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Special Issue: North Carolina Crossroads: Culture, Community, and the Environment

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(1) The need for the advancement of geographic knowledge in schools, colleges, and public life throughout North Carolina.
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INTRODUCTION TO THE NORTH CAROLINA GEOGRAPHER, VOLUME 21

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This special issue, titled "North Carolina Crossroads: Culture, Community, and the Environment," marks a highly anticipated return for *The North Carolina Geographer* after a brief publishing hiatus. This special issue, an endeavor of significant scholarly commitment, proudly aligns with our mission as the official journal of the North Carolina Geographical Society to foster geographic education, research, and professional practice across the state.

Production of this volume is a testament to the robust and collaborative academic network within North Carolina. We are particularly pleased to acknowledge the substantial contributions from our partners in higher education, whose dedication has been instrumental in bringing this work to fruition. A special note of sincere gratitude is extended to the esteemed faculty members and their institutions—Appalachian State University, East Carolina University, North Carolina Central University, the University of North Carolina at Chapel Hill, UNC Charlotte, UNC Greensboro, UNC Pembroke, UNC Wilmington, Western Carolina University, and Winstons-Salem State University—for their tireless efforts in advancing the vital discipline of geography throughout our diverse state. Their collective engagement underscores the importance of this journal as a platform for rigorous, place-based scholarship.

This issue presents a diverse collection of articles that collectively illuminate the critical intersection of infrastructure, public health, and spatial justice within North Carolina. The first study evaluates the connectivity of public transportation at the state's five busiest airports, revealing a significant misalignment between bus schedules and airport operating hours. The authors find that current bus schedules do not cover the full duration of working hours at any primary airport, a gap that disproportionately affects "captive riders"—employees and low-income travelers who cannot afford expensive ride-share options and rely on affordable mass transit for economic access. Shifting from transportation to environmental resilience, a second article offers a harrowing geographic account of Hurricane Helene's impact on Asheville, specifically the catastrophic failure of the city's water infrastructure following a "1000-year weather event". This narrative details how torrential rains and landslides compromised the North Fork reservoir and treatment plant, leaving the city without potable water for nearly two months and forcing a reevaluation of floodplain development and green infrastructure to mitigate future climate risks.

Complementing these infrastructure analyses, two studies utilize advanced data visualization to address deep-seated social disparities. One paper employs

Geographic Information Systems (GIS) to analyze the relationship between cancer mortality rates and socioeconomic factors across North Carolina, identifying high-mortality clusters in rural western and eastern counties. This research validates the socio-ecological model of health by demonstrating statistically significant associations between higher cancer death rates and lower household incomes, higher diabetes prevalence, and limited access to healthy food sources, often termed food deserts. similarly focused on data-driven equity, the final paper details the development of the Forsyth County Neighborhood Opportunity Atlas (FCNOA), a digital dashboard designed to benchmark spatial justice. By aggregating over 50 variables—ranging from economic well-being to justice and social capital—this tool allows stakeholders to visualize neighborhood-level disparities, thereby moving beyond anecdotal evidence to inform more equitable budgeting, programming, and policy decisions.

Together, these studies are vitally important as they demonstrate the power of geographic inquiry to expose structural inequalities and guide resilient community planning. The research on airport accessibility and the Forsyth County Atlas underscores the necessity of aligning public services with the actual needs of underserved populations to promote economic mobility and spatial justice. Simultaneously, the analyses of Asheville's water crisis and statewide cancer mortality highlight the urgency of addressing environmental vulnerabilities and the social determinants of health. By leveraging spatial data to make these invisible disparities visible, these papers provide essential baselines and methodological frameworks that policymakers and planners can use to target interventions, improve infrastructure resilience, and ultimately reduce the inequitable burdens placed on marginalized communities across North Carolina.

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ASHEVILLE WATER

Richard L. Mattson
Historical Preservation Planner

I moved to Asheville from Charlotte just months before Hurricane Helene, which ravaged the southern Appalachians between September 25 and September 27 of last year. In fact, I had previously moved to Charlotte in September of 1989, just in time for Hurricane Hugo. Each storm was devastating in its own way. With Hugo, it was tremendous winds—gusting up to 100 miles per hour—ripping through neighborhoods and felling countless oaks across streets and onto houses and power lines. Nearly all of the homes and businesses in the city lost electricity, which took many weeks to restore.

With Helene in Asheville, it was water. No question, Helene's fierce winds shattered the forested southern Appalachians, and millions lost power. But Asheville's 95,000 souls, plus the thousands living in surrounding communities, will remember the storm mainly for the flooding and landslides it wrought, and for the months without clean water running from faucets. The winds and rains would subside as the storm moved on. But in the still of the days and weeks that followed, the water damage would be deafening. And while stricken by floods, Asheville also thirsted for water. As the adage goes, water can be your best friend and worst enemy. Helene battered the municipal reservoir and treatment plant, so amidst the inundation we all queued up for water to drink. Authorities issued a boil water advisory for cooking and cleaning to avert a public health calamity. We immediately discovered that water is heavy. A five-gallon bucket of the liquid weighs about 42 pounds. No wonder that when trillions of gallons rained down from the sky and were propelled down the mountainsides by the force of gravity and shocking winds destruction ensued. Helene's waters and landslides claimed countless buildings and over 100 lives in the region, including 42 lives in Asheville and Buncombe County. The flooding was historic and the clean-up Herculean.

Why did Helene strike Asheville so hard? Geography is key. Humid hurricane-force winds moving northward from the Gulf jetted up the steep Blue Ridge escarpment to condense and then release torrential rains from the cooler mountain tops. Asheville's setting in a basin in the Blue Ridge made it especially prone to flooding and landslides as rain-swollen rivers and creeks rushed down rugged slopes. When Helene blew through Asheville on the heels of a preceding storm, some 14 inches of rain soaked the city. Mount Mitchell saw over 24 inches. The French Broad and the Swannanoa rivers poured down upon the town at record levels, exceeding previous crests during the Great Flood of 1916—the grim standard for comparing floods in North Carolina. The French Broad crested above 24 feet in Asheville—exceeding its 1916 high by a foot and a half. The Swannanoa River, which runs east-west from Black Mountain to Asheville, surpassed 27 feet, an astounding five feet above the 1916 mark.

Coursing down from its headwaters atop the Blue Ridge in Transylvania County, the French Broad boiled over into the city's mile-long River Arts District in the floodplain. In the late 19th and early 20th centuries, a mix of sturdy, red-brick mills, tanneries and other manufactories filled this buildable narrow plain alongside the river and the Southern Railway tracks. These structures largely

Figure 1. *After the flood: River Arts District (Photograph by author)*

withstood the 1916 storm. Over time most were vacated and shuttered and by the 1980s, enterprising local artists and gallery owners began moving in, taking advantage of cheap and adaptable spaces facing the French Broad. In organic fashion the River Arts District steadily took shape to represent hundreds of artists and prosper as a tourist hotspot. As in the Great Flood, the district's durable industrial buildings withstood Helene, but river water and toxic mud engulfed the precious interior art spaces. One estimate has it that the flooding damaged some 80 percent of the galleries and studios in the district (Figure 1).

The Swannanoa River meets the French Broad at the south end of downtown Asheville, within the magnificent Biltmore Estate. Here lies another of Asheville's premier tourist destinations: historic Biltmore Village. It was erected for George W. Vanderbilt in the years before and after 1900 as a storybook manorial village. The collection of buildings, including All Souls Cathedral, an architectural gem in the Gothic style, occupy vulnerable bottomland beside the river. At the eve of construction, workers hauled in wagonloads of infill to lift the land above the waterway. But the village stayed in harm's way. The Swannanoa proceeded to flood the village in 1916, and soon thereafter the Vanderbilts sold off most of the property. In recent memory, the river swamped this area during Hurricane Frances in 2004. Now it was Helene's turn, and while the buildings stood firm, cresting water and mud soaked the myriad art galleries, restaurants, and shops that have come to mark the village. All Souls Cathedral, which stands at the highest point in the village, saw the river enter its sanctuary and parish hall for the first time ever (Figure 2).

In the Black Mountains east of Asheville, the North Fork of the Swannanoa River holds the Burnett Reservoir, the city's primary source of running water. In 1903, Asheville acquired 5,000 acres of the North Fork Valley from the Burnett family and others, and began piping drinking water into the city. Asheville ultimately purchased 22,000 acres of the valley's pristine forested watershed, and in 1955 created the 355-acre reservoir and North Fork dam and water treatment plant. Helene despoiled the lake and disabled the plant. Water charged down the valley

Figure 2. *Biltmore Village (Photograph by author)*

in the dark evening of the storm, uprooting trees and bucketing sand and soil into the reservoir. In this terrible whirl, the lake's bottom layers of sediment and clay were churned up to the surface, and the once-crystal blue lake turned chocolate brown. The raging water destroyed the treatment plant's distribution lines and washed-out roads leading to the plant. Just like that, the city lost its chief water supply and the means to reach the lake and assess the damage. Amidst the wreckage the dam held firm, most likely because of a massive auxiliary concrete spillway which was just completed in 2021. The spillway's first of eight massive concrete gates performed as designed: to break open in the event of a 1000-year flood. Had the spillway failed and the dam burst, the gates of Hell would have opened. A spokesperson for the Asheville Water Resources Department declared to the press, "If that North Fork dam had failed and unleashed six billion gallons of water, it would've meant complete annihilation of everything and every person between Black Mountain and Biltmore Village."

Nevertheless, flood waters and landslides struck the heavily developed Swannanoa River Valley with a fury. Asheville geologist Peter Prince, who has reported on Helene's impact on the Blue Ridge, states that some of the highest ranges in the Blue Ridge border this precarious corridor below the reservoir. The headwaters of the Swannanoa River begin to the north in the Black Mountains—peaking at about 6,000 feet above sea level. The Swannanoa Mountains to the south rise to some 4,000 feet. Thus, the swelling tributaries barreled down steep mountainsides into the Swannanoa with a vengeance, destroying everything in their path.

When Helene swamped properties which were deeply rooted in the history of the area, a sense of place suffered as well. For much of the 20th century the community of Swannanoa was intimately tied to the Beacon Manufacturing Company, the world's largest maker of cotton blankets. During the 1920s and 1930s, Beacon built a massive brick mill alongside the railroad tracks and the river, and constructed a village of modest bungalows for its workforce. The factory shut down in 2002 and

burned to the ground the following year. Only the mill village survived. In the dark morning of September 27, waters rose to the rooftops and ravaged most of the 77 mill houses—now owned or leased mostly by locals. It remains to be seen how many of these dwellings can be rescued. Surveying the disfigured landscape, Fire Chief Anthony Penland lamented to a local newspaper reporter, "There goes the history of Swannanoa right there."

While in and around Asheville resilient property owners faced the long road to recovery, everyone began searching for usable water. H20 questions abounded: Where could we find safe drinking water? What about water for cleaning? Showering? Flushing? When would the reservoir and North Fork treatment plant recover? Indeed, many of us had never before even heard of the North Fork, let alone about the source of Asheville tap water beyond our own nozzles. Because internet, cable, and cell services were out for weeks, families gathered round radios for daily news briefings about such things. We learned that the National Guard and volunteers were making available potable and non-potable water at distribution sites, like Pack Square in downtown. Folks pulled small wagons and pushed hand trucks up to spigots fed by pipes from ponderous water trucks idling nearby. Impromptu signs taped to storefronts or chalked onto sidewalks alerted passersby as to the whereabouts of water and other essentials. My neighbors and I drew flushing water from a nearby creek, gaining purchase on the rocks before dipping plastic buckets into the flow (Figures 3 and 4).

Others discovered non-potable water in eye-catching, industrial-grade plastic containers (or "totes") which revealed themselves, like small miracles, at street corners across the city. In truth their appearance demanded hard work and resourcefulness. A grassroots team of volunteers named Flush AVL came together to collect donated totes, fill them with water, and truck these plastic gems throughout Asheville. Within days, Flush Avl in partnership with others

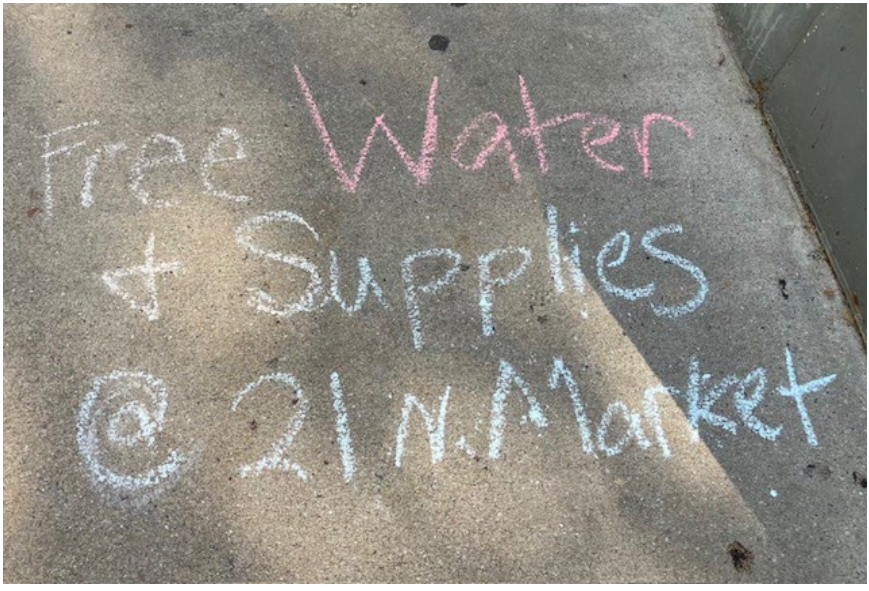

Figure 3. *Directions downtown to potable water (Photograph by author)*

***Figure 4**. Neighbors collecting flushing water at Reed Creek in Asheville's Montford neighborhood (Photograph by author)*

distributed thousands of gallons of water to the needy in 400 totes. Just as extraordinary were the appearances of portable emergency water filtration units, called AquaBlocks, specifically designed to filter creek water for consumption. In a week, the charities Planet Water and Americares set up a series of metal-clad AquaBlocks in both Asheville and Swannanoa to release 17,000 gallons of healthy water daily (Figure 5).

In the mountains high above these feats, federal agencies teamed with city employees and local contractors to restore the reservoir. The labor was day and night, and Mayor Esther Manheimer called it nothing if not "heroic work." City staff begged off committing to any sort of timeline for recovery: the results would be "measured in weeks, not days." There was simply too much uncertainty: sediment covered the lake like chocolate milk, and the city's entire 1,800-mile water system demanded inspection for leaks. Many of us reckoned that we would be without safe running water until Christmastime. To reduce the high concentrations of floating deposits ("turbidity levels" in the precise wording of the Department of Water Resources), workers treated the lake with doses of coagulant chemicals to sink the sediment, and installed "turbidity curtains" to strain out residue. Helene had washed out the main water pipes as well as a later bypass line. Yet by mid-October, just a few weeks after the storm, the bypass line was rebuilt and pressurized, and the city began pumping raw water--heavily treated with chlorine--into Asheville. To be sure, the mandatory boil water notice remained in effect and most of us still used bottled water for drinking, but drawing the dear commodity from our faucets was cause for applause.

Figure 5. *Drinking water to the rescue (Photograph by author)*

On November 18, 2024, nearly two months after Helene, came reason for cheer. On that day, Asheville residents once again drew potable water from their taps. The city lifted the boil water notice and pushed over 20 million gallons of water through the treatment plant. The destroyed transmission lines were back in action and the obdurate turbidity brought to heel. The upended waterworks were now essentially under control and back to normal.

Nevertheless, one cannot overstate how many nearby mountain communities would remain waterless for weeks to come. And to this day, in the new year, some of the more remote places hard hit by the storm are still without electricity to run their wells. In this age of climate change, the year 2025 confronts Asheville with challenges. Climatologists have termed Helene a "1000-year weather event", which is actually not about time, but probability. There is a one in a thousand chance of a storm of Helene's magnitude striking the Blue Ridge in any given year. As the numbers of extreme storms increase, odds will drop. How will Asheville and the region respond? At the Burnett Reservoir the Army Corps of Engineers has installed a state-of-the-art filtration system equipped to control high turbidity. And city contractors have fortified the rebuilt transmission lines with armor and buried them deeper. Appalachian architects are raising concerns about the lack of building regulations and up-to-date building codes that would mitigate the magnitude of such punishing storms.

Big questions persist about buildings in the floodplain and on the hillsides. Should portions of the River Arts District be given over to wetland serving as a natural buffer for construction on higher ground? Addressing this particular issue, the

Asheville weekly Mountain Xpress points out that the town of Brevard, near the headwaters of the French Broad, has written into law tight controls on riverfront development. Floodplain projects in the region, like those initiated in Henderson County by Conserving Carolina, a land trust, create and protect native wetlands and woodlands. Replacing buildings and other infrastructure in upriver floodplains with natural areas gives rivers space to flood and takes pressure off the water system down river, like in Asheville. On a collective scale, the city and its citizens can help safeguard Asheville with "green infrastructure"—installing rain gardens, rain barrels, and permeable drives to reduce rain runoff and flooding.

Tourism is a mainstay of the Asheville economy, and Helene packed a ferocious punch at the onset of the lucrative fall leaf season. As the city recovers, visitors are returning and sections of downtown are pulsing with purpose. But the full panoply of businesses so distinct to this Blue Ridge city--from eateries and inns, to microbreweries and rafting outfitters--will be feeling the blow for some time. The clean-up and rebuilding continue at Biltmore Village and many shop owners appear committed to return. But some will move away. Same goes for the River Arts District. Finally—just for the record--given my misfortune with moves and hurricanes, I am staying put.

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THE DEVELOPMENT OF THE FORSYTH COUNTY NEIGHBORHOOD OPPORTUNITY ATLAS (FCNOA): BENCHMARKING A COMMUNITY'S PROGRESS TOWARDS SPATIAL JUSTICE

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ABSTRACT

In the Summer of 2021, the Spatial Justice Studio (SJS) was contracted to develop a Neighborhood Opportunity Atlas (NOA). The focus of the proposal was to provide a holistic analysis of conditions across Forsyth County that can be used to identify, compare, and assess neighborhoods now and into the future for planning, programming, budgeting, and evaluation. The atlas is an innovative, statistical, and geographic product that provides quantitative census tract level information for a wide range of community indicators and began a process to identify, target, and tackle underperforming neighborhoods. The NOA uses a combination of the knowledge of urban studies and the power of data science to explore opportunities and challenges at the census tract level. By combining these two areas, Forsyth County can get an accurate baseline for existing conditions within communities throughout the county and target programs, policies and budgets to help all neighborhoods achieve a level of spatial justice. This paper seeks to share the process, problems, and potential of a "Neighborhood Opportunity Atlas" for communities who are dealing with myriad issues and are searching for quantitative methods by which to tackle these issues.

KEYWORDS

Community, Data-Driven, Data Dashboards, Spatial Justice

INTRODUCTION

Communities across the United States face persistent inequalities and injustices, including disparities in public services, a lack of affordable housing, and food deserts. Many of these disparities constitute forms of spatial injustice—systemic imbalances that disproportionately affect specific spaces, neighborhoods, and communities (Soja, 2013). The spatial manifestation of these issues presents a critical opportunity to investigate why certain challenges arise in specific locations. By leveraging urban studies and data science, communities can systematically identify, analyze, and address various forms of spatial injustice.

The availability of data has never been greater, offering communities a wealth of information to better understand their local conditions. From U.S. Census data to locally sourced datasets, cities and municipalities have unprecedented access to quantitative insights. Urban data analytics and interactive dashboards have become valuable tools in translating these data into actionable solutions for the

public good. Large cities such as New York and Chicago have embraced urban data analytics to engage citizens in addressing complex urban challenges (City of Chicago, 2025; City of New York, 2025). For example, Boston has successfully utilized crowdsourcing through the 'Street Bump' app to identify and repair potholes (Street Bump, 2017). Additionally, municipal governments increasingly rely on data-driven tools to enhance efficiency across various administrative functions (Kitchin et al., 2015; 2017).

Communities in North Carolina are also beginning to recognize the potential of data science to tackle complex problems. Forsyth County, NC, recently launched an initiative to integrate data-driven decision-making into community planning efforts. In the summer of 2021, the county issued a call for proposals aimed at utilizing data to provide a more comprehensive analysis of local conditions. Specifically, the county sought the development of a tool capable of identifying, comparing, and assessing neighborhood-level opportunities—both now and in the future—to inform planning, programming, budgeting, and evaluation efforts.

This paper explores the development and implications of a "Neighborhood Opportunity Atlas" designed to support North Carolina communities in addressing spatial injustices through quantitative methods (FCNOA, 2025a). The remainder of the paper is organized as follows: Section 2 reviews relevant literature, while Section 3 provides background on Forsyth County's previous data-driven initiatives. Section 4 details the study's methodology, followed by a discussion of key findings in Section 5. Finally, Section 6 presents conclusions and outlines potential next steps.

LITERATURE REVIEW

The amount of data available around the globe is truly astonishing. According to Statista.com, "The total amount of data created, captured, copied, and consumed globally is forecast to increase rapidly, reaching 64.2 zettabytes in 2020 (equivalent to 64.2 trillion gigabytes). Over the next five years up to 2025, global data creation is projected to grow to more than 180 zettabytes" (Taylor, 2024). Much of this data is being generated in urban environments, which has led many people to ask, how can this data be used to improve our communities?

One potential use of the data is through the development of community dashboards. Community dashboards are digital platforms that visualize data to support decision-making, enhance transparency, and improve community engagement. These dashboards aggregate and present various datasets, including socioeconomic indicators, environmental metrics, and public services, to inform policymakers, organizations, and citizens. The Neighborhood Opportunity Atlas is like a dashboard, from which communities can check the 'temperature' of a variety of issues afflicting the community. Jing, et al. (2019) discuss the potential of geospatial dashboards in monitoring smart city performance. The NOA is akin to a geospatial dashboard for Forsyth County. Academic research on dashboards shows that they are utilized for a myriad of reasons ranging from community-wide benchmarking to issue specific projects (Kitchin et al., 2015). Additional research has focused on the design of dashboard and how to collect and visual data through dashboards (Grey et al., 2016; Young and Kitchin, 2020).

Dashboards grew in popularity following their use during the COVID19 pandemic. For most of the citizenry, this was people's first exposure to the power and potential of a community dashboard (Dong et al., 2020). However, dashboards can have limitations and McArdle (2017) has identified six key issues to consider when developing a dashboard. These issues include epistemology, scope and access, veracity and validity, usability and literacy, use and utility, and ethics. Few (2012) and Heer et al. (2016) both highlight the need for the inclusion of community stakeholders in the dashboard design process to ensure usability and relevance. Finally, Tufte (2001) found that a wide variety of visualization techniques including bar charts, heat maps and geospatial representations, help to facilitate comprehension. While not perfect, dashboards provide a unique way of sharing and showing data to the public to be transparent and accountable.

BACKGROUND/OVERVIEW

Forsyth County is in the Piedmont Region of North Central North Carolina. According to 2020 U.S. Census data, Forsyth County has a population of approximately 395,000 (U.S. Census Bureau Quick facts, n.d.) and the largest city is Winston-Salem. The county has a rich agricultural and manufacturing heritage. R.J. Reynolds Tobacco, Hanes Brands and regional banking companies have all called the County home. Over the last several decades, the county has experienced a shift in economic activities from manufacturing to services and technology (Norby 2009). This has resulted in some residents experiencing prosperity, while others have been left behind. According to a report by Chetty, et al. (2014) Forsyth County is the third worst county in the United States for economic mobility. Residents in some Forsyth County neighborhoods face limited economic mobility due to geographic disparities, while others thrive. This two-fold reality manifested itself in the county, through an uneven pattern of development that has been reinforced over the decades by prejudicial planning practices, private disinvestment and racist practices and general neglect (Herbin-Triant, 2019; Smith, 2019; Rothstein, 2017; Usher, 2015). In sum, parts of Forsyth County prospered, others declined, and a spatially unjust geography ensued.

Beginning in the mid-2010s, Forsyth County sought a way to explore the growing inequalities across communities within the County (e.g. urban v. rural, East v. West, etc.). As a result, the Distressed Community Report was developed by MapForsyth. MapForsyth is the City-County Department charged with developing, maintaining, and utilizing geographic information for Forsyth County. The Distressed Community Report examined a wide variety of 'standard' variables across Forsyth County (e.g. median household income, poverty level, unemployment rate, etc.). The result of this endeavor was the creation of numerous maps that all highlight the same stretch of poor performing neighborhoods that run along the eastern side of US 52. The neighborhoods identified by this predecessor to the NOA, have been communities of color and have been impacted by redlining, urban renewal, and prejudicial planning practices (City of Winston-Salem, 2021, Jones- Correa, 2000). This report was updated several times, with new data, but the findings were always the same: East Winston was performing poorly along most metrics.

Armed with this already known information, the County sought a new and innovative way to expand the Distressed Community Report to shed light on the nuanced differences afflicting unique geographies. To that end, the county issued

a call for proposals to rethink and reimagine the Distressed Community Report as a more useful and insightful tool by which local government, non-profits, the private sector, and individual residents could learn more about their community and find solutions to historical problems afflicting spaces across the County.

The Spatial Justice Studio @ the Center for Design Innovation answered the call for proposals and was contracted to develop what would become the Neighborhood Opportunity Atlas (NOA). The focus of the proposal was to provide a more holistic analysis of conditions across the county that can be used to identify, compare, and assess neighborhoods in Forsyth County now and into the future for planning, programming, budgeting, and evaluation. The atlas was presented as an innovative, statistical, and geographic product that could provide quantitative census tract level information for a wide range of community indicators and begin a process to identify, target, and tackle underperforming neighborhoods.

The mission of the Spatial Justice Studio (SJS) is to establish and sustain inter-institutional, interdisciplinary, and inter-sectoral programs that bring faculty, students, and the community together across disciplines into diverse experiences to develop meaningful solutions to issues related to spatial (in)justice. SJS explores alternative possibilities for urban areas and ways of achieving more equitable urban futures through active research agendas, engaged teaching practices and community based participatory research which will lead to the creation/regeneration of equitable, functional, and sustainable communities for all (Spatial Justice Studio 2023).

The goals of the NOA included: developing a holistic analysis of neighborhood conditions across a wide range of variables; expanding upon the Distressed Communities Report – 2016; creating a 'benchmark' document for evaluating projects, programs and budgets; and growing conversations focused on making decisions that promote access, equity, inclusivity, justice and sustainability within Forsyth County. The NOA uses a combination of the knowledge of urban studies and the power of data science to begin to explore opportunities and challenges at the census tract level. By combining these two areas, Forsyth County can get an accurate baseline for existing conditions within communities throughout the County and target programs, policies and budgets to help all neighborhoods achieve a level of spatial justice.

METHODOLOGY

There is a wealth of data available about neighborhoods across the United States, and the FCNOA aimed to collect and present the most useful information in various formats to serve a broad range of users. Our first set of results, Tract Facts, provides summaries for each of Forsyth County's 95 neighborhoods (census tracts). The second set includes interactive maps, while the third offers detailed tables of results.

Tract Facts includes summary write-ups for each neighborhood, highlighting key demographic details, major landmarks, and features that significantly differ from the county. For example, Figure 1 shows the first page of a tract's summary, which includes the tract's geographic dimensions, location within the county, and key demographic statistics (FCNOA, 2025b). Notably, key landmarks and major roads

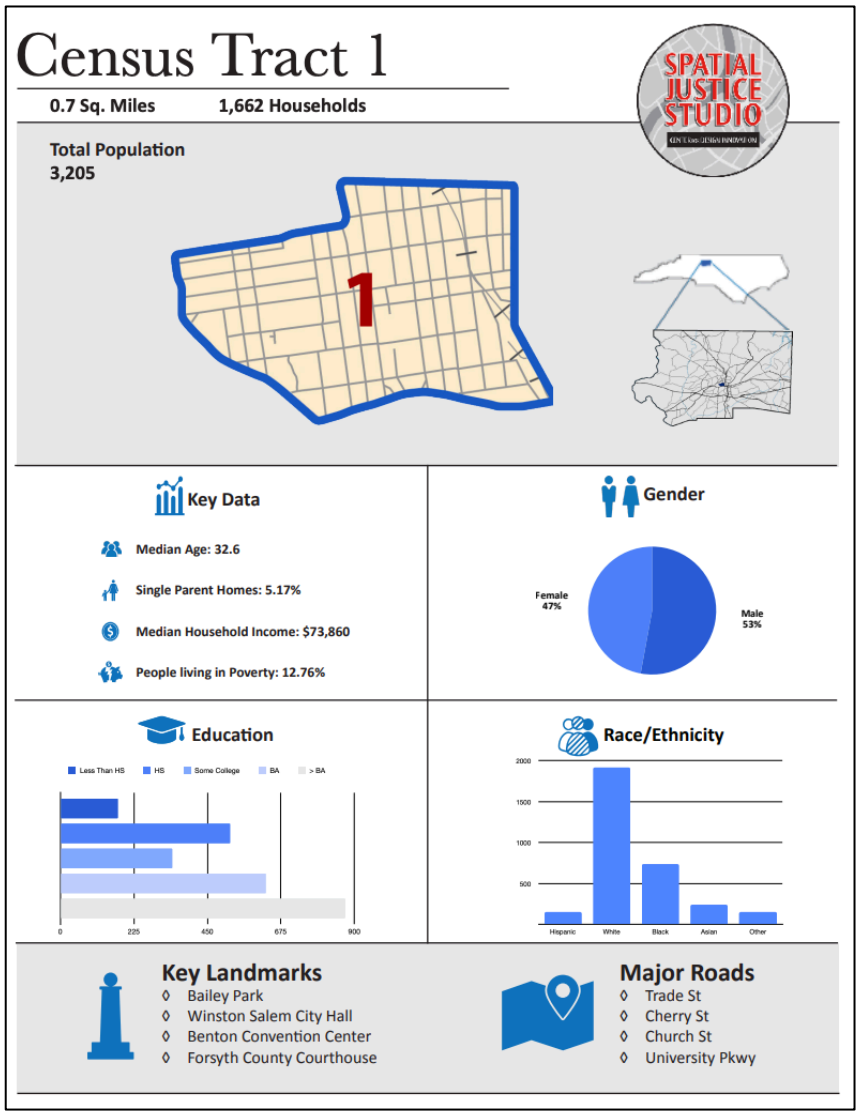


Figure 1. *Tract Fact Sheet: Part I*

are also listed. This summary offers a high-level description of the neighborhood's key characteristics.

Figure 2 displays column charts comparing five key variables where the neighborhood differs significantly from the county (FCNOA, 2025b). Blue bars indicate better performance relative to the county, while red bars highlight areas where the neighborhood performs worse. For instance, in the first row, second column, the crime rate in the tract (519) is significantly higher than the county's average (130.6).

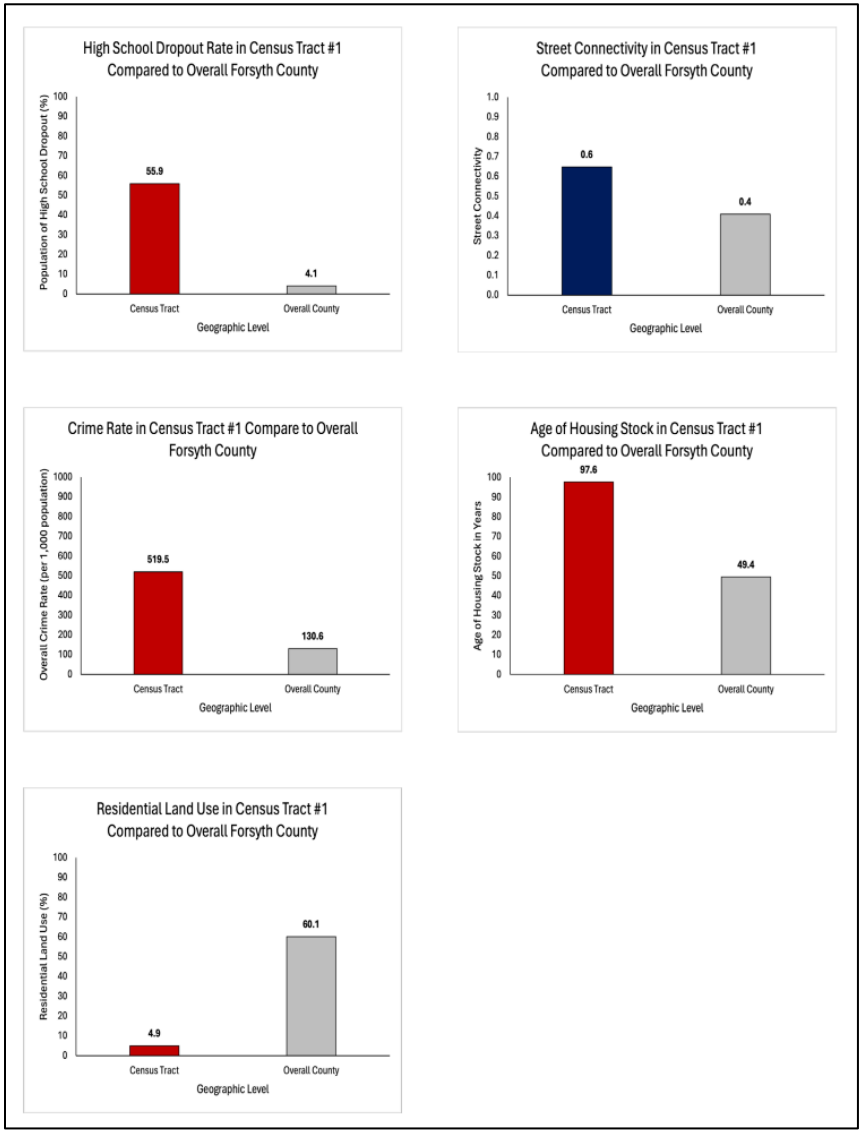


Figure 2. *Tract Fact Sheet: Part II*

To assess the differences between neighborhoods and the county, the FCNOA converted neighborhood-level data into z-scores and tested for statistical significance. Next, the z-scores were mapped across Forsyth County, with bluer areas indicating neighborhoods that perform better than the county, and redder areas indicating those that perform worse. This allows users to quickly see how individual neighborhoods compare to the county overall.

The project includes a wide variety of variables, categorized into seven key domains: 1) Access & Infrastructure (e.g., distance to grocery stores), 2) Built

Environment (e.g., property conditions), 3) Justice & Social Capital (e.g., voter participation rates), 4) Economic Well-Being (e.g., poverty rates), 5) Education (e.g., school performance scores), 6) Health & Wellness (e.g., opioid overdoses), and 7) Demographics (e.g., migration). In addition to the snapshot maps for each year, the FCNOA also included maps showing changes over time, allowing users to observe both the current state and trends in neighborhood performance.

For example, Figure 3 shows a map of voter participation rates in the 2020 General Election (FCNOA, 2025c). Redder areas indicate lower participation rates relative to the county, while bluer areas show higher rates. The map reveals that tracts in the eastern part of the urban center have significantly lower participation, while those in the western part of the county have higher participation. Hovering over a tract will display additional details in a pop-up window.

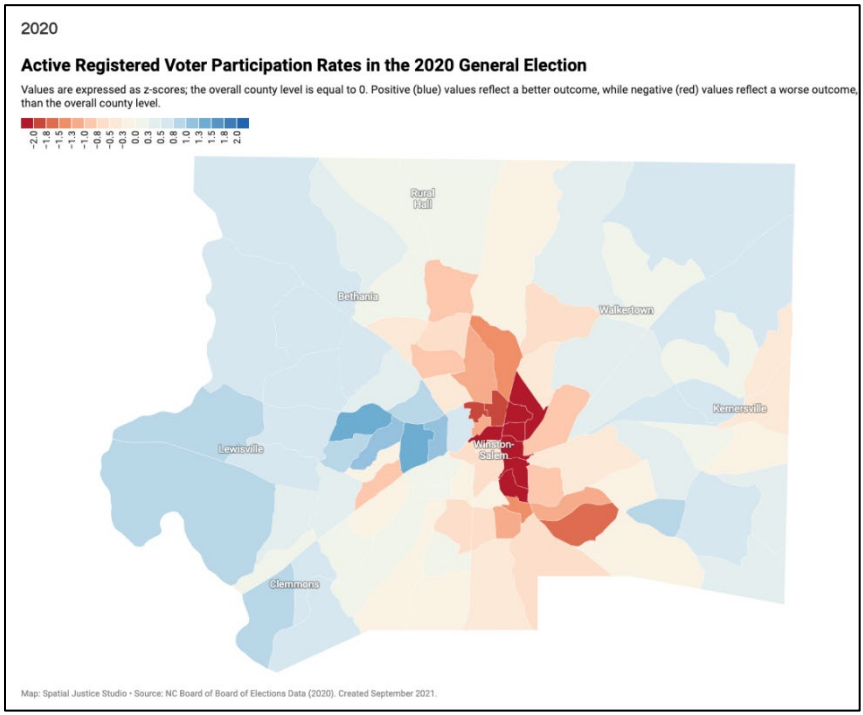
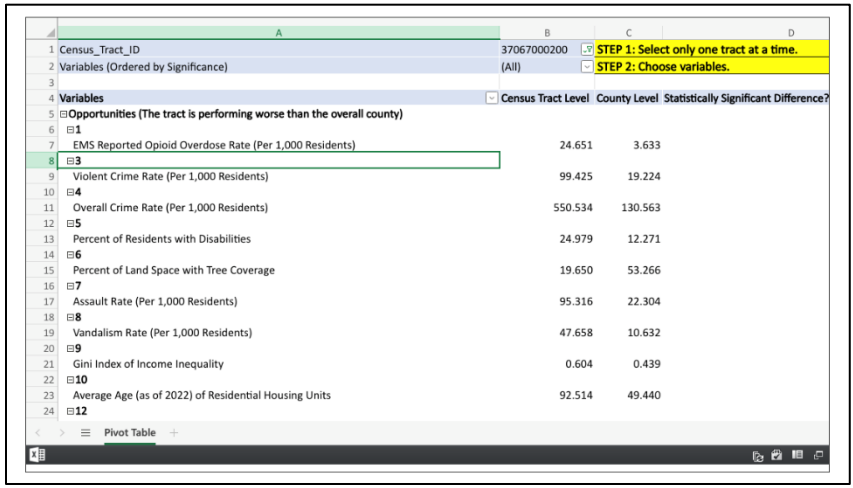


Figure 3. *Interactive Map on the FCNOA*

The creation of an overall Neighborhood Opportunity Index aggregates all individual measures into a single score. Higher values on this index indicate greater opportunity, while lower values suggest less opportunity. The map further highlights the top and bottom three domains where each neighborhood excels or faces challenges.

For users who prefer data in tabular form, the FCNOA offers an interactive table that allows users to select different census tracts and view all measures in one place, ordered by how each tract compares to the county overall. Figure 4 illustrates the interactive table for census tract 200, showing the variables where the tract performs worse than the county (FCNOA, 2025d). Notably, opioid overdoses in this tract (24.7) are significantly higher than the county's rate (3.6), marking this as the area with the greatest disparity.



	A	B	C	D
1	Census_Tract_ID	37067000200	STEP 1: Select only one tract at a time.	
2	Variables (Ordered by Significance)	(All)	STEP 2: Choose variables.	
3				
4	Variables	Census Tract Level	County Level	Statistically Significant Difference?
5	⊟Opportunities (The tract is performing worse than the overall county)			
6	⊟1			
7	EMS Reported Opioid Overdose Rate (Per 1,000 Residents)	24.651	3.633	
8	⊟3			
9	Violent Crime Rate (Per 1,000 Residents)	99.425	19.224	
10	⊟4			
11	Overall Crime Rate (Per 1,000 Residents)	550.534	130.563	
12	⊟5			
13	Percent of Residents with Disabilities	24.979	12.271	
14	⊟6			
15	Percent of Land Space with Tree Coverage	19.650	53.266	
16	⊟7			
17	Assault Rate (Per 1,000 Residents)	95.316	22.304	
18	⊟8			
19	Vandalism Rate (Per 1,000 Residents)	47.658	10.632	
20	⊟9			
21	Gini Index of Income Inequality	0.604	0.439	
22	⊟10			
23	Average Age (as of 2022) of Residential Housing Units	92.514	49.440	
24	⊟12			

Pivot Table

Figure 4*. Interactive Pivot Table on the FCNOA*

Discussion and Current State of Affairs

Now in its fourth year, the Neighborhood Opportunity Atlas (NOA) has continued to expand, update, and reach a broader audience. Since its inception, the NOA has identified both challenges and opportunities across Forsyth County, offering a more nuanced analysis of the various factors influencing residents' quality of life. Currently, the NOA includes over 50 variables across seven categories—Access & Infrastructure, Built Environment, Justice & Social Capital, Economic Well-Being, Education, Health & Wellness, and Demographics—providing a comprehensive and detailed picture of conditions at the census tract level. Additionally, select variables have been designated for longitudinal analysis, enabling assessments of change over time.

While many historically disadvantaged census tracts continue to experience systemic challenges, the NOA's in-depth analysis has also revealed areas of progress. One notable finding was that some communities traditionally classified as "disadvantaged" performed comparatively well on several access-related factors, including healthcare availability, grocery store proximity, street connectivity, and broadband access. These findings suggest that, geographically, these communities possess foundational assets that could support further improvement. Conversely, the NOA also highlighted that some suburban communities—often perceived as "better off"—face significant accessibility challenges. Without private automobiles, residents in these areas may struggle to access essential services, signaling potential future concerns.

The NOA's greatest strength lies in its ability to facilitate multiple community-driven functions, including issue identification, budget prioritization, and program evaluation. First, the NOA provides a data-driven approach to identifying the most pressing community needs. While data alone cannot determine priorities—political considerations and community input remain essential—the NOA offers a user-friendly tool for identifying statistically significant issues. Second, the NOA's data visualization dashboard enables users to track changes over time, allowing for the assessment of program and policy impacts. Before the NOA's development, funding decisions for nonprofit initiatives often relied on historical trends and anecdotal evidence. Now, Forsyth County can require funding applicants to demonstrate how their projects align with NOA data and establish measurable community impact benchmarks.

In the past year, greater efforts have been made to increase public awareness and engagement with the NOA. Until 2024, the tool was primarily used by Forsyth County staff—particularly within the Public Health Department, the Department of Social Services, and City-County Planning—to access critical data on various community challenges. However, recognizing the value of broader public involvement, the county dedicated the project's fourth year to expanding outreach. A series of community workshops were organized to educate residents, nonprofits, and community organizations about the NOA's history, purpose, data variables, and applications. These workshops have fostered a deeper understanding of Forsyth County's most pressing issues while providing elected officials, county staff, and community members with a shared foundation for addressing quality-of-life improvements.

CONCLUSIONS

The volume of publicly available data is growing exponentially, prompting cities and counties across the United States to explore innovative ways to share this information with the widest possible audience for maximum impact. Efforts to develop dashboards, online maps, and other digital tools aim to make data more accessible, enabling communities to ask new questions and devise data-driven solutions to pressing local challenges.

In Forsyth County, NC, elected officials, county staff, and residents recognized the potential of online tools to enhance data accessibility. This led to the development of the Forsyth County Neighborhood Opportunity Atlas (FCNOA), an interactive tool that compiles and visualizes county-specific data across more than 50 variables, with ongoing expansion. The FCNOA serves as a shared foundation for stakeholders—government agencies, nonprofit organizations, and residents—to understand community conditions and use data for problem identification, program evaluation, budgeting, and trend analysis. By providing all groups with access to the same dataset, the FCNOA facilitates informed discussions about the county's most pressing issues and fosters collaboration in developing solutions.

Over the past four years, the FCNOA has played a crucial role in bridging gaps between community data and decision-making. However, several challenges remain. First, not all entities within the county actively utilize the FCNOA, and concerns over data as a form of power have, at times, hindered the inclusion of new datasets. Second, the county has yet to formally integrate the FCNOA into its budgeting and programmatic processes. Although discussions have taken place

within county government, the use of the FCNOA is not mandated for funding requests or problem identification. Establishing explicit guidelines that require the FCNOA's use in these processes could lead to more equitable and data-driven decision-making. Finally, the project currently operates on a year-to-year basis, raising concerns about its long-term sustainability.

Despite these challenges, the FCNOA demonstrates how communities can leverage data to improve residents' quality of life. While not without limitations, the tool provides a critical starting point for more inclusive and evidence-based decision-making. The introduction of community workshops in Year 4 has expanded public engagement, demonstrating the power of data to those interested in using it for local improvement.

As a result of the new emphasis on community engagement, more than 1,100 individual users have accessed the website since May 2024. Those users represent a third of all users to the site since its establishment in 2022. The method by which users came to engage with the FCNOA website in the last year varies with 676 connecting through a direct entry of the website's address, 192 through a referring link, and 180 by way of organic searches according to Google analytics. The two most visited pages, after the home page, are the Tract Facts page and Data Details page. Both pages contain a lot of content, unlike the one-dimensional map pages. Moving forward, the FCNOA aims to incorporate additional community-identified variables, address sustainability concerns, and advocate for its integration into Forsyth County's formal budgeting and program evaluation frameworks.

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A GIS Approach to Exploring the Correlation between Cancer Death Rate and Socioeconomic Disparities

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Abstract

Cancer remains a leading cause of death globally, with socioeconomic disparities significantly influencing cancer outcomes. This study examines the relationship between cancer mortality rates and socioeconomic factors in North Carolina, utilizing Geographic Information Systems. Key socioeconomic indicators, including median household income, poverty rate, diabetes prevalence, and access to healthy food, were examined. Data from North Carolina's 2021 vital statistics, covering 747 ZIP codes, were analyzed using spatial mapping and statistical methods, including a two-tailed t-test and Ordinary Least Squares (OLS) regression. The results reveal significant geographic disparities in cancer mortality, with rural areas experiencing higher rates. These areas exhibit lower household incomes, reduced access to healthy food, and higher diabetes rates. The OLS analysis confirms that lower income and greater distance to supermarkets are strong predictors of higher cancer mortality, while the prevalence of diabetes also shows a significant association with elevated mortality. Despite these findings, the study acknowledges the need for more granular data and additional factors such as healthcare quality, environmental exposures, and comorbid conditions to fully explain variability in cancer mortality.

Keywords

Public Health, Mortality, Food Deserts, Spatial Analysis, Healthcare Access

Introduction

Cancer remains one of the leading causes of mortality worldwide, with its incidence and mortality rates reaching almost 10 million deaths in 2020 (Cancer Fact Sheet 2022). Numerous studies have shown that socioeconomic disparities play a crucial role in influencing cancer outcomes, with individuals from lower socioeconomic backgrounds often experiencing higher cancer incidence and mortality rates compared to their more affluent counterparts (Singh and Jemal 2017). Understanding the spatial distribution of cancer death rates and their relationship with socioeconomic factors is essential for informing targeted public health interventions. Geographic Information Systems offer a powerful tool for analyzing and visualizing spatial data, allowing researchers to explore the relationship

between cancer mortality and socioeconomic determinants at various geographic scales (Cromley and McLafferty 2012).

This study positions cancer mortality within a socio-ecological framework, recognizing that interactions among individual, community, and broader environmental factors shape health outcomes. Social determinants of health—including economic stability, education, healthcare access, neighborhood environment, and community context—affect health behaviors, exposures, and stress levels, which in turn influence cancer outcomes (Alcaraz et al. 2020). By situating our research within this conceptual framework, we acknowledge that spatial disparities in cancer mortality reflect underlying structural inequalities rather than purely biological differences.

In addition to exploring income, poverty, and food access, we explicitly consider diabetes prevalence as a marker of comorbid chronic disease. People with type 2 diabetes have been shown to have more than a 1.5-fold increased risk of colorectal, pancreatic, liver, and endometrial cancer mortality compared with the general population (Giovannucci et al 2010, Ling et al. 2023). Including diabetes prevalence in our model, therefore, provides insight into whether metabolic health acts as an independent predictor of cancer mortality across different geographic regions.

Building on prior GIS research, we aim to answer two key questions: 1) What ZIP-level socioeconomic and health-related variables are statistically associated with higher cancer mortality rates in North Carolina? 2) How do spatial patterns of cancer mortality correspond with indicators such as income, diabetes prevalence, and access to healthy food across ZIP codes?

REVIEW OF RELEVANT LITERATURE

Cancer Mortality and Socioeconomic Disparities

Extensive literature highlights the close relationship between socioeconomic factors, including income, education, and access to healthcare, and cancer outcomes. The CONCORD 3 program reported that five year net survival for many cancers is highest in high income countries such as the United States, Canada, Australia and Northern Europe, whereas survival for the same cancers is often less than half as high in low and middle income countries (e.g., 90 percent five year breast cancer survival in the United States vs. ~40 percent in South Africa) (Allemani et al. 2018). Even within wealthy countries, systematic reviews show that socioeconomic disparities persist after accounting for clinical factors. A meta-analysis of 74 studies found that stage at diagnosis and treatment account for part of the socioeconomic differences in survival, while comorbidities, health-related behaviors, and tumor characteristics contribute substantially. For colorectal and lung cancers, these factors explain the disparities better than stage and treatment (Afshar et al. 2021). These findings emphasize that socioeconomic disadvantage influences cancer outcomes through multiple pathways beyond access to screening.

Socioeconomic disparities also manifest through differential exposure to cancer risk factors such as smoking, poor diet, and environmental pollutants. These disparities contribute to persistent inequalities in cancer mortality across

socioeconomic groups (Henley et al. 2020). Bevel et al. (2023) conducted a county-level ecological study and found that areas classified as food swamps had significantly higher obesity-related cancer mortality rates. Using an age-adjusted, generalized, mixed-effects regression model, the study highlighted how limited access to healthy food contributes to cancer risk at the population level, reinforcing the importance of food environment variables in spatial cancer research (Bevel et al. 2023).

Research suggests that incidence is higher in populations with greater socioeconomic deprivation, reflecting greater exposure to risk factors and delays in detection and treatment (Singh and Jemal 2017; Singh et al. 2011; Lundqvist et al. 2016). Disadvantaged individuals often experience poorer outcomes due to late presentation, comorbidities, and less effective treatment (Singh and Jemal 2017).

These findings justify our inclusion of comorbidity (diabetes prevalence) and food environment variables as potential predictors, underscoring the limited explanatory power of socioeconomic variables alone.

Geographic Information Systems and Spatial Analysis

GIS has become an increasingly critical tool in public health research for geographically mapping cancer incidence and mortality. The spatial analysis capabilities of GIS enable researchers to investigate the intersection of geographic, environmental, and socioeconomic variables, providing insights into how these factors influence health outcomes (Cromley and McLafferty 2012, Bertazzon 2014). Studies like those by Lei et al. (2020) have demonstrated that GIS can be instrumental in identifying high-incidence cancer regions, particularly for lung cancer, enabling more targeted interventions and informed public health planning.

Lei et al. (2020) conducted a study that utilized GIS to analyze the spatial and temporal distribution of lung cancer in Shenzhen, China, from 2008 to 2018. The study revealed distinct patterns of lung cancer incidence, with rural areas experiencing higher rates compared to urban centers. The spatial clustering analysis identified high-incidence "hotspots" where socioeconomic disadvantages, coupled with higher environmental pollution levels, significantly contributed to the elevated cancer risk.

A critical foundation for this study is the research conducted by Burwell et al. (2023), which explores the geospatial associations between female breast cancer mortality rates and environmental socioeconomic indicators in North Carolina. The study examines a similar context of cancer mortality and socioeconomic disparities, making it highly relevant to this work's focus on the broader spectrum of cancer deaths. Using GIS, Burwell et al. (2023) analyzed spatial patterns in breast cancer mortality across North Carolina, identifying significant socioeconomic factors associated with high cancer mortality rates. These included lower household income, higher poverty rates, and a higher percentage of minority population, factors also considered in the present study's analysis of all cancer mortality rates. The study by Burwell et al. (2023) revealed that geographic and environmental factors play a substantial role in cancer health disparities.

Socioeconomic Determinants of Health and Cancer Outcomes

Socioeconomic determinants, including income, education, and access to healthcare, are key factors influencing cancer outcomes (Alcaraz et al. 2020). Lower-income populations, particularly those living in food deserts, are at increased risk of poor cancer survival due to inadequate nutrition, limited healthcare access, and higher prevalence of comorbid conditions (Fong et al. 2021). A review of 75 studies from low- and lower middle-income countries found that lower socioeconomic groups have substantially higher prevalence of tobacco and alcohol use and lower consumption of fruits, vegetables, and fiber (Allen et al. 2017). Such behavioral patterns elevate cancer risk and may worsen survival by contributing to obesity and metabolic disease. Evidence from developed countries similarly shows that living in a "food desert" not only reduces access to healthy foods but is associated with higher prevalence of diabetes and tobacco use; in a large cohort from the California Cancer Registry, five year survival was 78 percent vs. 80 percent for breast cancer and 60 percent vs. 64 percent for colorectal cancer among food desert residents vs. others, and these differences persisted after controlling for treatment (Fong et al. 2021).

Food deserts—areas with limited access to fresh, healthy foods—are significant contributors to health disparities (Walker et al. 2010). Individuals living in food deserts or food swamps consume more processed, high-fat foods and have higher rates of obesity and diet-related cancers (Larson et al. 2009, Bevel et al. 2023). Studies show that cancer patients residing in food deserts have a 16 percent higher five-year mortality risk for breast cancer and a 12 percent higher risk for colorectal cancer compared with those not in food deserts (Fong et al. 2021).

A comprehensive policy response to cancer disparities must therefore address both socioeconomic deprivation and comorbid health conditions. Interventions targeting economic stability, education, healthcare access, and neighborhood environment—core domains of social determinants of health—can reduce the burden of cancer (Alcaraz et al. 2020).

Conceptual and Theoretical Framework

The study is grounded in the socio-ecological model, which posits that health outcomes result from interactions among individual, interpersonal, community, and societal factors (Falcone et al. 2024). Within this framework, cancer mortality is influenced by personal behaviors (e.g., smoking, diet), neighborhood characteristics (e.g., food access, healthcare infrastructure), and larger structural determinants such as economic policies and systemic inequities (Falcone et al. 2024; Alcaraz et al. 2020). Falcone et al. (2024) propose a conceptual model in which structural racism and racial discrimination promote adverse social determinants of health that increase exposure to environmental hazards and chronic stress, leading to epigenetic and immune dysregulation and ultimately higher breast cancer mortality. The authors emphasize that structural racism shapes economic and housing opportunities (e.g., through redlining) and limits access to high-quality care, producing neighborhood disadvantages that manifest as delayed diagnosis, aggressive tumor subtypes, and higher mortality. Integrating this perspective highlights that spatial patterns of cancer mortality may reflect structural inequities rather than individual behaviors.

Our hypothesis stems from this theoretical perspective: areas with high cancer mortality rates will have higher spatial correlations with economic disparities—such as high poverty rates, low income, limited access to healthy food—and greater health inequalities. We further posit that diabetes prevalence may serve as an independent predictor of cancer mortality, reflecting the burden of chronic disease. This assumption is based on previous literature addressing the association of chronic disease and cancer mortality (Kim and Kim 2022). This theoretical framework informs the selection of variables and highlights the relevance of incorporating comorbidity indicators into spatial analysis to capture the multifaceted determinants of cancer outcomes.

The theoretical framework explicitly integrates GIS as the methodological bridge connecting multilevel socio-ecological determinants to spatial patterns of cancer mortality. By geocoding socio-economic indicators, food environment measures, and comorbidity data at the ZIP code level, GIS enables us to operationalize the socio-ecological model and visualize the spatial interaction of economic stability, healthcare access, neighborhood context, and chronic disease (Skiba et al. 2024). This integration clarifies the rationale for using spatial analysis and informs the choice of variables, including income, poverty, minority composition, age structure, food environment, and diabetes prevalence (Embury et al. 2022).

DATA AND METHODS

Data Management

The data for this study were obtained from the North Carolina vital statistics database, which includes all recorded deaths for the year 2021. The dataset was downloaded in Comma Separated Value (CSV) format and subsequently imported into ArcGIS Pro for spatial analysis. The data included information such as the primary cause of death, ZIP code, and population figures. To focus exclusively on cancer-related deaths, the dataset was filtered using the “Select by Attribute” function in ArcGIS Pro, isolating records where the primary cause of death (COD1) corresponded to an International Classification of Diseases (ICD) code starting with the letter "C," indicative of cancer-related fatalities.

Once filtered, the cancer-related deaths were aggregated by ZIP (Zone Improvement Plan) code using the "Summarize" tool in ArcGIS Pro. This resulted in cancer-related death counts for each of the 763 ZIP codes in North Carolina. The summarized data were then joined to a pre-existing ZIP code shapefile using the “Join Table” function, which spatially links data to a geographic boundary. A new field, "cancer rate per 10,000 persons," was calculated for each ZIP code to normalize the mortality rates according to population size. This standardization assumed that the average population per ZIP code contains approximately 10,000 people. Any ZIP codes with population sizes below 50 were removed from the dataset (16 records) to avoid statistical bias or issues resulting from the small number problem, leaving a final dataset of 747 ZIP codes.

Map Visualization

To visualize spatial disparities, we created a choropleth map using the calculated cancer mortality rates per 10,000 persons. To focus on areas with the greatest burden, we classified ZIP codes into high- and low-mortality groups. ZIP codes

with cancer mortality rates exceeding 28 % (approximately the top quartile of the distribution) were categorized as 'high-mortality' regions, while those below this threshold were categorized as 'low-mortality' regions. This cutoff was chosen based on distribution percentiles and previous literature identifying high-risk thresholds (Burwell et al. 2023) and was tested for robustness by evaluating alternative percentiles (25th and 33rd). The 28 percent threshold used to delineate high-mortality ZIP codes corresponds approximately to the top quartile of cancer mortality rates. Nevertheless, the epidemiological justification for such thresholds remains limited, and future research may explore data-driven clustering or risk classification methods.

Statistical Analysis

We conducted two principal statistical analyses: a two-tailed t-test to compare cancer mortality rates between high- and low-mortality regions, and an Ordinary Least Squares (OLS) regression to evaluate the relationship between cancer mortality and multiple socioeconomic variables. The two-tailed t-test was performed in Microsoft Excel, while the OLS was performed in ArcGIS Pro version 4.0.

The two-tailed t-test assesses whether the means of two independent samples differ significantly. The test statistic is calculated as:

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $\bar{x}_1$ and $\bar{x}_2$ are the mean cancer mortality rates in the high- and low-mortality groups, n1 and n2 are their respective sample sizes, and s_p is the pooled standard deviation. A significance level of 0.05 was used to evaluate the null hypothesis that the group means are equal.

The OLS regression model estimates the linear relationship between cancer mortality (dependent variable) and several independent socioeconomic variables: median household income, poverty rate, percent minority, median age, diabetes rate, distance to the nearest supermarket, spending on fruits and vegetables, and the modified retail food environment index (mRFEI). The basic OLS equation is:

$$\begin{aligned} CancerMortality = {} & \beta_0 + \beta_1(MedianIncome) + \beta_2(PovertyRate) \\ & + \beta_3(PercentMinority) + \beta_4(MedianAge) \\ & + \beta_5(DiabetesRate) + \beta_6(DistanceToSupermarket) \\ & + \beta_7(FruitVegetableSpending) + \beta_8(mRFEI) + \varepsilon \end{aligned}$$

Coefficients (β) were estimated using least squares, and p-values were calculated to test whether each predictor significantly differs from zero. We assessed model fit using the adjusted R^2 statistic. Multicollinearity was evaluated with variance inflation factors (VIFs).

While OLS provides a straightforward approach for assessing linear associations, it assumes that observations are independent and spatially homogeneous. To address potential spatial autocorrelation, future studies could incorporate spatial lag or spatial error models, as well as geographically weighted regression (GWR),

to explore local variations in predictor effects (Matthews and Yang 2012; Anselin and Rey 2014). Additionally, non-parametric tests or analysis of variance (ANOVA) may be appropriate when normality assumptions are violated.

Results and Discussion

The choropleth map shown in Figure 1 revealed marked geographic disparities in cancer mortality across North Carolina. High-mortality clusters were concentrated in rural western and eastern counties, while urban and suburban areas generally exhibited lower mortality. These clusters correspond closely with regions characterized by lower median household incomes, higher poverty rates, and limited access to healthcare services and healthy foods.

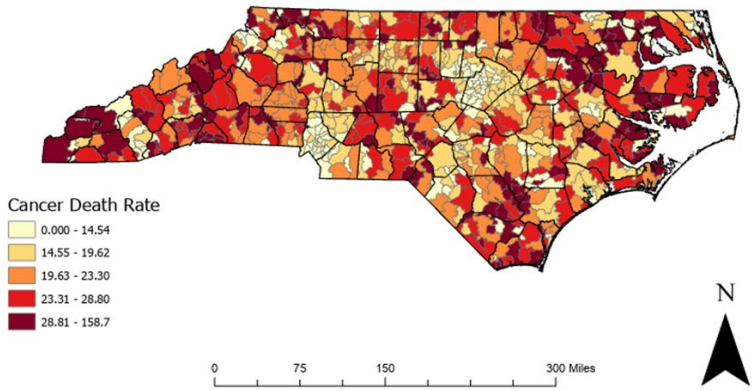

Figure 1. *Map showing cancer mortality rate based on 2021 death data for North Carolina.*

Two-tailed t-test results (Table 1) showed statistically significant differences between high- and low-mortality cohorts for several variables. High-mortality ZIP codes had significantly lower median household incomes, reduced spending on fruits and vegetables, longer distances to the nearest supermarket, older median age, and higher diabetes rates. The difference in poverty rate and mRFEI was not statistically significant, although trends pointed in the expected directions.

In the OLS regression model (Table 2), median household income ($\beta \approx -0.000094$; robust $t \approx -2.79$; $p \approx 0.0055$) and distance to the nearest supermarket ($\beta \approx 0.666$; robust $t \approx 2.19$; $p \approx 0.029$) emerged as statistically significant predictors of cancer mortality—higher income is associated with lower mortality, and greater distance to healthy food access is associated with higher mortality. Diabetes rate also showed a significant positive association ($\beta \approx 0.205$; robust $t \approx 2.71$; $p \approx 0.0069$), showing how chronic disease comorbidity relates to spatial patterns of mortality. While median age had the strongest effect in the model (robust $t \approx 11.10$; $p < 0.001$), fruit and vegetable spending were marginally non-significant ($\beta \approx -0.10$; $p \approx 0.06$), suggesting a possible but not definitive protective effect. The model explained approximately 20 % of the variance in cancer mortality (adjusted $R^2 \approx 0.20$), indicating that unmeasured factors—such as environmental

Table 1. Two-tail t-test results comparing socioeconomic factors in high vs. low cancer mortality cohorts. Statistical significance is indicated by *** ($p < 0.01$).

	High Cancer Mortality Cohort	**Low Cancer Mortality Cohort**
Description	Highest Quintile of Cancer Mortality in the state (n = 149)	All other Quintile of Cancer Mortality in the state (n = 598)
Median Household Income	$44,684.24***	$48,835.11***
Poverty Rate	17.01%	17.72%
Spending on Fruits and Vegetables	$773.04***	$826.95***
MRFEI	14.27	14.78
Median Age	72.26 years***	68.71 years***
Distance to nearest supermarket	4.90 miles***	3.30 miles***
Diabetes Rate	26.77%***	16.88%***

Table 2. Ordinary Least Squares regression analysis for Cancer mortality rate

Variable	**Coefficient [a]**	**StdError**	**t-Statistic**	**Probability [b]**	**Robust_SE**	**Robust_t**	**Robust_Pr [b]**	**VIF [c]**
Intercept	-0.74741	2.736741	-0.2731	0.784858	2.319189	-0.32227	0.74735	--------
MED_HH_INC	-9.40E-05	0.000032	-2.91162	0.00371*	0.000034	-2.7867	0.005462*	1.147468
DIST_TO_NEAR	0.665921	0.148042	4.498187	0.00001*	0.304391	2.187712	0.028987*	1.053965
DIABETES_RAT	0.204946	0.024379	8.406631	0.0000*	0.075635	2.709671	0.006888*	1.095553
MEDIAN_AGEYR	0.312893	0.033453	9.353123	0.0000*	0.028193	11.09823	0.0000*	1.071972

exposures, health care access quality, stage at diagnosis, screening rates, or genetic predispositions—likely contribute substantially to mortality differences across ZIP codes. The observed association between diabetes prevalence and cancer mortality highlights metabolic health as a key independent predictor of cancer outcomes. Individuals with type 2 diabetes face significantly higher mortality risks from cancers such as colorectal, pancreatic, and liver, potentially due to chronic inflammation and hormonal dysregulation (Ling et al. 2023). The inclusion of the diabetes rate variable supports the argument that chronic disease burdens must be considered alongside socioeconomic indicators when addressing cancer disparities.

The poverty rate and percentage of minority individuals were not significant in the multivariate model, suggesting that income or health variables, such as diabetes, may mediate their effects. This supports the case for localized modeling approaches such as Geographically Weighted Regression (GWR), which can uncover spatially variable associations (Matthews and Yang 2012; Anselin and Rey 2014). Additionally, while median age had a measurable effect, it alone does not explain spatial differences, reinforcing the need for age-standardized rates and interaction analysis between age and socioeconomic status.

The model's adjusted R^2 of 0.20 indicates that other critical factors are not captured. Prior studies emphasize that while socioeconomic and comorbidity variables account for part of the disparity, much remains unexplained—such as stage at diagnosis, tumor biology, access to treatment, and health behaviors (Alcaraz et al. 2020). Consistent with the socio-ecological framework, multilevel and structural influences must be integrated into future research, with mediation analysis and longitudinal data needed to clarify causal pathways (Williams and Mohammed 2013; Tervonen et al. 2017; Quaglia et al. 2013).

CONCLUSION

The spatial distribution of cancer mortality rates across North Carolina reveals significant geographic disparities, with higher mortality rates concentrated in rural and socioeconomically disadvantaged regions, particularly in the western and eastern portions of the state. These areas are characterized by lower median incomes, higher poverty rates, and limited access to healthcare and nutritious food, all of which are likely to contribute to elevated cancer mortality. Conversely, urban and suburban ZIP codes generally exhibit lower cancer mortality rates, reflecting improved access to healthcare, increased preventive screenings, and socioeconomic advantages that mitigate cancer risk.

Descriptive statistical analysis of the dataset further underscores these disparities. Among the 747 ZIP codes analyzed, cancer mortality rates ranged from 0 to 158.7 deaths per 10,000 persons, with a mean of 22.8, a median of 21.6, and a standard deviation of 14.2. The positive skewness (4.0) and high kurtosis (33.1) suggest that while most ZIP codes experience moderate cancer mortality rates, a subset of regions faces disproportionately high mortality, contributing to a long-tailed distribution. Findings from Table 1 (t-test results) and Table 2 (OLS regression analysis) reinforce these patterns, indicating that median household income, poverty rate, distance to supermarkets, and diabetes prevalence are significant predictors of cancer mortality. The OLS regression results confirm that lower-income communities and those with greater distances to grocery stores exhibit

significantly higher cancer mortality rates, emphasizing the role of socioeconomic determinants in shaping cancer outcomes.

LIMITATIONS

Several limitations should be noted. First, the adjusted R^2 of 0.20 indicates that the socioeconomic variables considered explain only a portion of the variability in cancer mortality. Important factors, such as environmental exposures, health behaviors, genetic predispositions, and the quality of medical care, were not included in the analysis and may account for a substantial share of the unexplained variance.

Second, the study relies on cross-sectional data aggregated at the ZIP code level, which may obscure within-area heterogeneity and limit causal inference. An ecological fallacy may arise when drawing individual-level conclusions from aggregated data (Kwan 2012). Future research should incorporate finer spatial units (e.g., census tracts) and longitudinal data to capture temporal dynamics.

Third, we did not formally test for spatial autocorrelation or heteroskedasticity in the residuals, which may bias OLS estimates. While initial diagnostics suggested mild clustering, spatial regression techniques such as spatial lag, spatial error, or GWR models are recommended for future analyses to account for spatial dependence and non-stationarity.

Finally, median age was included as a crude demographic control, but it does not fully adjust for age structure. Stratifying analyses by age groups or using age-standardized mortality rates would provide a more accurate assessment of socioeconomic effects. Additionally, the 28 percent threshold used to define high-mortality areas, although informed by distribution percentiles, is somewhat arbitrary; sensitivity analyses using alternative cutoffs indicated similar spatial patterns, yet further justification from epidemiological thresholds would strengthen the classification.

IMPLICATIONS FOR PUBLIC HEALTH POLICY

The findings from this study have immediate implications for public health policymakers seeking to reduce cancer disparities. First, targeted investments in rural and low-income areas should focus on improving access to healthy foods by expanding supermarkets, farmers' markets, and SNAP programs. Reducing food deserts and food swamps can lower obesity-related cancer risks and improve diet quality (Fong et al. 2021).

Second, public health strategies must prioritize diabetes prevention and management through screening, education, and the expansion of primary care services. Integrating chronic disease management with cancer prevention efforts can address the intertwined burden of diabetes and cancer mortality.

Finally, policies that address broader social determinants—such as poverty, education, and housing—and structural inequities are essential for long-term reductions in cancer disparities (Babatunde et al. 2021). Multisector collaboration among health, transportation, economic development, and community

organizations is critical for implementing comprehensive interventions (Montez and Zajacova 2019; Alcaraz et al. 2020).

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PUBLIC TRANSPORT ACCESSIBILITY AT AIRPORTS IN NORTH CAROLINA – A CASE OF BUS SCHEDULES AND THEIR OVERLAP WITH AIRPORT HOURS OF OPERATION

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HIGHLIGHTS

- This study assesses the overlap between flight and bus schedules in North Carolina
- It was found that bus schedules fail to encompass the entire duration of working hours at any of the primary airports in NC
- It is suggested that the bus schedule should align with the airport schedule to increase bus utilization

ABSTRACT

This research aims to assess the overlap between flight and bus schedules to calculate the percentage of time an individual can depend exclusively on public transportation for airport access in North Carolina. This study posits that despite the availability of various options for airport access, public transport, specifically bus connectivity, plays a crucial role in ground transportation. This study demonstrates that bus schedules fail to encompass the entire duration of working hours at any of the primary airports in North Carolina. The discrepancy between the airport schedule and the bus schedule often results in issues that typically affect passengers who rely on bus transportation to and from the airport. These include workers who may require drop-off or pick-up services because the airport bus schedule does not align with their needs, as well as passengers who can use the bus for only one segment of their journey (arrival or departure). This study recommends that to reduce airport congestion and increase bus service utilization, the bus schedule should align with the airport schedule, encompassing the entire period from the first arrival to the last departure.

KEYWORDS

Public Transport, Flight Schedules, Pre-Ride Share

INTRODUCTION

Air travel is an important mode of transportation in North Carolina, but the state's major airports are located a few kilometers from city centers. This is different from bus and rail transportation, which form an important part of central business districts such as downtown Durham, Greensboro, and Raleigh, where bus stops

and train stations are in the heart of the city and in proximity to each other. This study focuses on bus connectivity between downtown and the airport at the 5 largest airports by passenger count in North Carolina. These are Charlotte (CLT), Raleigh-Durham (RDU), Greensboro (GSO), Asheville (AVL), and Wilmington (ILM) (Figure 1). These airports are classified as Commercial Primary and Publicly owned with scheduled passenger service and further sub-classified as Large, Medium, Small, and Non-hubs (FAA 2022). Charlotte is the only airport classified as Commercial – Large (a hub for American Airlines), whereas RDU is Commercial – Medium, and GSO, AVL, and ILM are classified as Commercial – Small airports.

The average distance from the city center to the airport is sixteen kilometers for these five busiest airports in NC, and all these airports offer park-and-ride, shuttle, and ride share options. As none of these five large airports in NC are connected using rail or light rail, only bus schedules were included in this research. The only planned exception to this is Charlotte, but even then, the light rail will not reach the terminals directly when it becomes operational (Sands 2024). Therefore, buses are the only public transportation option providing service from the city center to these airports in the foreseeable future.

The focus of this research is to determine the degree of overlap between flight and bus schedules to find the percentage of time a person can rely solely on public transportation to get to and from these airports. The premise of this study is that, even though passengers have several options to arrive and depart from airports, public transport (bus connectivity) is an important part of the ground transportation equation. This remains true even after the introduction of popular ride-share options, which are expensive compared to bus transportation. The cost of a ride-share trip from downtown to these airports varies with demand, but the average bus ticket costs $2. This cost disparity is particularly important, because bus transportation serves employees who are considered regular, captive riders to and from these airports. Captive riders also include others who lack access to private vehicles or who can't typically afford the high cost of ride-sharing options. This study shows that bus schedules do not cover the full duration of the working hours at any of the major airports in NC. The mismatch between airport and bus schedules creates problems that disproportionately affect captive passengers. Examples of the impact of this mismatch include workers who may have to be dropped off or picked up as the bus service to the airport does not match their schedule, or passengers who may be able to use the bus for one side of the trip (arrival or departure) but not both. The recommendation from this study is that, to increase bus service utilization and make bus transportation a viable alternative for airport travel, the bus schedule should overlap with the airport schedule, covering the full duration from the first arrival to the last departure. Having this cheaper alternative to access the airport during hours of operation also supports socio-economic reasons, such as access to jobs at the airport, and access to air transportation for people who lack vehicle ownership.

LITERATURE REVIEW

While the focus of this research is on public transportation access to airports, the introduction of ride share has significantly altered transportation (Henao and Marshall 2017). Therefore, the literature review on ground transportation is separated into pre-ride share and post ride share timeframes.

Pre Ride-Share

The Transportation Research Board of the National Academies has conducted extensive research on ground transportation at airports (Coogan 2000, Coogan 2002, Coogan 2008). These reports are very detailed and hold important insights from the pre ride-share era. The 2000 report looks at ground transportation options, including buses, for 16 international airports. Its key findings on ground transportation were that the current systems should expand service area, increase service frequency, and improve efficiency to cater to increased demand. These reports provide a snapshot of ground transportation in the US in the 2000s, highlight differences in public transportation levels between the United States and Europe, and suggest that the strategies listed above can be used on both continents. The 2008 report focuses on encouraging high-occupancy services such as hotels and regional shuttles. Another study (Mandle et al. 2000) determined that the ceiling, or maximum percentage of people opting for non-car transportation options, is ten to fifteen percent at most airports. However, it should be noted that this ceiling has most likely changed since the pandemic and the proliferation of ride-share options. The study also indicated that the market for rail and light rail exists for passengers who are riding downtown and to the airport, have little or no baggage, and are familiar with the light rail system. The study also encouraged transportation planners to focus on bus and van services to connect airports to the rest of the city. Therefore, these reports do not reflect current realities in ground transportation, as the impact of ride-share options has been profound. Neufville (2006) noted that many airport employees commute to work by public transportation. This holds true even today: airport employees are generally captive riders, whereas passengers who ride the bus by choice are regular and cost-conscious customers of public transportation. Therefore, when looking at bus schedules for the airports, it is important to include the overlap between the airport's operating hours and public transportation.

Post Ride-Share

The 2015 Commercial Ground Transportation report (LeighFisher et al. 2015) included ride-share services alongside taxis and other commercial options. In this report, the impact of this new mode of transportation is indelible. Ride-sharing has had an impact on all ground transportation options at major airports by moving people conveniently and efficiently, but at a cost comparable to private transportation. Hermawan and Regan (2017) studied the impact of ride-sharing on airport pickups at Los Angeles Airport (LAX) and stated that Lyft and Uber started curbside pickups in 2015 and 2016, respectively. The impact of ride sharing was felt on airport parking options, and a statistically significant reduction in parking at John F. Kennedy Airport (JFK), Newark Liberty International Airport (EWR), and LaGuardia Airport (LGA) was observed (Wadud 2020), as well as a similar impact on shuttle services (Feng et al. 2014). This increase in ride-share ridership comes at the cost of transit ridership (Ma 2017). All the airports in North Carolina included in this study offer this curbside pickup option by ride-share vehicles. At least at RDU, ride-sharing induced congestion is an issue, and some authors have also proposed dynamic ride sharing to alleviate congestion created by the proliferation of ride-sharing options (Agatz 2010).

The literature review illustrates that buses and light rail (if available) are not the main options for the general public. Even before the introduction of ride share

options, people shunned bus access to airports, and perceptions of bus transport are a big factor for people avoiding this option (Stradling 2007). However, if we consider price as an option, nothing will beat the bus fare from downtown to the airport and back. Therefore, this research focuses on captive riders, and the assumption is that if scheduled bus service covered all arrivals and departures at a given airport, it would support the overlooked and underserved airport employees and passengers. The service should be predictable, somewhat frequent, and span the entire duration of flight arrivals and departures (from the first arrival to the last departure).

METHODS

This study examined the bus schedules for the five busiest airports by passenger count in North Carolina and compared them with the airports' operational hours. The airports included in this study are Charlotte (Commercial Service – Large), Raleigh-Durham (Commercial Service - Medium), Greensboro (Commercial Service – Small), Asheville (Commercial Service – Small), and Wilmington (Commercial Service – Small). These airports were selected based on their 2019 passenger volumes (Figure 1) (FAA 2022). Data collected for each airport included information such as the first flight arrival at the airport when the airport opens in the morning, the first flight departure, as well as the last flight departure and last flight arrival, which can stretch past midnight into the next day. This information was used to determine the operational span at each airport. Overlapping this information was the span of bus operations at each of these airports, from the first bus arrival to the last bus departure.

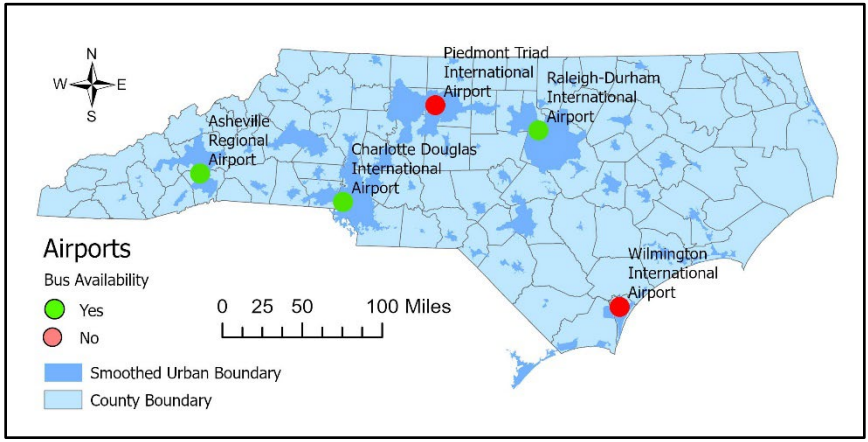

Figure 1*. GIS Map-Airports considered, and bus availability*

In addition to this overlap that provided travel insights by reviewing the flight and bus schedules, this study also looked at the travel distance from the airport to downtown (city center), the average cost of ride share to the airport from downtown, the option to park at these airports, and ride share availability at these airports. The data helped create a snapshot of transportation options that captive passengers and workers rely on to travel to and from these airports. This snapshot helped understand the role of bus schedules. For example, some important

questions that captive travelers face include: can a worker or employee use the bus to travel to and from the airport at the beginning and end of their work shift? What percentage of airport hours can passengers depend on bus schedules to travel downtown and to destinations beyond? What is the average price difference in a bus and a ride-share trip to or from the airport? What options, if any, are available to passengers who solely depend on bus transportation to get to and from the airport?

The study includes information on the frequency of bus trips to and from the airports, but this varies from thirty minutes to an hour. Other data not included were the impact the introduction of light rail would have on Charlotte Douglas International Airport, the largest airport by passenger count in North Carolina. During data collection, it was also noted that two of the five busiest airports in NC, Greensboro and Wilmington, do not have scheduled bus services to and from their downtown areas. This makes it impossible for captive bus riders to rely on an affordable option to get to and from these airports.

RESULTS

Of the five busiest airports in NC, only three, CLT, RDU, and AVL, have scheduled bus services from downtown to the airport. Of the other two airports, ILM has no scheduled bus service to the airport, and GSO has on-call service (Figure 2). The bus fare ranges from $1.00 (Asheville) to $2.50 (Raleigh-Durham) and is much lower than the average ride-share fare, which ranges from $36 to Asheville airport from downtown Asheville to $22 to Charlotte airport from downtown Charlotte. As can be seen from this information, bus transportation is the cheapest travel option to these three airports. Distance-wise, CLT is the closest to downtown (ten kilometers), whereas RDU is twenty-one kilometers from both Durham and Raleigh downtowns, and Asheville airport is twenty-four kilometers from downtown Asheville.

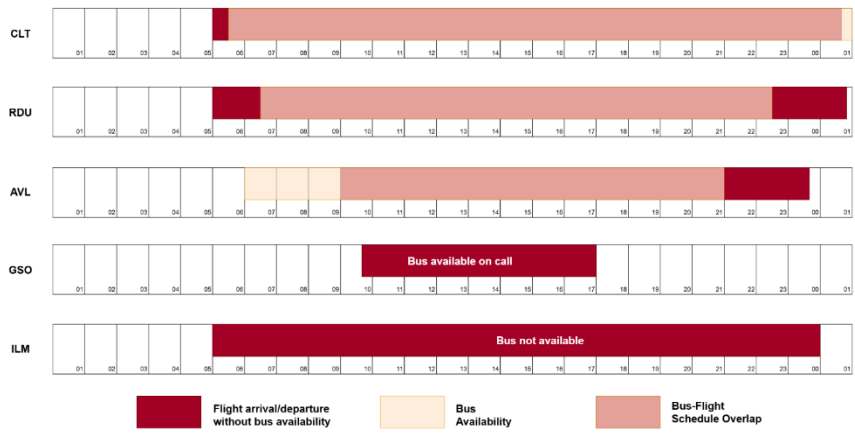

Figure 2. *Flight bus overlaps*

At the two busiest airports in NC, CLT and RDU, flights start arriving and departing as early as 5:00 AM, and the late arrivals and departures can run over

into the next day (1:00 AM). This essentially means that these two airports operate approximately 20 hours a day. The earliest bus arrival at CLT is almost 6:00 AM (5:56 AM), and the last bus departs from CLT at 1:00 AM (Figure 2). There is only a small window at CLT where airport and bus schedules do not overlap; overall, the schedule alignment at CLT is very high, at ninety-seven percent. This gap in flight operations and bus schedules is much bigger at AVL and RDU airports, where the airport - bus overlap is eighty one percent and seventy nine percent respectively (Table 1). Therefore, from an availability perspective, CLT is the best airport, and from an economic perspective, AVL is the most affordable airport. Of the three airports, RDU has the lowest percentage overlap between airport operations and bus arrivals and departures. This means that relying solely on bus transportation to and from the RDU airport is not feasible unless a person specifically takes the bus schedule into consideration while booking their arrival and departure at the RDU.

Table 1. Overlap analysis

	Airport	Overlap Percentage
1	CLT	97.49
2	AVL	81.63
3	RDU	79.51
4	GSO	NA
5	ILM	NA

Another factor that would help the use of public transport is the frequency of buses arriving and departing from the airport, as well as their travel directions. For example, during off-peak hours, passengers have to wait almost an hour for a bus from RDU airport to the transit hub from where they take buses to Raleigh, Durham, or Chapel Hill. This causes passengers to shun public transportation. A bus service is considered 'frequent' if the service is 15 minutes (Frequency + Transit 2018). Based on the bus service to RDU airport (GoTriangle n.d), the minimum bus frequency to and from the airport should be thirty minutes as opposed to the current frequency that varies from 30 minutes to an hour based on the time of the day. This would provide enough time between buses for passengers to collect their belongings, but not so long that they shun public transportation.

This research focused solely on time and therefore did not include peak arrivals and departures. The main reason not to include flight scheduling information was that scheduling is the purview of individual airlines and varies considerably from day of the week to season. If most flights arrive during the overlap between flight operations and bus schedules, passengers who rely on public transportation would have more viable travel options to and from the airport. However, it is also known that airline fares are usually cheaper in the early and late hours of the day as demand is lower during these times. Airlines often use lower prices to shift demand toward these off-peak hours (Cervero 1986, Tseng and Verhoef 2008).

CONCLUSIONS

While there are several reasons why it is important for people to be able to rely on public transportation, the primary reason is the difference between choice and

captive riders, for whom cost is the major factor in travel decisions. Moreover, public transportation does not serve employees during off-peak and night hours (Kazda and Caves 2000). Take the example of an employee without a car at one of these airports. They either have to plan their work around the bus schedule or rely on a more expensive option (ride-sharing) or a ride from someone in their social circle. So, in either case, there is an economic or social cost of asking for a favor. Aligning the bus schedule with airline schedules, or at least with popular airport hours when most establishments are open, would help low-income earners consider employment at the airport and become more independent.

Aligning the bus schedule with the airport schedule would also attract more riders and help alleviate the cost of airport parking or ride-sharing. This is an added benefit that reduces traffic at the airport, where a crash of ride-share and private vehicles creates significant issues. For example, RDU now has signs encouraging passengers to be picked up from both the arrivals and departure terminals due to congestion. On any given day, ride-share and off-airport pickups, such as hotel, rental, and parking shuttles, fight for limited pickup slots at RDU. Public transportation constitutes a form of shared social capital, and the cost of operating bus services in alignment with the airport's hours of operation may be regarded as a collective investment in the broader public good. This study explores and promotes alternative options beyond passenger vehicles. It is important to attract both choice and captive riders by aligning bus transit hours and frequency so that public transit plays a significant role in airport ground transportation.

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