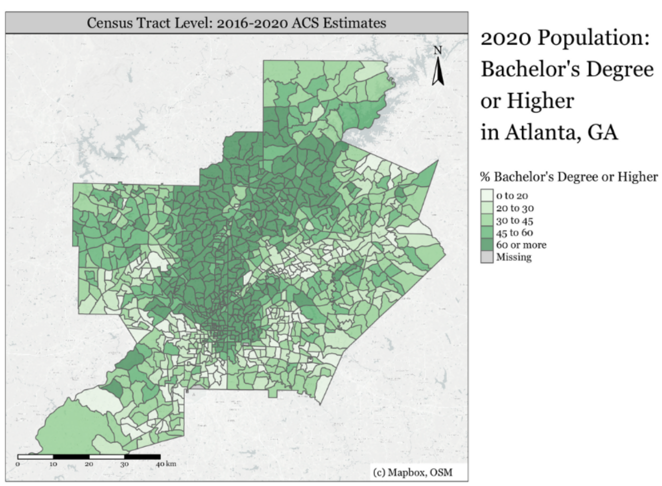


Figure 2.3: Atlanta Census Tract Maps: Educational Attainment







Conley Regression Estimation

To measure the statistical significance of whether high internet speeds are relative to race, OLS linear regression was taken based on the Conley Standard Errors of these demographic variables against download and upload speeds. Conley standard errors "account for spatial correlation in the data" by considering a potential dependence on the spatial proximity of these standard errors (Düben, 2021, pg. 1). Computing spatial distances between each observation within a selected radius, enables standards errors to be adjusted to account for some form of spatial dependence. Since network performance data is assessed in a geographical context, it is most appropriate to employ Conley Regression to evaluate further the significance of race, income, and educational attainment on high internet speeds.

In this study, OLS linear regressions were separately conducted for download and upload speeds from each year: 2010 and 2015. Initially, all census tract data, including race, income, and educational attainment were consolidated and joined to download and upload speed data. A natural log transformation of the outcome variable, internet speed (MeansThroughMbps) was taken and stored as *logUpload* and *logDownload* for both upload and download speeds. After, these variables were regressed against the following variables: *minority_pop_perc*, *median_income,* and *bach_perc*. The results of the estimates from this method are shown in **Tables 3.1 and 3.2.** Due to computational issues in processing large volumes of network data, the Conley Regression could not be generated for download and upload speed data for 2020 as it encompassed more than three million observations. For the 2020 download and upload datasets, these methods are limited in calculating adjusted standard errors for the distance matrix. Since these datasets were substantially large, this study was not able to evaluate the correlation among internet speeds on race, income, and educational attainment.

The Conley regression estimations to evaluate internet speeds and race is shown in **Table 1.1.** Both download and upload speeds are adjusted by the natural logarithmic transformation and regressed on the primary variable of interest: race and potential confounding variables: median income and educational attainment.

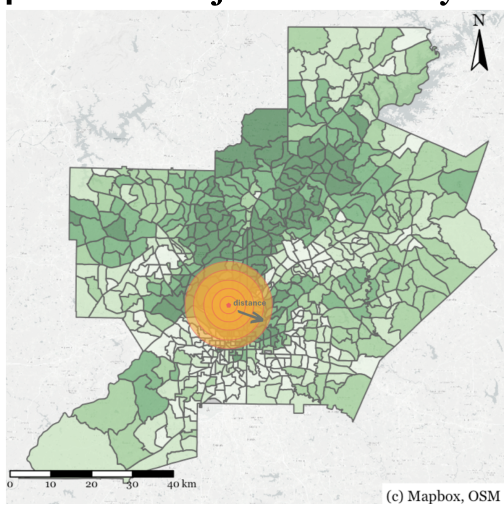
Table 1.1: Conley Regression Estimations

$$logUpload = minority\_pop\_perc + median\_income + bach\_perc + \epsilon_i$$

$$logDownload = minority\_pop\_perc + median\_income + bach\_perc + \epsilon_i$$

In order to evaluate the potential dependence on spatial proximity, I had to manipulate distances to understand whether increasing the geographical field of a cluster of speed observations would yield significant estimates of the correlation between internet speeds and race. To adjust for distance (**Figure 2.4**), I employed 10 different Conley regressions by changing the magnitude of the radius (r) from 1 km to 10 km. With a given radius of interest, the regression will consider all observations within a field to potentially hold some spatial dependence among the residuals of their standard errors. Observations outside of the field will presume the residuals of the standard errors of these observations to be independent. Furthermore, adjusting for distance will reveal if decreasing the field of potential spatial dependence on residuals of standard errors will increase the statistical significance of the estimates from the estimates of internet speeds regressed on race, confounding on income and educational attainment within a given year.

Figure 2.4: Distance Adjusted in Conley Regressions



Results

To effectively assess internet performance data in tandem with changes in the Atlanta population, this study specifically examines the following years: 2010, 2015, and 2015. By evaluating these following years, I was able to visually contextualize whether the magnitude of internet speeds or the frequency of speed tests had drastically shifted among the Atlanta population. (**To see supplementary materials that encompass visualizations from 2010-2021, please see the Appendix*).

Measurement Lab: Download and Upload Speeds

Table 2.1 represents the total number of download and upload speed observations that were evaluated in 2010, 2015, and 2020. The average download and upload speeds in **Table 2.2** reveal whether the average internet speeds post-2010 correspond to the FCC definition for broadband speeds, which refers to the minimum download speed of 25 Mbps and a minimum upload speed of 3 Mbps. In **Table 2.2,** the average download speed in 2015 was not compliant with the FCC minimum download speed of 25 Mbps which suggests that a majority of the Atlanta population was not adhering to minimal broadband capabilities.

Table 2.1: M-Lab Network Performance Data in 2010, 2015, & 2020

M-Lab: Number of Speed Test Observations			
Internet Speed	**2010**	**2015**	**2020**
Download	40,383	23,942	3,198,173
Upload	47,325	26,205	3,005,394

Table 2.2: Average Internet Speeds from 2010-2020 in Atlanta

Average Speed (Mbps)			
Speed Type	**2010**	**2015**	**2020**
Download	10.71	20.69	59.18
Upload	2.42	7.41	29

Frequency of Download and Upload Speeds

Based on the FCC definition for broadband in 2010 which defined a minimum download speed of 4 Mbps and a minimum upload speed of 1 Mbps, **Figures 3.1 and 3.2** demonstrate a majority of download and upload speeds exceeding this threshold in 2010. Further, the distributions of upload and download speeds in 2010 are skewed to the left, further suggesting that a majority of internet speeds fall below 25 Mbps. In 2010, the Atlanta population was experiencing broadband capabilities of an average of 10.71 Mbps for download speeds and an average of 2.42 Mbps for upload speeds which was far above the FCC definition of broadband. This suggests that a large number of households are being served with broadband in 2010.

Figure 3.1: Histogram of Download Speeds in 2010

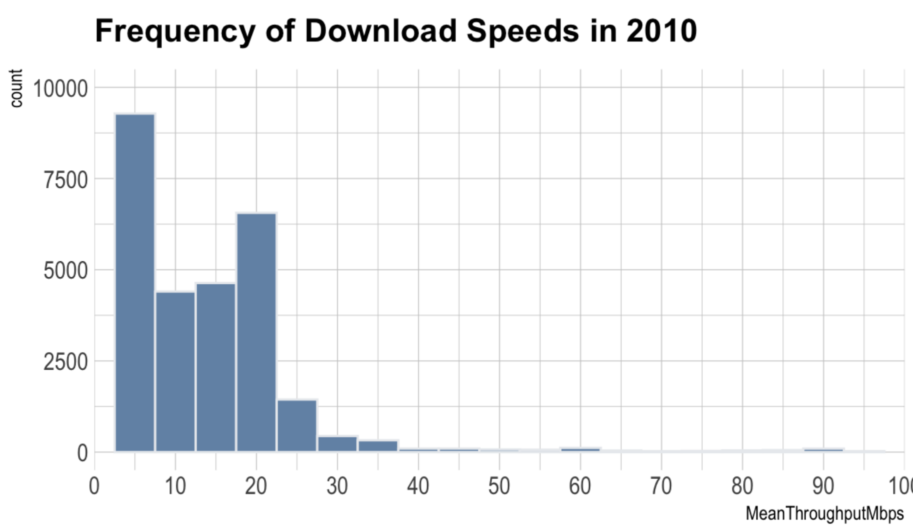
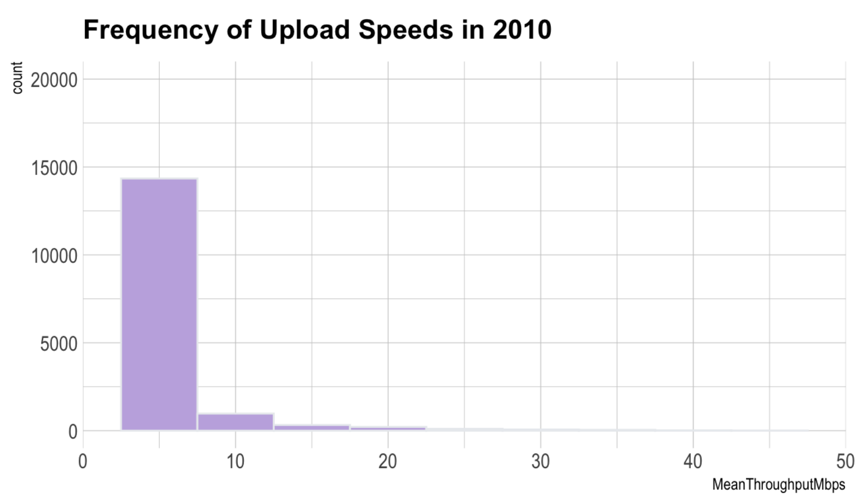


Figure 3.2: Histogram of Upload Speeds in 2010



Figures 3.3 and 3.4 demonstrate a rise in variability for download and upload speeds in 2015. Despite the increase in the number of speed tests, a majority of download and upload speeds fluctuate below 25 Mbps. In relation to the updated FCC benchmark for broadband speeds in 2015, this data reveals that most download speeds are below the FCC minimum average of 25 Mbps further implying a large number of households being underserved for broadband coverage. On the contrary, upload speeds are consistently over the FCC minimum average of 3 Mbps in spite of a large majority of upload speeds falling below 25 Mbps.

Figure 3.3: Histogram of Download Speeds in 2015

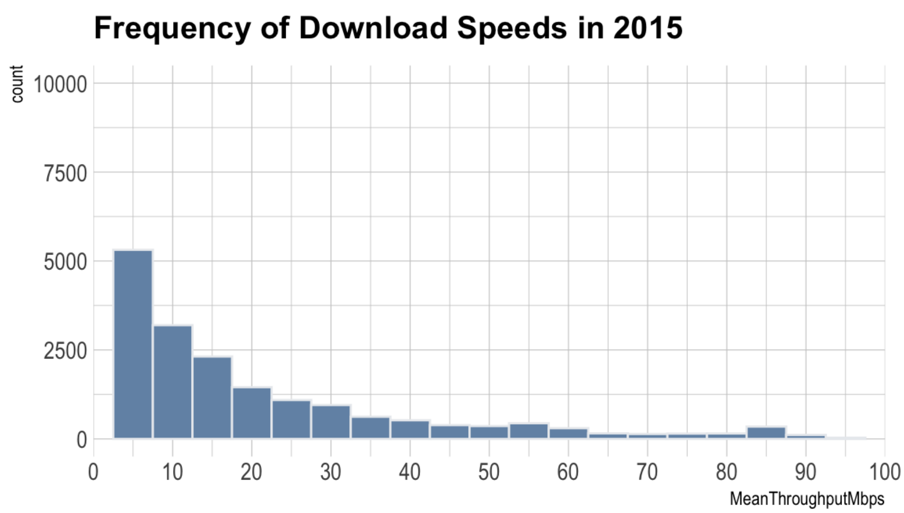
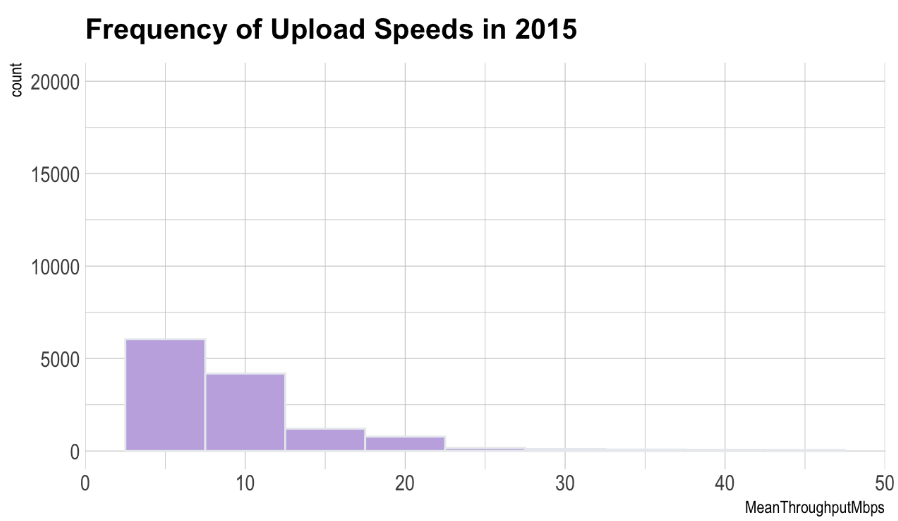


Figure 3.4: Histogram of Upload Speeds in 2015



In 2020, the increase in network performance data also widened the variability in download and upload speeds. The sudden increase in the number of speed tests may also suggest growth in knowledge of internet capabilities among the Atlanta population. As mentioned in **Figures 3.5 and 3.6**, both download and upload speeds have risen drastically, achieving an average speed well above the FCC minimum of 25 Mbps for download speeds and 3 Mbps for broadband internet. In spite of these new high internet speeds, a majority of download speeds fluctuate below the average speed of 59 Mbps and upload speeds fluctuate below the average speed of 29 Mbps. This suggests that few households are being served with larger and more consistent broadband whereas a majority of households are not being served with the same conditions. In retrospect, variability in internet coverage may suggest inconsistency in broadband deployment across the Atlanta population.

Figure 3.5: Histogram of Download Speeds in 2020

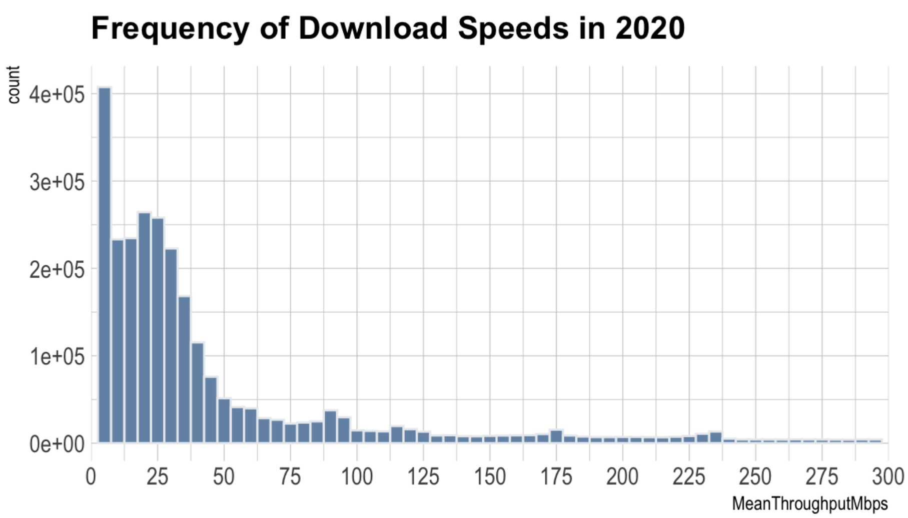
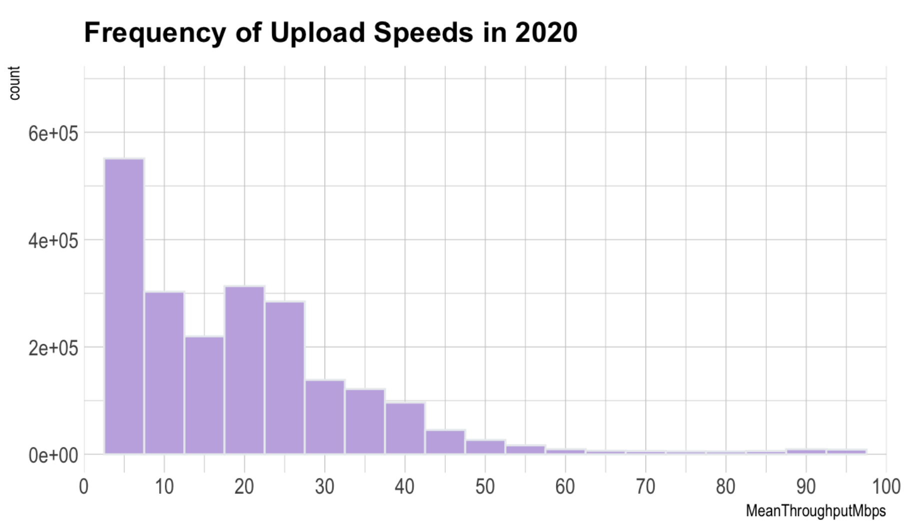


Figure 3.6: Histogram of Upload Speeds in 2020



Internet Speeds and Race

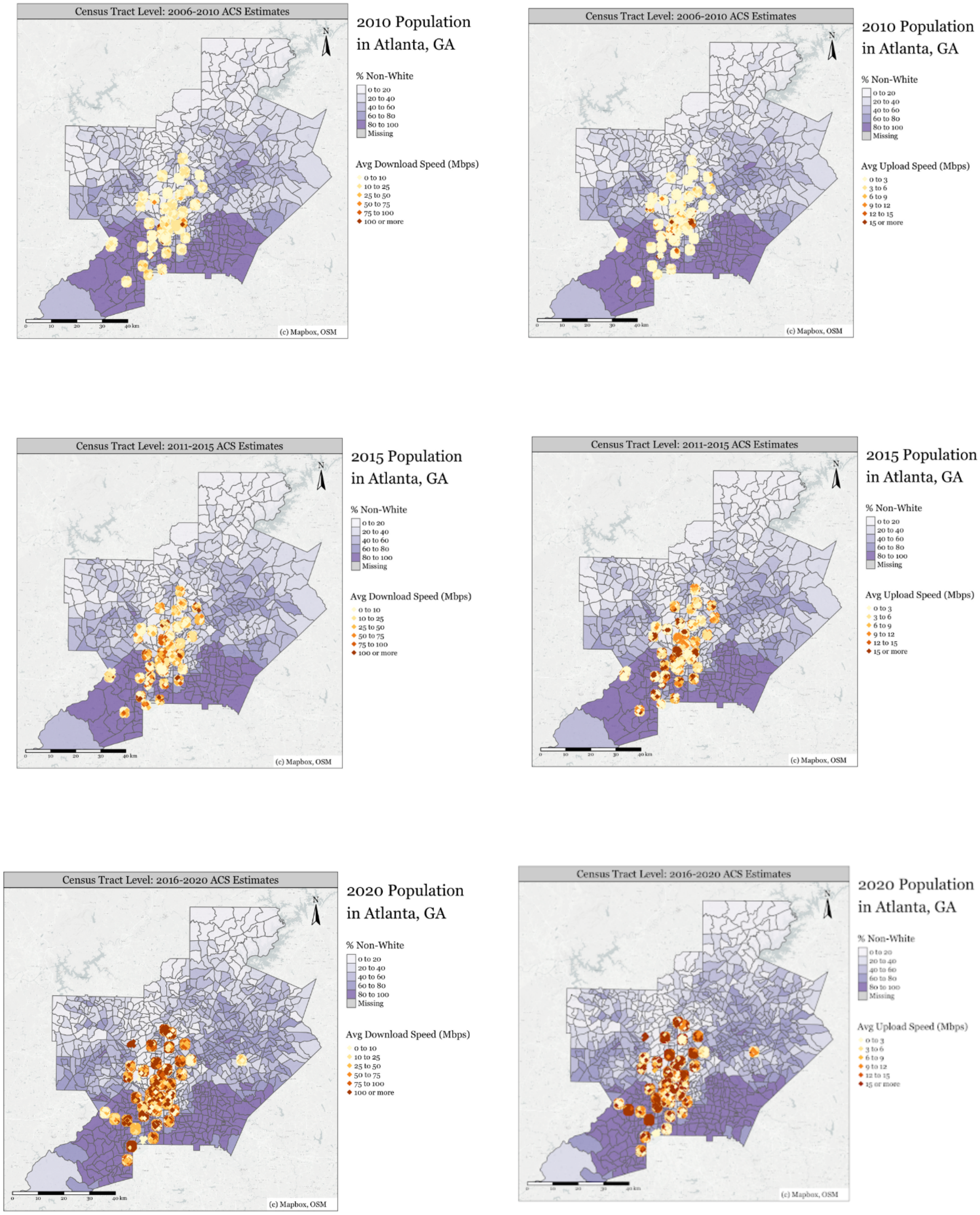
In order to understand how broadband coverage differentiates among Atlanta's minority population, **Figure 4.1** demonstrates how internet performance has shifted with population changes in 2010, 2015, and 2020. A majority of internet speed tests in 2010 were concentrated in downtown and Southwest Atlanta, having a predominantly white and Black population accordingly. Clusters of download speeds greater than 25 Mbps were mostly positioned near downtown Atlanta, where the population was less than 40% non-white in 2010. Of the few upload speeds greater than 3 Mbps, these observations were situated in areas where the population was at most 60% non-white in 2010.

In 2015, clusters of high download and upload speeds were more frequent than those in 2010. Download speeds of at least 75 Mbps were abundant in downtown and Southwest Atlanta; however, a larger number of high download speed clusters existed in downtown Atlanta where the population was at most 40% non-white in 2015. A majority of upload speeds in 2015 were less than 3 Mbps. Upload speeds of at least 3 Mbps were located in areas where the population was at most 60% non-white in 2015. Similar to clusters of high download speeds in 2015, clusters of high upload speeds were situated in predominantly white areas. Strikingly, Southwest Atlanta experienced some clusters of high upload speeds in 2015.

The number of download speed and upload speed test observations drastically increased in 2020. Similarly, the number of download speeds of at least 75 Mbps and upload speeds of at least 15 Mbps magnified in 2020. In previous years 2010 and 2015, clusters of high download speeds and upload speeds were more frequent in Southwest Atlanta where the population is at least 80% non-white. Compared to areas where the population is predominantly white in 2020, areas with a population of less than 40% non-white people still contained large portions of high internet speeds.

Overall, the contextualization of internet speed coverage on race in Atlanta suggests that clusters of high internet speeds exist more persistently in predominantly white areas near downtown or North Atlanta. Since Southwest Atlanta is largely comprised of Black neighborhoods, **Figures 4.1** reveal that broadband capabilities are extended to these communities. More importantly, **Figures 4.1** demonstrate that clusters of high internet speed coverage are more available to predominantly white communities than predominantly Black communities.

Figure 4.1: Internet Speeds and Race



Internet Speeds and Income

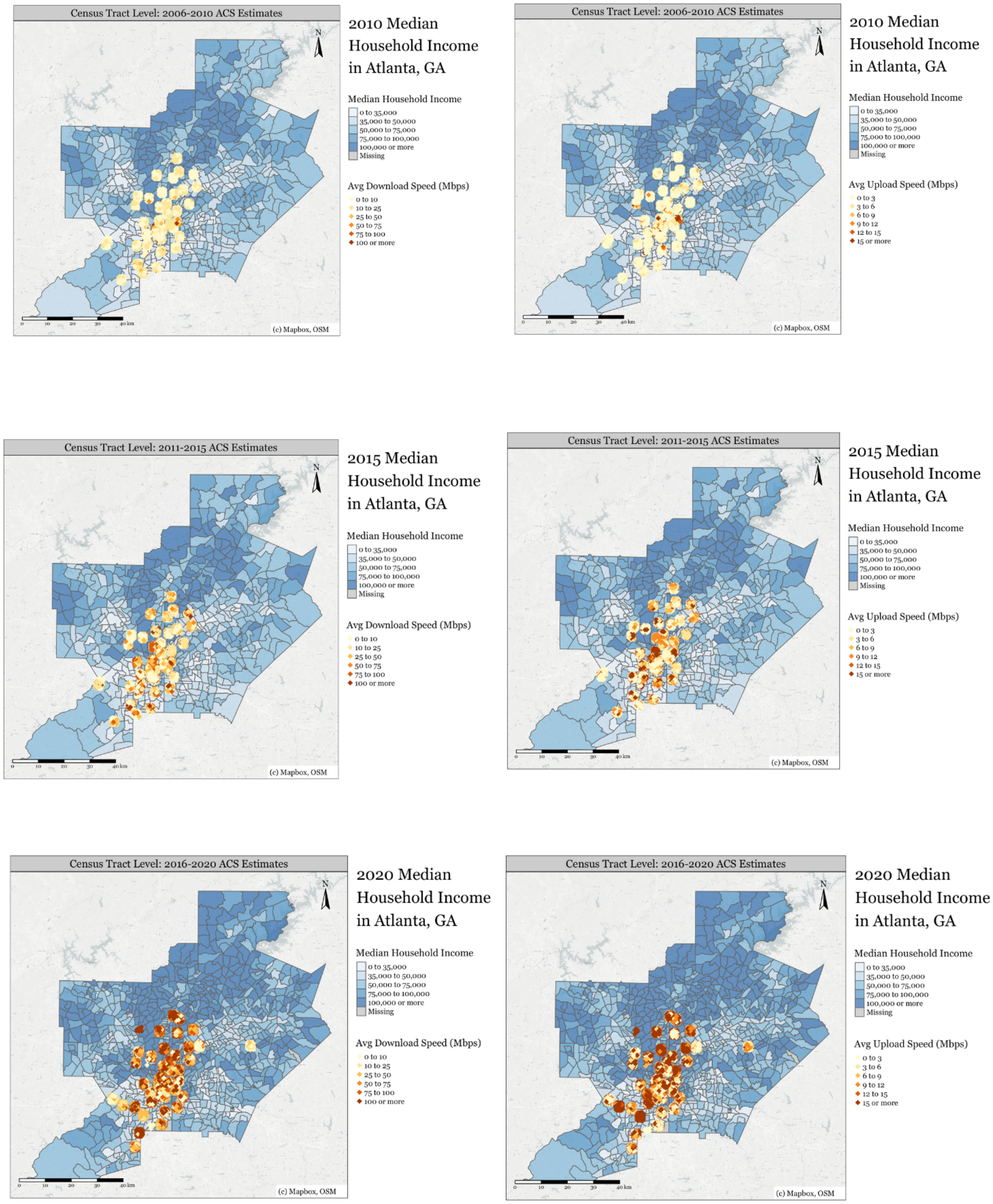
Given that race and income are closely linked, evaluating internet coverage on the median income in **Figure 4.2** reveals how broadband capabilities have been delivered to affluent white and affluent Black populations in Atlanta. A majority of internet speeds in 2010 were concentrated in downtown and Southwest Atlanta, which aligns with the residence of both wealthy white and Black populations accordingly. The few download speeds that were greater than 25 Mbps in 2010 were situated in areas where the median household income was at least $50,000. Similarly, high upload speeds in 2010 were also located in areas where the median household income was $50,000 or more.

In 2015, the increase in clusters of high download speeds of at least 75 Mbps was positioned in areas where the median household income was at least $50,000 whereas the clusters of high upload speeds were situated in areas where the median household income of $35,000 or above. Based on the changes from 2010 and 2015, an increase in clusters of high internet speeds in 2015 may correspond to areas of higher median household incomes.

The majority of high internet speeds in 2020 were consistently observed in areas of higher median income near downtown Atlanta. Download speeds of 100 Mbps or greater were relatively aligned in census tracts where the median household income was at least $75,000 in 2020. A majority of high upload speeds were not situated in areas where the median household income is below $35,000 in 2020. In areas of lower median household income, upload speeds of at most 12 Mbps are available.

High internet speed coverage has largely concentrated in areas of higher median household income which are located near downtown and North Atlanta. **Figure 4.2** demonstrates positive changes in median household income which coincided with a larger number of clusters of high internet speeds in Atlanta over time. Further, clusters of high internet speed coverage were less available in areas of low median income which encompassed areas outside of downtown Atlanta. In correspondence to internet coverage and race in **Figure 4.1**, **Figure 4.2** confirms that clusters of high internet speeds are more frequent among affluent white communities than affluent Black communities in Atlanta.

Figure 4.2: Internet Speeds and Median Household Income



Internet Speeds and Educational Attainment

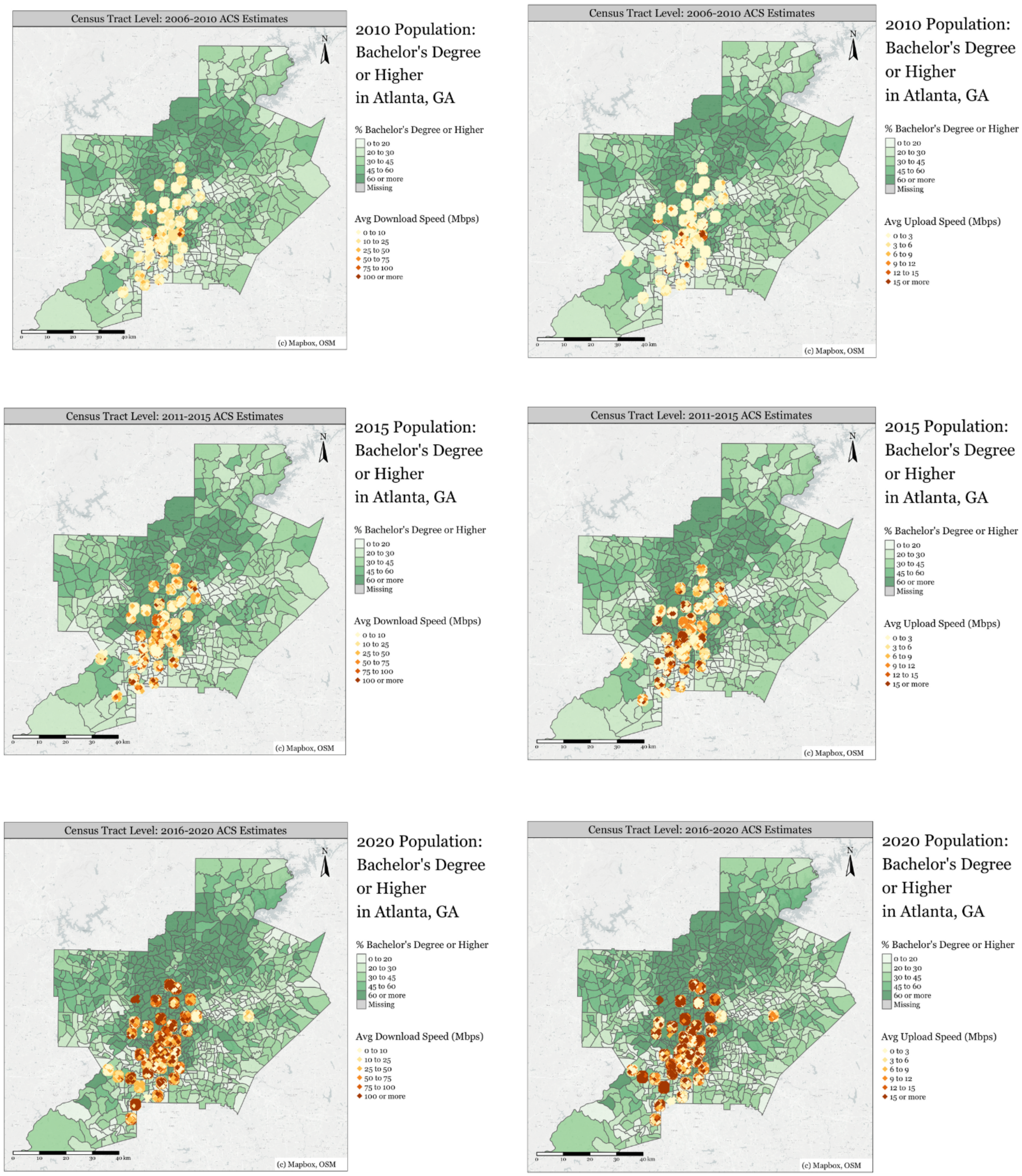
Similar to income, the intersection between educational attainment and race are closely related and the relationship between internet coverage and educational attainment may reveal greater knowledge of the elite white and elite Black populations in Atlanta. **Figure 4.3** demonstrates how internet speed coverage differs across changes in educational attainment from 2010 to 2020. In 2010, areas where at least 30% of the population possessed a bachelor's degree or higher experienced higher internet speeds. Mostly, a majority of download and upload speeds in 2010 had largely varied across areas of different educational attainment rates.

In 2015, clusters of high internet speed continued to vary among areas of contrasting educational attainment rates. In areas where at least 30% of the population possessed a bachelor's degree or higher, the number of high upload speeds of at least 12 Mbps drastically increased from 2010 to 2015. From 2010 to 2015, changes in high internet coverage according to higher educational attainment were not similarly consistent to race and median income in **Figures 4.1 and 4.2** accordingly.

The increase in clusters of high internet speeds in 2020 was contingent on the increase in educational attainment rates. As of 2020, download speeds of at least 100 Mbps exist in areas where more than half the population is from a background with a bachelor's degree or higher. Clusters of high upload speeds of at least 15 Mbps were also more frequent in areas of higher educational attainment in 2020. In comparison to 2010 and 2015, growth in educational attainment rates in 2020 surrounding downtown Atlanta had experienced greater clusters of high internet speeds.

While high educational attainment and high internet speed coverage did not become evident until 2020 in **Figure 4.3**, the rapid growth of educational attainment where areas consist of 60% or more individuals possess higher education may be indicative of higher internet speed coverage While high internet speed coverage is available in Southwest Atlanta, which is mostly comprised of Black communities, these clusters do not align with high educational attainment. It is possible these clusters of high internet speed coverage may encompass Atlanta's prestigious Black institutions located in Southwest Atlanta. Overall, **Figure 4.3** mostly confirms that clusters of high internet speed coverage are more available among wealthy, elite white communities.

Figure 4.3: Internet Speeds and Educational Attainment



Conley Regression

Since it was difficult to assess clear patterns between internet speeds and race, employing the Conley regression to evaluate this relationship will provide more significant information. The Conley regression estimations yield estimates for assessing the Conley Standard errors. **Tables 3.1** and **Table 3.2.** display estimates of the correlation between internet speeds and the percentage of the minority population. Because I had evaluated download and upload speeds on race in both 2010 and 2015, I had evaluated all the estimates at the Bonferroni corrected p-value threshold of 0.0125. At the adjusted p-value level of 0.0125, none of the results in **Tables 3.1 and 3.2** are significant to reject the sharp null hypothesis that there is no effect between internet speeds and race.

Despite these results, there are clear indicators of a negative relationship between internet speed and race in **Tables 3.1** and **3.2**. The coefficients of the estimates fit the hypothesis that an increase in the minority population may result in a decrease in internet speed. For instance, estimates in **Tables 3.1 and 3.2** suggest that for every 1% increase in the minority population of Atlanta, there is a negative change by a certain threshold in the natural log of Download speeds and the natural log of Upload speeds, when controlling for education attainment and median income. Even though these estimates provide strong evidence there is a negative change between race and internet speeds, failure to reject this hypothesis at the adjusted p-value level of 0.0125 does not confirm this belief.

Table 3.1: Estimates for Download Speeds in 2010 and 2015

Minority_pop_perc Estimates						
	2010			2015		
Distance (Km)	estimate	std. error	Pr(>|t|)	estimate	std. error	Pr(>|t|)
1	-0.00407	±0.00269	0.13	-0.00284	±0.00374	0.45
2	-0.00406	±0.00261	0.12	-0.00284	±0.00374	0.45
3	-0.00406	±0.00256	0.11	-0.00284	±0.00375	0.45
4	-0.00406	±0.00252	0.11	-0.00284	±0.00376	0.45
5	-0.00407	±0.00249	0.10	-0.00284	±0.00379	0.45
6	-0.00407	±0.00250	0.10	-0.00284	±0.00396	0.47
7	-0.00407	±0.00253	0.11	-0.00284	±0.00411	0.49
8	-0.00407	±0.00256	0.11	-0.00284	±0.00416	0.50
9	-0.00407	±0.00259	0.12	-0.00284	±0.00421	0.50
10	-0.00407	±0.00262	0.12	-0.00284	±0.00427	0.51

Table 3.2: Estimates for Upload Speeds in 2010 and 2015

Minority_pop_perc Estimates						
	2010			**2015**		
Distance (Km)	estimate	std. error	Pr(>|t|)	estimate	std. error	Pr(>|t|)
1	-0.00535	±0.00227	0.019	-0.00314	±0.00346	0.36
2	-0.00535	±0.00227	0.018	-0.00314	±0.00347	0.36
3	-0.00535	±0.00227	0.018	-0.00314	±0.00347	0.37
4	-0.00535	±0.00225	0.018	-0.00314	±0.00353	0.37
5	-0.00535	±0.00225	0.017	-0.00314	±0.00359	0.38
6	-0.00535	±0.00227	0.018	-0.00314	±0.00377	0.40
7	-0.00535	±0.00227	0.018	-0.00314	±0.00392	0.42
8	-0.00535	±0.00226	0.018	-0.00314	±0.00405	0.44
9	-0.00535	±0.00228	0.019	-0.00314	±0.00414	0.45
10	-0.00535	±0.00231	0.021	-0.00314	±0.00424	0.46

Discussion

Based on the results of this study, there is no conclusive evidence whether an increase in the minority population yields a decrease in internet speeds. Mostly, **Tables 3.1 and 3.2** demonstrate the correlation between internet speeds and the proportion of the minority population is not statistically significant at the Bonferroni corrected p-value of 0.0125. Further, this suggests that adjustments in the distance which expanded the field of potential spatial dependence did not change the statistical significance of these estimates. Since the Conley regressions yielded clear negative changes, it is possible that an alternative statistical analysis may provide more conclusive results on whether there is an effect between internet speeds and race. Even though the Conley regression estimations were not circumstantial, the visualizations in **Figures 4.1, 4.2, and 4.3** demonstrate patterns of high internet speed clusters in predominantly affluent, elite white communities in downtown and North Atlanta compared to predominantly Black communities in Southwest Atlanta. In correspondence to Immergluck's claims of Atlanta's trajectory in racialized gentrification, shifts in the Atlanta population in 2010, 2015, and 2020 further foresaw larger concentrations of high internet speeds. Moreover, the absence of high internet speed observations in previously redlined areas or predominantly non-white areas in **Figures 4.1, 4.2, and 4.3** does not guarantee a lack of broadband infrastructure or delivery as this study does not consider immeasurable factors. Because this study only evaluates available M-Lab speed test data, this study cannot generalize individuals with no broadband access and those with little technological knowledge of which M-Lab network performance data is not measurable. For this reason, the methods and results of this study suggest the evaluation of internet performance strongly requires extensive nuanced analysis.

Limitations

The M-Lab network accumulated performance data by measuring the speed at which a signal is delivered and returned to the server site. As nearly thousands of speed tests are daily conducted, these measurements may be subjected to noise due to parameters affecting the behavior of these speed tests. For this reason, this study exhibits limitations due to the quality of the M-Lab data. Time, location, and network congestion are some parameters that may distort the efficacy of speed tests which may underestimate or overestimate internet speeds (Masala et al, n.d.). Further validating M-Lab data is difficult as evaluating large volumes of upload and download speed data creates immense challenges. Implications in employing traditional data-processing applications in assessing Big data such as M-Lab network performance data further subject this study to imperfect measurements.

Additionally, M-Lab relies on IP addresses to determine the location of speed tests. Geolocations of tests are rounded and suitable for identifying the city or respective region of the user rather than the exact location. In spite of randomly adjusting the spatial coordinates of speed test observations to visualize network performance data, this aggregated data provides geographical context to a limited degree of granularity (Broadband Mapping Coalition, 2022). Therefore, the limited granularity of speed test observations challenges the precisions of this study in examining internet speeds on demographic shifts in Atlanta. Another consequence of visualizing the M-Lab data with limited granularity was that it created challenges in assessing clear patterns of internet speeds on race, income, and educational attainment. This study cannot be certain of whether high upload or download speeds are definitive in areas composed of predominantly wealthy, elite white communities from **Figures 4.1, 4.2, and 4.3**.

Moreover, race, income, and educational attainment are complex social mechanisms, and evaluating these variables against broadband accessibility needs more consideration. Contextualizing the impacts of the broader scope of these demographic variables may not be the best measure to solely explore the probable effects of digital redlining. By evaluating the criterion on which ISPs base their decisions to establish broadband infrastructure, it would be constructive to examine other socioeconomic conditions including poverty, violence, pollution, and housing which are largely correlated to these demographic variables. By considering the meaningful interaction of these socioeconomic conditions and internet speeds, additional studies under these claims may provide circumstantial results. While limitations in my digital applications challenged the scope of analysis, results from this study strongly encourage complex analysis to uncover the discrepancies in broadband accessibility under a socioeconomic lens.

Further, problems with data collection may create inconsistencies in evaluating M-Lab network data. For instance, the number of speed tests generated is inconsistent every year which corresponds with the dissimilarities in the number of upload and download speeds. While there is no clear intention of initiating speed tests, clarifying these irregularities is cumbersome (Broadband Mapping Coalition, 2022). Since the primary interest of this study had largely evaluated the internet performance data sourced from the Measurement Lab (M-Lab), it would be worthwhile to evaluate other publicly available network performance data from third-party organizations such as Ookla. Both Ookla's Speedtest and M-Lab's Net Diagnostic Tool (NDT) provide publicly available network performance metrics, but each entity employs varying methods to calculate speed measurements. The Ookla Speedtest utilizes servers hosted by ISPs and partner organizations within peripheral areas. Each server is close to a testing device that measures the performance of an ISP's network (Broadband Mapping Coalition, 2022). An Ookla Speedtest sends connections to open multiple streams of data which compensate for issues from the impact of a single stream of data. By using multiple streams, these speed tests measure link capacity or document the "total traffic carrying capacity of a link or path in a network" which likely correspond with ISP advertised speeds (Broadband Mapping Coalition, 2022). Assessing Ookla network data in accordance with ISP plans will facilitate more knowledge in regard to broadband adoption and internet coverage in Atlanta.

Apart from limitations in M-Lab data, a multitude of factors affects the internet speed coverage, even those unrelated to the phenomenon of digital redlining. Internet cables and fiber optics are not consistently established throughout Atlanta as some broadband capabilities are less available and more expensive to implement. As a result, inconsistent internet services encompassing Atlanta may cause varying internet speeds in respective geographical areas. Internet speeds are largely dependent upon an ISP's technical capabilities and willingness to deliver higher speeds (Broadband Mapping Coalition, 2022). However, ISPs typically oversubscribe their connections which cannot guarantee consistent internet speeds for every household in an area. For instance, internet congestion, network interferences, and latency issues may affect a user's download and upload speeds as a service's bandwidth may not be feasible to optimally serve many users (Broadband Mapping Coalition, 2022). Further, poorly set up internet connections and end-user hardware issues may cause slowdowns in broadband or reduce internet speeds (Broadband Mapping Coalition, 2022). Under financial constraints, households that engage in limited data usage enable ISPs to slow down the remainder of their internet connections until a certain threshold of data is downloaded, further delivering low internet speeds for a certain time period (Broadband Mapping Coalition, 2022).

Conclusion

At least 120 million Americans do not experience the internet at broadband speeds per the FCC broadband definition (CNET, 2023). Based on this study which investigates broadband gaps in Metro Atlanta, it is evident that internet accessibility and broadband infrastructure require extensive longitudinal analysis to understand the probable effects of digital redlining. From the results, this study demonstrates that broadband speeds are not consistently delivered throughout Metro Atlanta. Because areas composed of predominantly affluent, elite white communities experience larger concentrations of high internet speeds than predominantly Black communities, there is a strong possibility that inadequate broadband capabilities may persist in the city. Further, the results of the study complement Immergluck's claims that rapid gentrification and investments have transformed the demographics of the city's population towards "less-Black, more affluent, and more college-educated" (Immergluck, 2022). While the expansion of broadband deployment and infrastructure may be synonymous with the city's growth, this study cannot certify whether disinvestments have contributed to the lack of broadband capabilities in certain parts of the city. Mostly, Atlanta presents itself as a unique case as it encompasses a prosperous Black population, unlike any other city. Further evaluating internet speed coverage without the interaction of high and low socioeconomic conditions causes shortcomings in analyzing internet speed coverage in metro Atlanta. Without nuanced knowledge of the larger implications of redlining and its changes in the socioeconomic conditions of Atlanta, comprehending the phenomenon of digital redlining is not feasible.

As the world becomes more technologically dependent, it is important to recognize that broadband coverage and accessibility are a necessity rather than a commodity. Exploring the correlation between low socioeconomic conditions and broadband speeds produces greater knowledge in determining whether digital redlining causes disproportionate access to broadband capabilities. As broadband accessibility is mostly privatized, it may be appealing to further gauge knowledge of Atlanta's main internet service providers. Often, customers may have limited options to choose subscription plans as a single ISP may be available within an area. Individually assessing internet coverage by each ISP will allow us to investigate broadband delivery corresponding to parts of Atlanta more specifically. Further, the criteria for ISPs to invest in broadband capabilities across Metro Atlanta should also be evaluated. Measuring socioeconomic factors such as violence, pollution, available housing, poverty, etc. will produce more nuanced results in uncovering broadband gaps.

A greater analysis of potential demographic and socioeconomic measures will provide significant knowledge of the dispersant effects of digital redlining and gentrification in Metro Atlanta in the next decade. As opposed to other major U.S. cities, Atlanta is racially diverse having a 49.79% Black population compared to a 40.42% white population (World Population Review, n.d.). In the last decade, Atlanta has undergone a rapid transformation with an influx of new residents and investments. Further, the Kemp administration recently announced plans to expand high-speed internet service to underserved areas in the upcoming years. To scope out these changes, continuing this study by evaluating internet performance in the next five years may also be indicative in understanding whether broadband investments have been exclusive to certain parts of the city. Investigating the impact of these investments on respective areas will derive a better understanding of the allocation of these funds and their socioeconomic effects on changing populations. As Atlanta continues to flourish, advancing research on disproportionate access to internet capabilities and broadband deployment will expand our understanding of digital redlining. By doing so, it will not only increase the transparency of digital inequities but also compel policymakers and ISPs to reconsider current tactics in delivering broadband capabilities. Internet connection is becoming a necessity that is inherent to the development of communities nationwide. Dependence on digital capabilities has made populations reliant on internet coverage and infrastructure for daily functioning. Thereby, expanding on consequential research in broadband delivery and accessibility will not only address digital inequities and broadband gaps but also gain momentum in recognizing the internet as a public utility. In hindsight, democratizing the internet will minimize systemic barriers and institutional disparities so that no group or individual is disadvantaged in taking part in the digital world.

References

Advertised vs actual internet speeds: What's the difference? (n.d.) Updater. Retrieved March

26, 2023, from https://updater.com/guides/internet-speeds-advertised-vs-actual#:~:text=Oversubscription%20of%20networks,slowdown%20during%20peak%20usage%20periods

American Community Survey (ACS). Census.gov. (2023, March 16). Retrieved April 8, 2023, from https://www.census.gov/programs-surveys/acs

Assessing available databases: Network Performance Measurements – Speed Test Datasets - Broadband Mapping Coalition. Broadband Mapping Coalition (2022, October 28). Retrieved March 26, 2023, from https://broadbandmappingcoalition.org/assessing-available-databases-network-performance-measurements-speed-test-datasets/

Atlanta, Georgia Population 2023. (n.d.). Retrieved March 27, 2023, from https://worldpopulationreview.com/us-cities/atlanta-ga-population

Atske, S., & Perrin, A. (2022, August 25). *Home Broadband Adoption, computer ownership vary by race, ethnicity in the U.S.* Pew Research Center. Retrieved March 26, 2023, from https://pewresearch-org-preprod.go-vip.co/fact-tank/2021/07/16/home-broadband-adoption-computer-ownership-vary-by-race-ethnicity-in-the-u-s/

Atske, S. (2020, July 9). *4. the internet will continue to make life better*. Pew Research Center: Internet, Science & Tech. Retrieved April 8, 2023, from https://www.pewresearch.org/internet/2019/10/28/4-the-internet-will-continue-to-make-life-better/

BigQuery QuickStart. M. (n.d.). Retrieved March 26, 2023, from https://www.measurementlab.net/data/docs/bq/quickstart/

Campbell, S., Castro, J. R., & Wessel, D. (2022, March 9). The benefits and costs of broadband expansion. Brookings. Retrieved March 26, 2023, from https://www.brookings.edu/blog/up-front/2021/08/18/the-benefits-and-costs-of-broadband-expansion/

Chakravorti, B. (2021, July 20). How to close the digital divide in the U.S. Harvard Business Review. Retrieved April 8, 2023, from https://hbr.org/2021/07/how-to-close-the-digital-divide-in-the-u-s

Corallo, B. (2021, September 22). *Housing affordability, adequacy, and access to the internet in homes of Medicaid enrollees*. KFF. Retrieved April 8, 2023, from https://www.kff.org/medicaid/issue-brief/housing-affordability-adequacy-and-access-to-the-internet-in-homes-of-medicaid-enrollees/

Fishbane, L., & Tomer, A. (2022, March 9). *Neighborhood Broadband Data makes it clear: We need an agenda to fight Digital Poverty*. Brookings. Retrieved March 26, 2023, from https://www.brookings.edu/blog/the-avenue/2020/02/05/neighborhood-broadband-data-makes-it-clear-we-need-an-agenda-to-fight-digital-poverty/

"Gov. Kemp announces additional broadband grants to expand high-speed internet" Governor

Brian P. Kemp Office of the Governor. (n.d.). Retrieved March 26, 2023, from https://gov.georgia.gov/press-releases/2023-02-17/gov-kemp-announces-additional-broadband-grants-expand-high-speed-internet

Hendrickson, J. (2019, July 4). *How do internet speed tests work? (and how accurate are they?)*. How. Retrieved March 26, 2023, from https://www.howtogeek.com/426757/how-do-internet-speed-tests-work-and-how-accurate-are-they/

How do we measure broadband? Benton Foundation. (2019, August 14). Retrieved March 26, 2023, from https://www.benton.org/blog/how-do-we-measure-broadband

Immergluck, D. (2022, November 3). Gentrification and the subsidizing city. Atlanta Studies. Retrieved March 26, 2023, from https://atlantastudies.org/2022/09/28/gentrification-and-the-subsidizing-city/

Isberto, P. by M. (2023, February 22). What is a speed test? and what does it test? Colocation America. Retrieved March 26, 2023, from https://www.colocationamerica.com/blog/what-is-a-speed-test-and-what-does-it-test

Leigh, E. (2020, December 11). *Atlanta: The Home of Black Excellence*. ArcGIS StoryMaps. Retrieved April 8, 2023, from https://storymaps.arcgis.com/stories/fecd5696821844468b96a1212b277bc6

Lingel, Jessa *'the gentrification of the internet'. (n.d.). Retrieved March 26, 2023, from https://www.fastcompany.com/90625837/jessa-lingel-gentrification-of-the-internet-excerpt*

Liu, C. (2023, January 31). The FCC broadband maps: Meet the new maps, same as the old maps. Electronic Frontier Foundation. Retrieved March 26, 2023, from https://www.eff.org/deeplinks/2023/01/fcc-broadband-map-has-problems

Masala, E., Basso, S., & Carlos De Martin, J. (n.d.). Analyzing network data measurements. Retrieved March 27, 2023, from https://www.measurementlab.net/publications/analyzing-network-data-measurements.pdf

McCall, T., Asuzu, K., Oladele, C. R., Leung, T. I., & Wang, K. H. (2022, June 22). A socio-ecological approach to addressing digital redlining in the United States: A call to action for health equity. Frontiers. Retrieved March 26, 2023, from https://www.frontiersin.org/articles/10.3389/fdgth.2022.897250/full#:~:text=Digital%20redlining%E2%80%94the%20systematic%20process,as%20healthcare%20and%20health%20information

Niesse, M., & Thieme, N. (2019, June 12). Internet far slower in Georgia than reported. AJC. Retrieved March 27, 2023, from https://www.ajc.com/news/state--regional-govt--politics/internet-far-slower-georgia-than-reported/cwH1H8cW70nEF6d2a0aVeN/

Overview (n.d.). *Measurement lab*. M. Retrieved March 26, 2023, from https://www.measurementlab.net/

Pascual, A. (n.d.). 5 things new census data says about Metro ATL . ARC. Retrieved March 26, 2023, from https://atlantaregional.org/whats-next-atl/articles/5-things-new-census-data-says-about-metro-atl/#:~:text=Metro%20Atlanta%20is%20still%20booming&text=The%20growth%20rate%2C%20however%2C%20cooled,in%20the%201980s%20and%201990s

Pew Research Center. (2023, March 2). *Internet/broadband fact sheet*. Pew Research Center: Internet, Science & Tech. Retrieved March 26, 2023, from https://www.pewresearch.org/internet/fact-sheet/internet-broadband/

Quaintance, Z. (2022, April 3). *The nuances of digital redlining, explained*. Governing. Retrieved March 26, 2023, from https://www.governing.com/community/the-nuances-of-digital-redlining-explained

Robert K. Nelson, LaDale Winling, Richard Marciano, Nathan Connolly, et al., "Mapping Inequality," American Panorama, ed. Robert K. Nelson and Edward L. Ayers, accessed April 2, 2023, https://dsl.richmond.edu/panorama/redlining/

Stewart, E. (2020, September 10). *Give everybody the internet*. Vox. Retrieved March 27, 2023, from https://www.vox.com/recode/2020/9/10/21426810/internet-access-covid-19-chattanooga-municipal-broadband-fcc

Technology equity. The Greenlining Institute. (2023, January 11). Retrieved March 26, 2023, from https://greenlining.org/work/economic-equity/technology-equity/?gclid=CjwKCAiA5Y6eBhAbEiwA_2ZWIePbl4yMWCW8D9L-EKOHWeSOQeKpvdswGqG6UVVATyJl6MZDsBNTchoC3ZQQAvD_BwE

Tibken, Shara (2021, June 28). *The Broadband Gap's dirty secret: Redlining still exists in digital form*. CNET. Retrieved March 26, 2023, from https://www.cnet.com/home/internet/features/the-broadband-gaps-dirty-secret-redlining-still-exists-in-digital-form/

Tomer, A., Fishbane, L., Siefer, A., & Callahan, B. (2022, March 9). *Digital Prosperity: How Broadband Can Deliver Health and equity to all communities*. Brookings. Retrieved April 8, 2023, from https://www.brookings.edu/research/digital-prosperity-how-broadband-can-deliver-health-and-equity-to-all-communities/#:~:text=Taking%20a%20macro%20lens%2C%20o

Understanding the urban digital divide. Bipartisan Policy Center. (n.d.). Retrieved March 26, 2023, from https://bipartisanpolicy.org/blog/urban-broadband-blog/

Vogels, E. A. (2021, September 10). *Digital divide persists even as Americans with lower incomes make gains in tech adoption*. Pew Research Center. Retrieved March 26, 2023, from https://pewresearch-org-preprod.go-vip.co/fact-tank/2021/06/22/digital-divide-persists-even-as-americans-with-lower-incomes-make-gains-in-tech-adoption/

References for R Programming

Bearman, N. (n.d.). *r-google-map-making*. RPubs. Retrieved March 27, 2023, from https://rpubs.com/nickbearman/r-google-map-making

Census data API: /data/2019/ACS/acs5/variables. Developers. (2011, November 28). Retrieved March 27, 2023, from https://api.census.gov/data/2019/acs/acs5/variables.html

Conleyreg: Estimations using Conley Standard Errors. (n.d.). Retrieved March 27, 2023, from https://cran.r-project.org/web/packages/conleyreg/conleyreg.pdf

Data at Urban. (2018, July 10). *How to create state and county maps easily in R*. Medium. Retrieved March 27, 2023, from https://urban-institute.medium.com/how-to-create-state-and-county-maps-easily-in-r-577d29300bb2

Draw symbols in TMAP: Thematic maps. R Package Documentation. (2022, March 18). Retrieved March 27, 2023, from https://rdrr.io/cran/tmap/man/tm_symbols.html

Düben, C. (n.d.). Introduction to conleyreg. Retrieved March 27, 2023, from https://cran.r-project.org/web/packages/conleyreg/vignettes/conleyreg_introduction.html#:~:text=Conley%20(1999%2C%202008)%20standard,dependence%20based%20on%20spatial%20proximity.

Gill, P. (2022 August 23). *Large-Scale Open Internet Measurement with M-Lab*. Google Colab. Retrieved March 27, 2023, from https://colab.research.google.com/drive/1PMp86RjIyTVmpiEQoLwsjL9d3q3bDRO1#scrollTo=lpMw03SZo_hV -QT

Holtz, Y. (n.d.). *Basic histogram with GGPLOT2*. – the R Graph Gallery. Retrieved March 27, 2023, from https://r-graph-gallery.com/220-basic-ggplot2-histogram.html

Mapping with mapboxapi. mapboxapi. (n.d.). Retrieved March 27, 2023, from https://walker-data.com/mapboxapi/articles/mapping.html

Mouselimis, L. (2023, January 12). Processing of GEOJSON data in R. Retrieved March 27, 2023, from https://cran.r-project.org/web/packages/geojsonR/vignettes/the_geojsonR_package.html

Ruhil, A. V. S. (n.d.). *Data Management, analysis and visualization with R*. 8 Working with Census Data in R. Retrieved March 27, 2023, from https://people.ohio.edu/ruhil/RBookNew/working-with-census-data-in-r.html

Scatter. Scatter plots on maps in R. (n.d.). Retrieved March 27, 2023, from https://plotly.com/r/scatter-plots-on-maps/

Spatial join, spatial filter - st_join. - st_join • sf. (n.d.). Retrieved March 27, 2023, from https://r-spatial.github.io/sf/reference/st_join.html

Tran, A. B. (n.d.). *Mapping Census Data*. Mapping Census data :: Journalism with R. Retrieved March 27, 2023, from https://learn.r-journalism.com/en/mapping/ggplot_maps/mapping-census/

Understanding and using ACS single-year and Multiyear estimates. (n.d.). Retrieved March 27, 2023, from https://www.census.gov/content/dam/Census/library/publications/2020/acs/acs_general_handbook_2020_ch03.pdf

Walker, K. E. (n.d.). *Chapter 3 wrangling census data with Tidyverse Tools: Analyzing US Census Data*. Chapter 3 Wrangling Census data with tidyverse tools | Analyzing US Census Data. Retrieved March 27, 2023, from https://walker-data.com/census-r/wrangling-census-data-with-tidyverse-tools.html

Walker, K. E. (n.d.). *Chapter 6 Mapping Census data with r: Analyzing US census data*. Chapter 6 Mapping Census data with R | Analyzing US Census Data. Retrieved March 27, 2023, from https://walker-data.com/census-r/mapping-census-data-with-r.html

Walkerke. (n.d.). *Blank API error returned* . GitHub. Retrieved March 27, 2023, from https://github.com/walkerke/tidycensus/issues/205