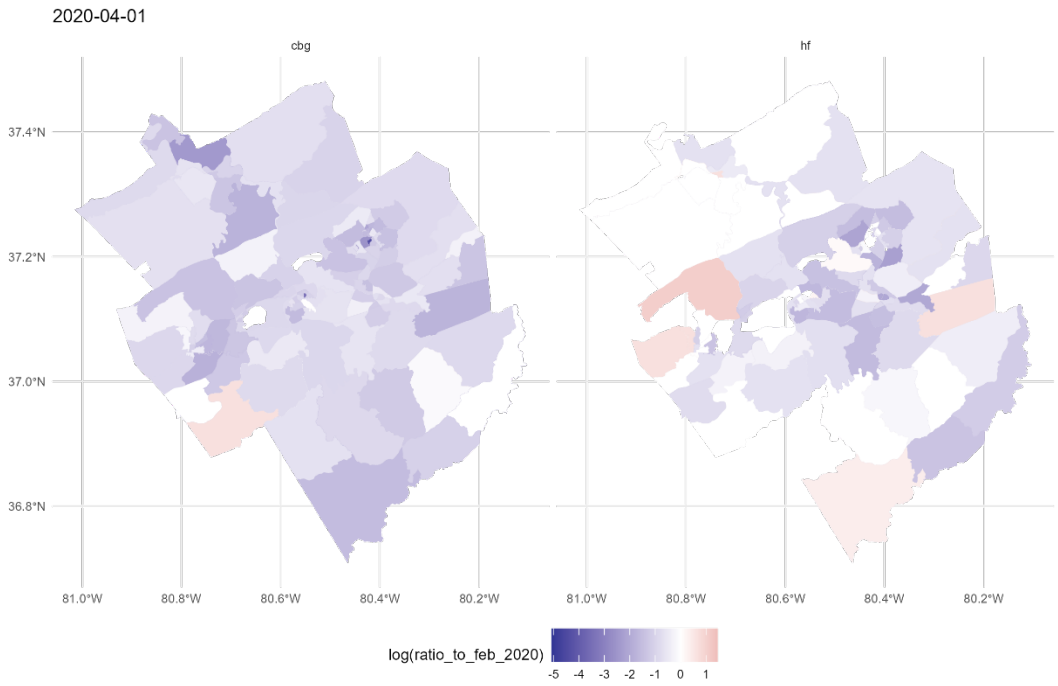
- Done - Healthcare accessibility varies across space and time, with critical downstream effects on detection of outbreaks, treatment of disease, and effort cost of visiting the doctor
- Done - This becomes especially important in rural areas, where doctors can often be difficult to access, and where wages, public transportation, and insurance may make regular doctor visits challenging
- Healthcare accessibility can also change during major natural disasters and events such as the COVID-19 pandemic
- Previous studies have underscored both of these healthcare accessibility challenges
- However, less is known about how these factors interact: What happens to healthcare accessibility patterns in rural areas during major events in the USA?
- It's also important to note how healthcare trips vary from other types of trips. How did change in healthcare accessibility patterns differ from overall travel patterns?
- Here, we examine healthcare accessibility across southwest Virginia:
    - How did overall healthcare utilization change from before and during the COVID-19 pandemic?
    - How did the healthcare utilization patterns themselves change (e.g. did distances traveled change?)
    - What characterized areas that were least likely to access healthcare?
    - What characterized areas that changed the most during the pandemic?
    - How did these changes differ from changes in travel to other types of locations?

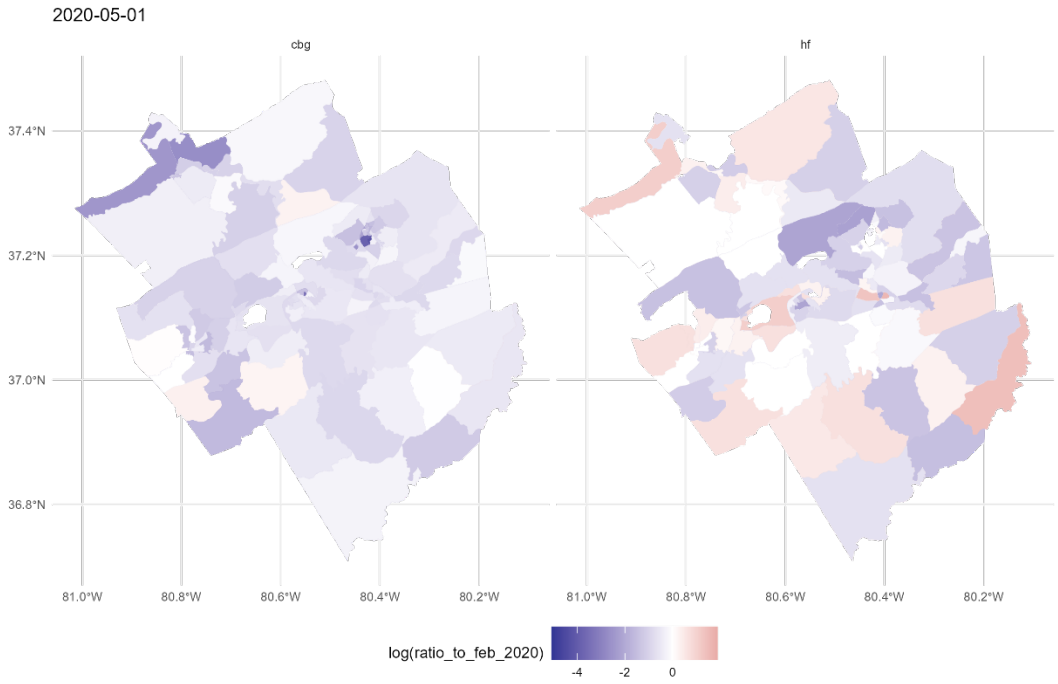
Figures:

Interesting examples of specific months:

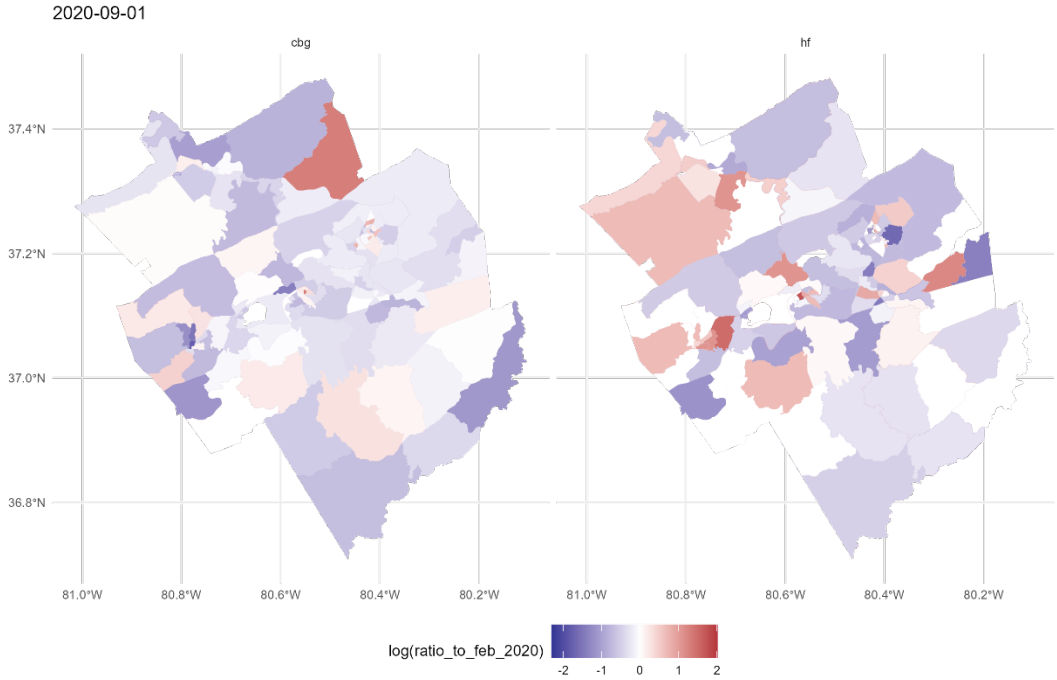
April 2020: Month after the start of the pandemic, reduced mobility to everywhere & healthcare centers



May 2020: Healthcare visits up in some areas, general travel down



Sept 2020: Continued pattern; general trips rose some, HF trips rose a in a lot of places



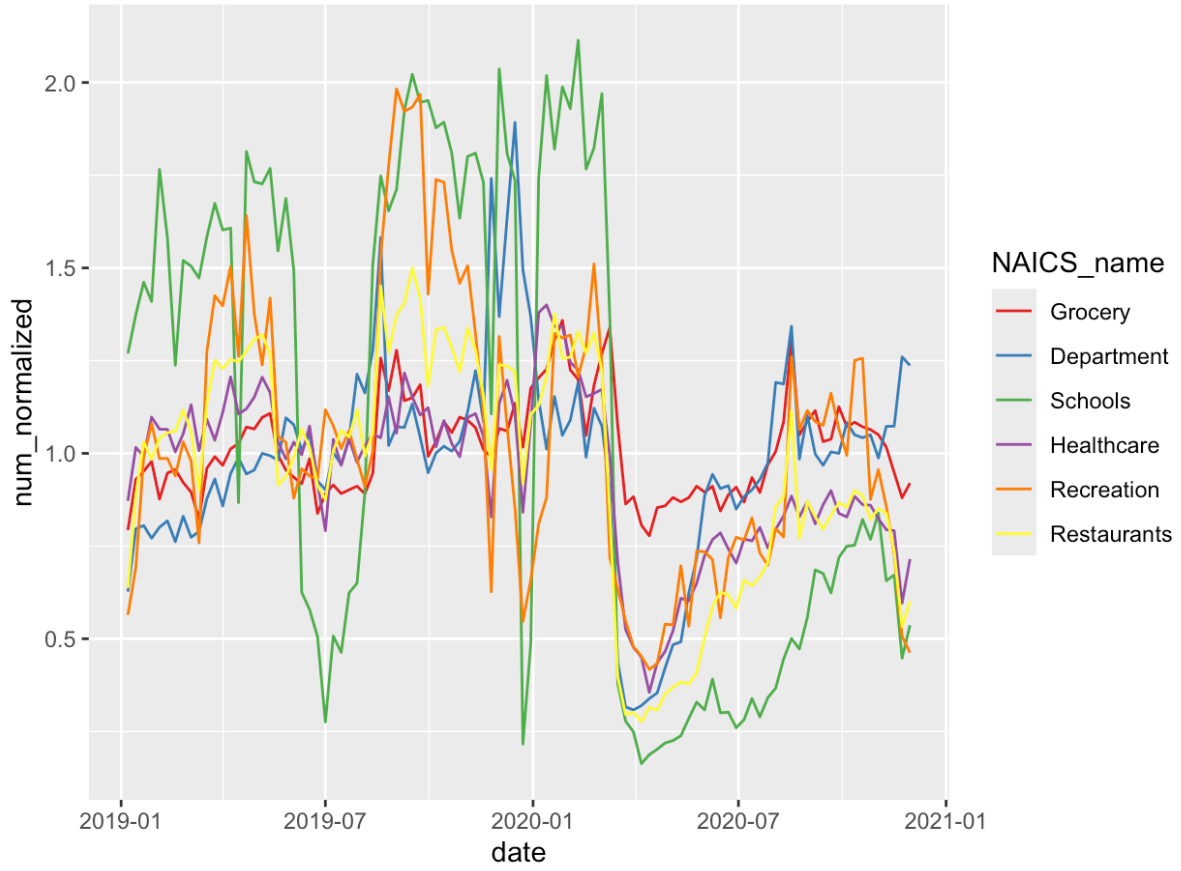
Regression results:

```
Call:
lm(formula = hf_number_visits_all$ratio_to_feb_2020 ~ hf_number_visits_all$prop_urban)

Residuals:
    Min      1Q  Median      3Q     Max
-1.0415 -0.5851 -0.1324  0.2456  8.9149

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                   1.132397   0.006219 182.100  < 2e-16 ***
hf_number_visits_all$prop_urban -0.047272   0.011610  -4.072 4.68e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8713 on 35597 degrees of freedom
Multiple R-squared:  0.0004655, Adjusted R-squared:  0.0004375
F-statistic: 16.58 on 1 and 35597 DF,  p-value: 4.676e-05
```

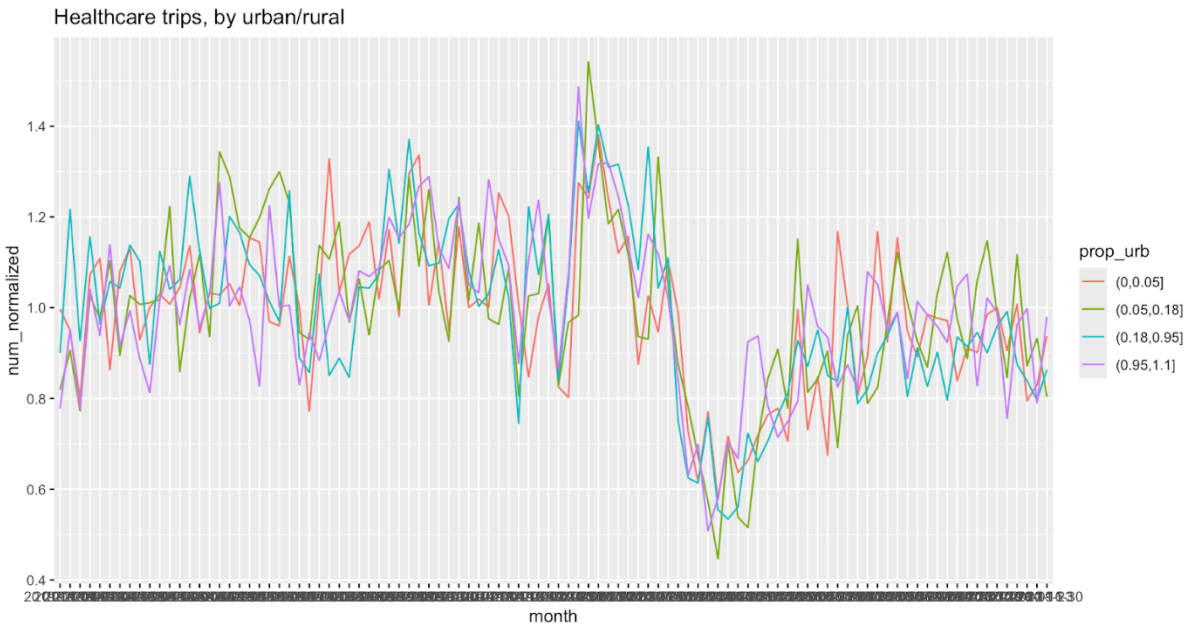
For healthcare facility trips, trips reduced in more urban areas

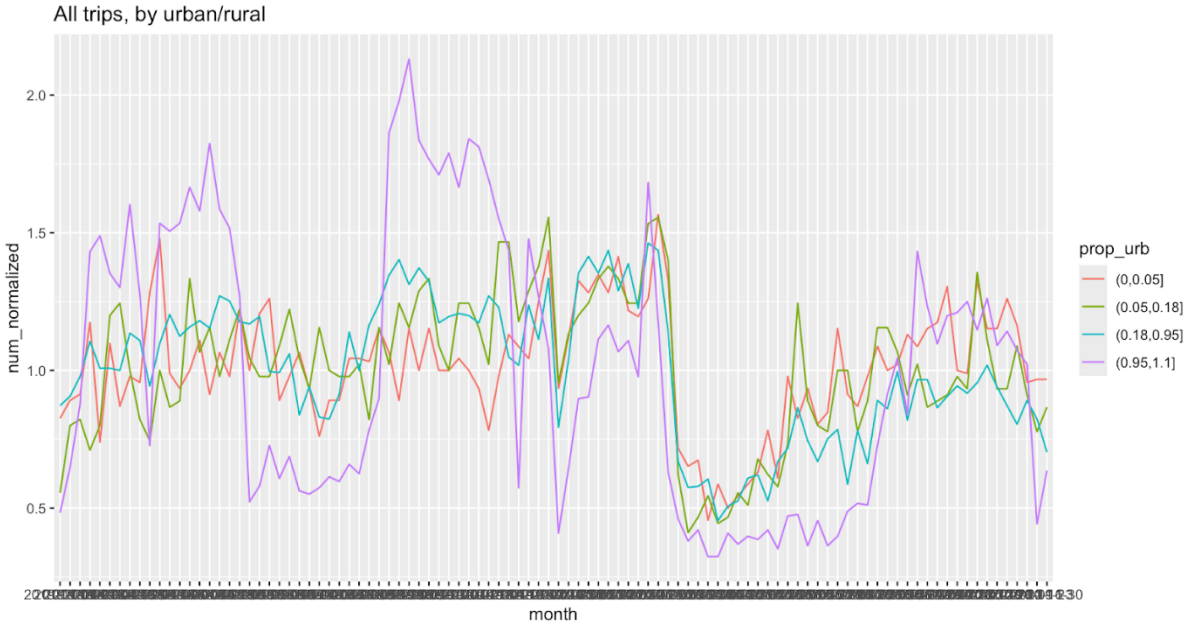
```
Call:
lm(formula = cbg_number_visits_all$ratio_to_feb_2020 ~ cbg_number_visits_all$prop_urban)

Residuals:
    Min      1Q  Median      3Q     Max
-0.9593 -0.3501 -0.1123  0.1570 12.8935

Coefficients:
                                Estimate Std. Error t value Pr(>|t|)
(Intercept)                     0.856471   0.003860  221.87   <2e-16 ***
cbg_number_visits_all$prop_urban 0.109008   0.006828   15.97   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6247 on 48527 degrees of freedom
Multiple R-squared:  0.005225,  Adjusted R-squared:  0.005205
F-statistic: 254.9 on 1 and 48527 DF,  p-value: < 2.2e-16
```

Meanwhile, for all trips, trips increased in more urban areas.



Here’s how healthcare trips varied with other trip types.





Finally, a comparison of trips to healthcare facilities and all trips over time, stratified by urbanization. Notably, the healthcare trips didn't vary much based on urbanization, but all trips did.

Mapping healthcare accessibility across communities in Central Appalachia, including Virginia's New River Valley, throughout the Covid 19 pandemic.

Abstract

Healthcare accessibility plays a crucial role in shaping public health outcomes, particularly in rural regions where healthcare resources are scarce and mobility barriers are prevalent. The COVID-19 pandemic further complicated healthcare delivery, restricting physical access and altering utilization patterns. This study investigates how healthcare accessibility changed before and during the pandemic across Central Appalachia, with a specific focus on Virginia's New River Valley (NRV). Using SafeGraph mobility data, spatial analyses were conducted to compare healthcare-related travel with general mobility patterns from August 2019 to May 2020. Metrics such as visit frequency, travel distance, and urban–rural variation were examined. The analysis reveals substantial temporal fluctuations in healthcare visits during the pandemic's early months, with the sharpest declines occurring in April 2020, followed by partial recovery in May. Regression analyses show that healthcare trips decreased most significantly in urban areas, whereas general trips increased, indicating a decoupling of essential and non-essential mobility behaviors. These findings demonstrate that proximity to healthcare facilities did not guarantee access during the pandemic and highlight the interplay between geographic, socioeconomic, and behavioral determinants of healthcare-seeking behavior. Results contribute to understanding spatial inequities in healthcare access during crises and provide evidence to support data-driven interventions that enhance rural health system resilience.

Introduction

Healthcare accessibility is a cornerstone of health equity and population well-being, shaping not only individual health outcomes but also the resilience of communities. It encompasses the physical availability of services as well as the ability of individuals to reach, afford, and effectively use them. Accessibility has been conceptualized across five dimensions approachability, acceptability, availability/accommodation, affordability, and appropriateness and shaped by individuals' corresponding abilities to perceive, seek, reach, pay, and engage with care (Leveseque et al., 2013). Disparities in healthcare access are evident across the United States, but they are particularly pronounced in the Appalachian region. According to the Appalachian Regional Commission, Appalachia performed worse than the national average in 33 of 41 key health indicators, underscoring long-standing inequities in both health outcomes and healthcare delivery (Marshall et al., 2017). Central Appalachia—spanning parts of West Virginia, Eastern Kentucky, Southwest Virginia, East Tennessee, and Western North Carolina—covers 29,773 square miles

and is home to approximately 2 million residents (The Stay Project, n.d.). This region is defined by rugged terrain, dispersed populations, and entrenched socioeconomic challenges, all of which contribute to persistent barriers to care. Studies consistently show that residents of Appalachian counties experience higher prevalence of chronic diseases and mental health conditions compared to non-Appalachian populations, emphasizing the urgency of addressing these disparities (Morrone et al., 2021).

Healthcare access is shaped by a complex interplay of system-level characteristics, population demographics, and individual-level resources. Andersen's Behavioral Model of Health Services Use highlights the role of predisposing factors (e.g., age, gender, race), enabling factors (e.g., income, insurance status, education, employment), and need-based factors (e.g., illness severity) in determining utilization (Andersen et al., 2002). Geographic inequalities in healthcare access are well documented and linked to negative health outcomes across disease conditions while longer travel times to healthcare facilities discourage healthcare-seeking behavior and lead to delays in diagnosis and treatment (Zipfel et al., 2021 and Alegana et al., 2018). In rural Appalachia, enabling factors such as limited insurance coverage, scarce transportation infrastructure, and shortages of healthcare providers present persistent obstacles. Even small disruptions, such as temporary clinic closures or lack of public transit, can significantly alter healthcare-seeking behavior and delay care. These conditions have made Appalachian communities disproportionately vulnerable to unmet health needs and adverse outcomes.

The COVID-19 pandemic introduced a profound disruption to healthcare access globally, altering patterns of healthcare delivery and utilization. Beginning in early 2020, restrictions on mobility, reallocation of healthcare resources to emergency care, and fear of viral transmission reshaped how individuals sought and received medical services. For regions like Central Appalachia, where healthcare access was already fragile, the pandemic further amplified existing inequities. Healthcare trips differ from other forms of mobility because they are less discretionary and often urgent, meaning that delays or avoidance can have serious downstream effects. This raises critical questions: How did healthcare utilization change before and during the pandemic in Central Appalachia? Did travel distances to healthcare facilities shift? Which geographic and socioeconomic groups were most affected? And how did these patterns differ from general travel to other destinations such as retail or workplaces?

Disruptive events, including pandemics, hurricanes, and earthquakes, can severely impact healthcare access by interrupting essential services, limiting healthcare delivery, and exacerbating inequities, particularly in vulnerable or resource-poor communities. (Singh et al., 2021) These events can damage healthcare infrastructure, disrupt transportation networks, and displace populations, creating both immediate and long-term barriers to care. For instance, hospital closures, road blockages, and power outages during hurricanes or earthquakes can prevent patients from reaching essential services, while emergency response efforts may temporarily redirect healthcare resources away from routine care. Similar to pandemic conditions, the urgency of healthcare needs means that delays or interruptions can result in exacerbation of chronic

conditions, increased morbidity, and higher mortality, particularly among vulnerable populations. Understanding how healthcare access changes across different types of crises allows policymakers and public health practitioners to develop adaptive strategies that ensure continuity of care, improve system resilience, and mitigate the disproportionate impact on at-risk communities.

The consequences of reduced healthcare access extend well beyond immediate health outcomes. When individuals delay or forgo care, conditions that are otherwise preventable may progress to advanced stages, leading to costly hospitalizations, avoidable complications, and higher mortality rates. Economically, untreated or poorly managed health problems contribute to rising healthcare expenditures, reduced workforce productivity, and significant strain on families already facing financial hardship. During the pandemic, mobility analyses revealed that while general travel increased in urban areas, healthcare trips declined sharply in those same areas. This paradox illustrates that proximity to healthcare facilities does not guarantee access; rather, access is shaped by a combination of geographic, socioeconomic, and behavioral factors. These findings underscore how crises like the COVID-19 pandemic create compounding cycles of medical, economic, and social disadvantage, particularly for rural and underserved populations.

National public health priorities, including those outlined in Healthy People 2030, emphasize the importance of equitable access to care through expanded insurance coverage, increased use of preventive services, and strengthened primary care capacity. For rural regions such as Central Appalachia, ensuring continuity of care during public health emergencies is not only consistent with these goals but also essential for reducing inequities. By examining healthcare accessibility in this context, researchers and policymakers can derive valuable lessons for building healthcare systems that are more resilient, adaptable, and equitable.

This study investigates spatio-temporal patterns of healthcare accessibility in Virginia's New River Valley (NRV) during the COVID-19 pandemic. Using SafeGraph mobility data combined with geospatial analysis, it examines changes in healthcare utilization relative to general mobility patterns, identifies geographic and socioeconomic characteristics of the populations most affected, and highlights disparities in travel burdens and access across rural and urban communities. By situating these findings within Andersen's Behavioral Model and the Health Belief Model, the study links structural determinants of healthcare access with individual perceptions of risk, benefits, and barriers.

The significance of this research lies in its ability to provide both conceptual and practical insights. Conceptually, it extends global literature on spatial inequities in healthcare by documenting how accessibility fluctuates under crisis conditions in rural U.S. contexts. Practically, it generates evidence that can inform targeted interventions such as expanded telehealth, transportation support, and resource allocation to high-burden communities. More broadly, the findings can guide preparedness planning for future crises, contributing to national efforts to achieve health equity and strengthen healthcare system resilience. Ultimately, this research demonstrates that understanding healthcare access requires not only examining how it varies under routine

conditions but also how it shifts in response to extraordinary events, offering critical lessons for promoting equity in underserved regions.

Methods

Study Area

This study focuses on Virginia's New River Valley (NRV), a subregion of Central Appalachia composed of five counties: Montgomery, Pulaski, Giles, Floyd, and the City of Radford. The NRV represents a mixed rural urban landscape with varying degrees of healthcare infrastructure, socioeconomic resources, and population density. Montgomery County includes the urban hub of Blacksburg and surrounding suburban neighborhoods, while other counties exhibit low population density and limited healthcare facility coverage. The geographic diversity of this region makes it an ideal case study for exploring disparities in healthcare accessibility and mobility during the COVID-19 pandemic.

Data Sources

The primary data source for this analysis was SafeGraph mobility data, a comprehensive dataset derived from anonymized, aggregated cell phone location information. SafeGraph's "Places Patterns" dataset provides monthly counts of visits to points of interest (POIs), including healthcare facilities, across U.S. census block groups. Each record includes the number of visits, median travel distance, and visitor home census block group, enabling both spatial and temporal analysis of mobility behavior.

Healthcare facilities were identified using North American Industry Classification System (NAICS) codes corresponding to hospitals, outpatient care centers, physician offices, and urgent care facilities. These data were compared to mobility trends for all trips aggregated across non-healthcare POIs such as retail, food, and recreation to contextualize healthcare-specific mobility patterns. Population and demographic data were obtained from the American Community Survey (ACS) 2019 5-year estimates, providing measures such as median income, vehicle ownership, insurance coverage, and urban rural classification.

Temporal Scope

The analysis covered the period from August 2019 through May 2020, capturing mobility patterns before and during the early months of the COVID-19 pandemic. February 2020 served as the baseline month, representing pre-pandemic mobility levels. Ratios of healthcare-related visits were calculated for selected months relative to February 2020 to measure temporal shifts. The months chosen August 2019, December 2019, April 2020, and May 2020 represent key points in pre-pandemic stability, onset of the pandemic, peak restrictions, and initial recovery, respectively.

Data Preprocessing

All SafeGraph data were processed in Python and ArcGIS Pro. Monthly visit counts were normalized by population at the census block group level to ensure comparability across areas of differing population sizes. The analysis employed spatial joins to link SafeGraph POI data to block group boundaries and calculate average travel distances and visit frequencies for healthcare facilities. To reduce potential bias from low-sample block groups, any unit with fewer than 50 monthly visits across the study period was excluded.

Healthcare visits were aggregated and expressed as ratios of visits per capita relative to February 2020, enabling visualization of percentage change in healthcare accessibility over time. Similar ratios were computed for all-trip mobility to compare pandemic-related changes across activity types.

Spatial Analysis

Spatial analyses were conducted to visualize and quantify changes in healthcare accessibility. Choropleth maps were created for each time ratio (August 2019: February 2020, December 2019: February 2020, April 2020: February 2020, and May 2020: February 2020) to display shifts in healthcare facility visit intensity. These maps highlight areas with the greatest declines or recoveries in healthcare visits, providing a visual representation of geographic disparities in healthcare access.

Spatial autocorrelation was assessed using Global Moran's I, which tests whether changes in healthcare visits exhibited spatial clustering or randomness. A positive Moran's I value would indicate spatial concentration of accessibility changes such as clusters of reduced visits in rural zones whereas a negative value would suggest spatial dispersion.

Statistical Analysis

To identify the determinants of healthcare mobility, multivariate regression analyses were conducted. The dependent variable represented the percentage change in healthcare visits from February to subsequent months (April and May 2020). Independent variables included measures of urbanization, median income, percentage of uninsured population, vehicle ownership rate, and median distance traveled.

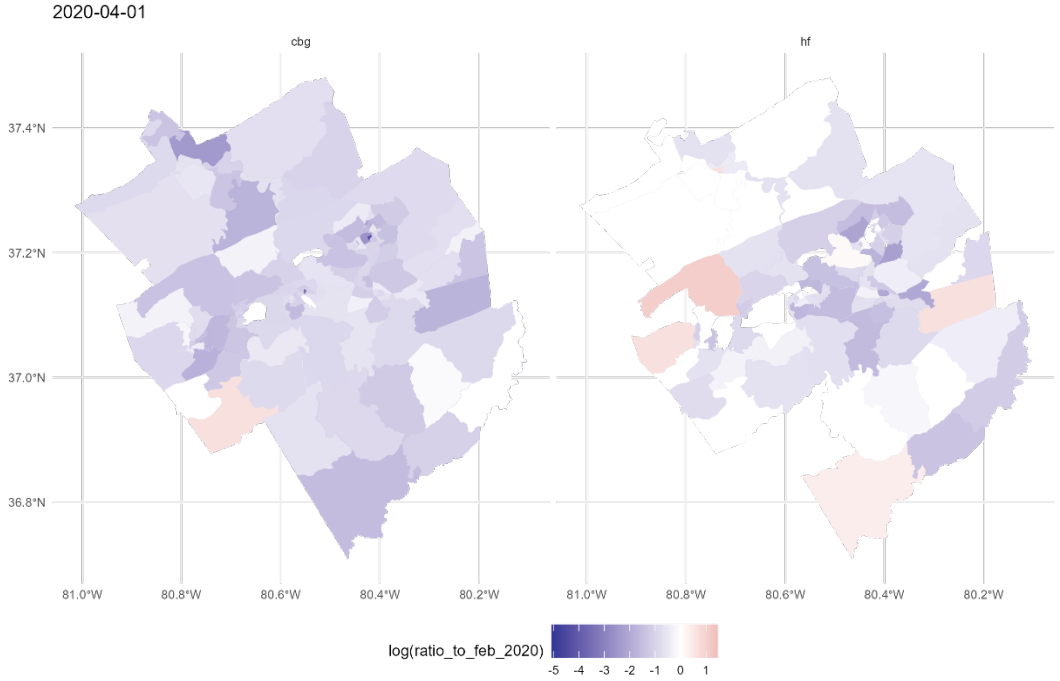
Separate models were estimated for healthcare-related trips and all trips to assess whether pandemic-related mobility changes differed across trip types. Regression diagnostics were performed to test for spatial dependence, and multicollinearity.

Preliminary results indicated that healthcare trips decreased more sharply in urbanized areas, while total trips increased in those same areas, suggesting distinct behavioral responses for essential versus non-essential mobility. These regression findings help explain the observed decoupling of healthcare access and general mobility patterns.

All data used in this study were publicly available, aggregated, and anonymized, ensuring compliance with institutional ethical guidelines and privacy standards. The analysis did not involve identifiable personal data.

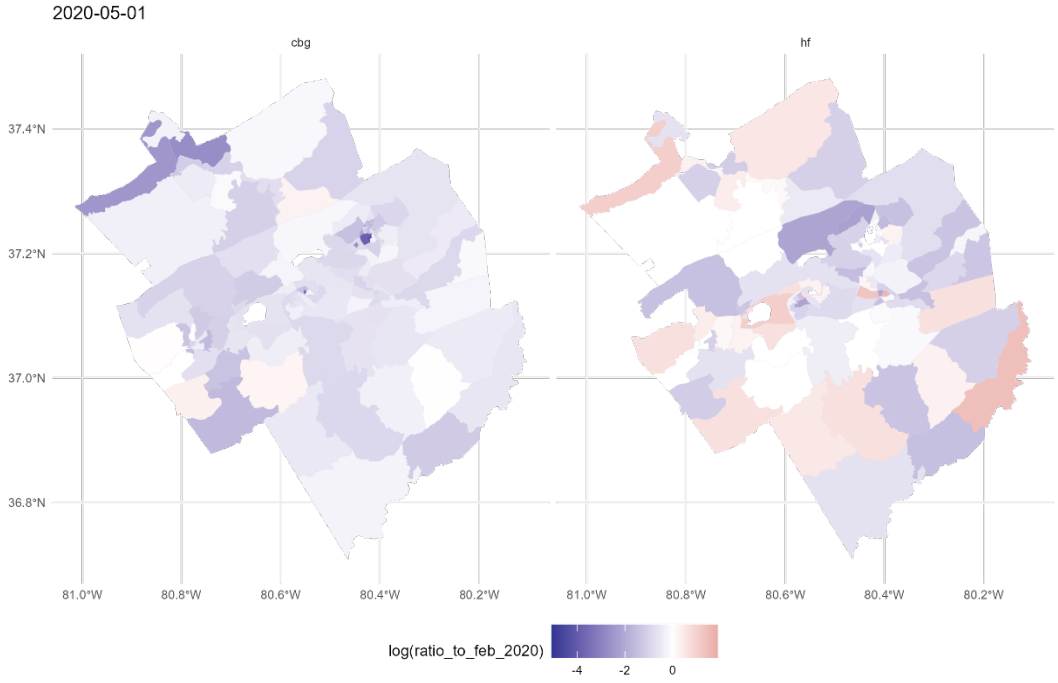
Results

Analysis of SafeGraph mobility data revealed substantial temporal fluctuations in healthcare visits across the New River Valley (NRV) during the early months of the COVID-19 pandemic. In April 2020, immediately following the onset of the pandemic, overall mobility declined sharply, with visits to healthcare facilities showing pronounced reductions across most census block groups.

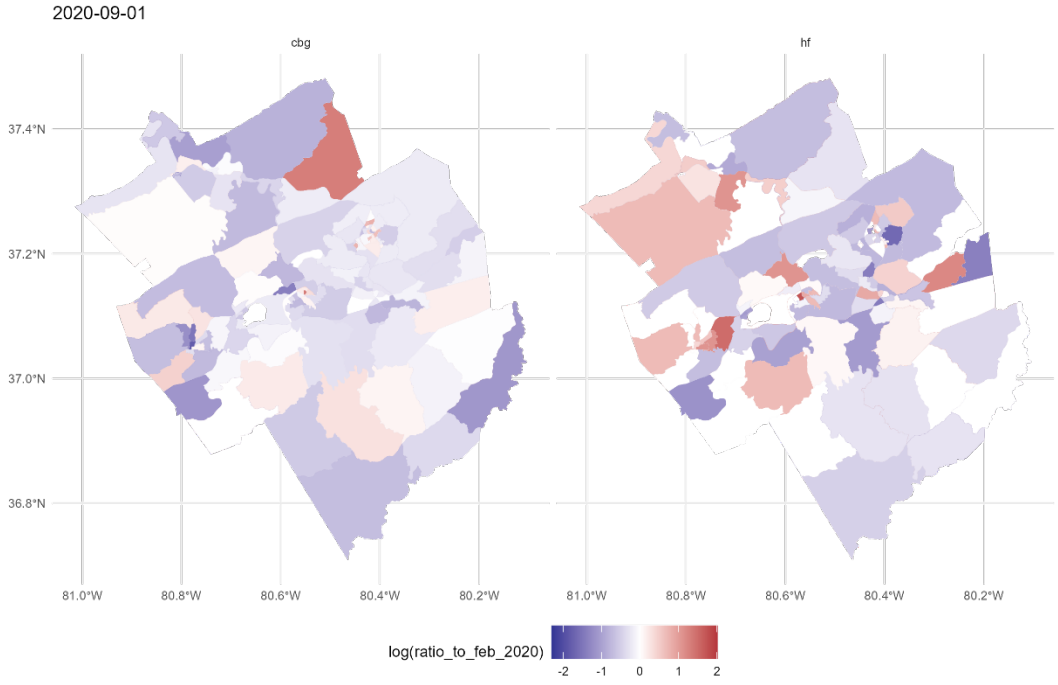


This decline reflected the combined effects of public health restrictions, temporary clinic closures, and heightened concerns about viral exposure. By May 2020, healthcare visits exhibited partial recovery in several areas, while general mobility to non-healthcare destinations declined slightly, suggesting that individuals prioritized essential healthcare visits while limiting discretionary

travel.

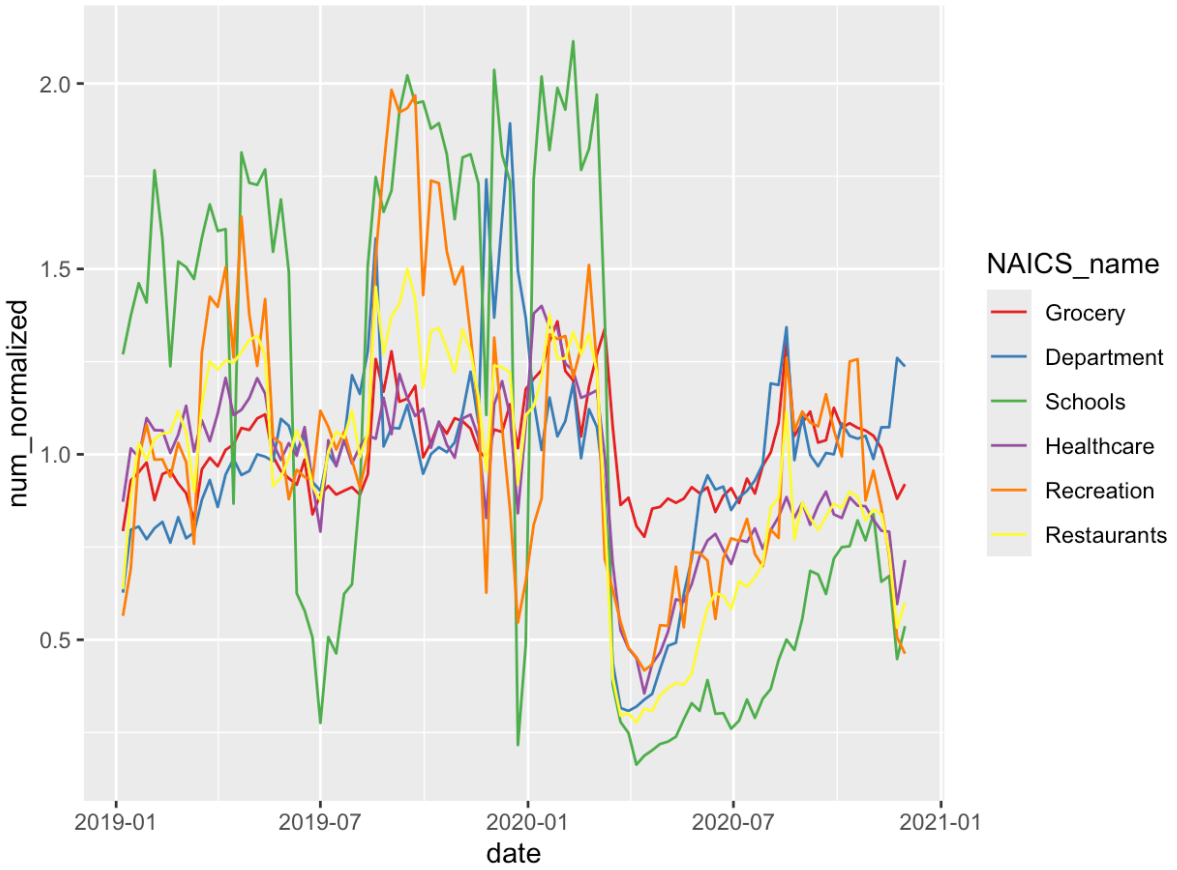


By September 2020, healthcare visits had increased in many regions, accompanied by modest rises in general trips, indicating gradual normalization of mobility patterns as communities adapted to pandemic conditions

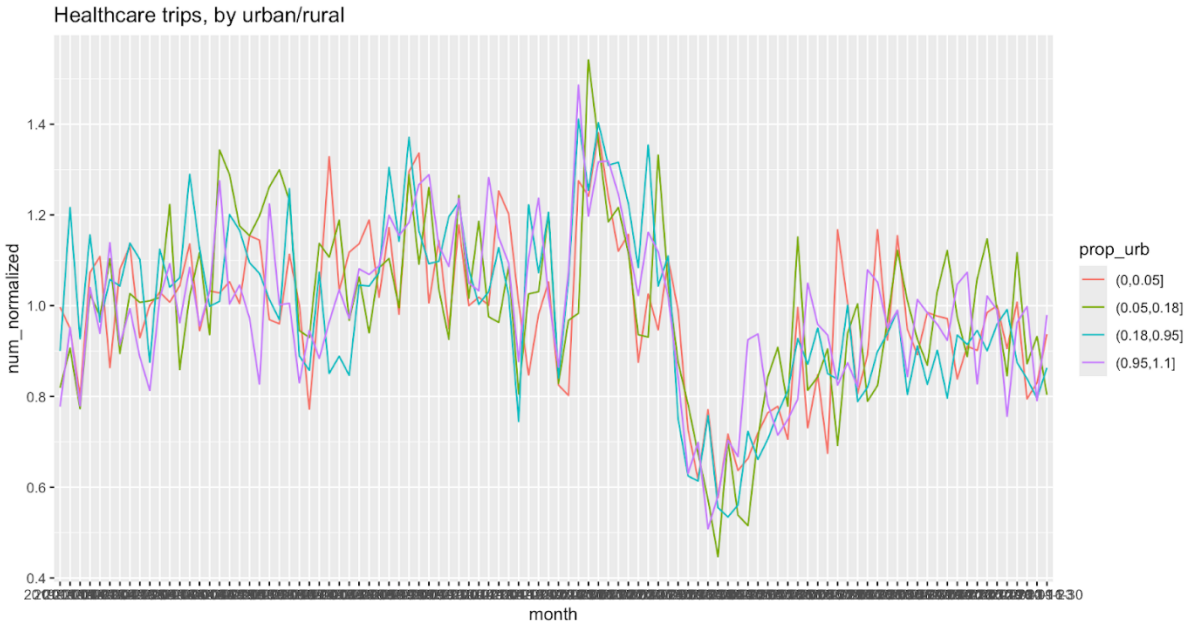


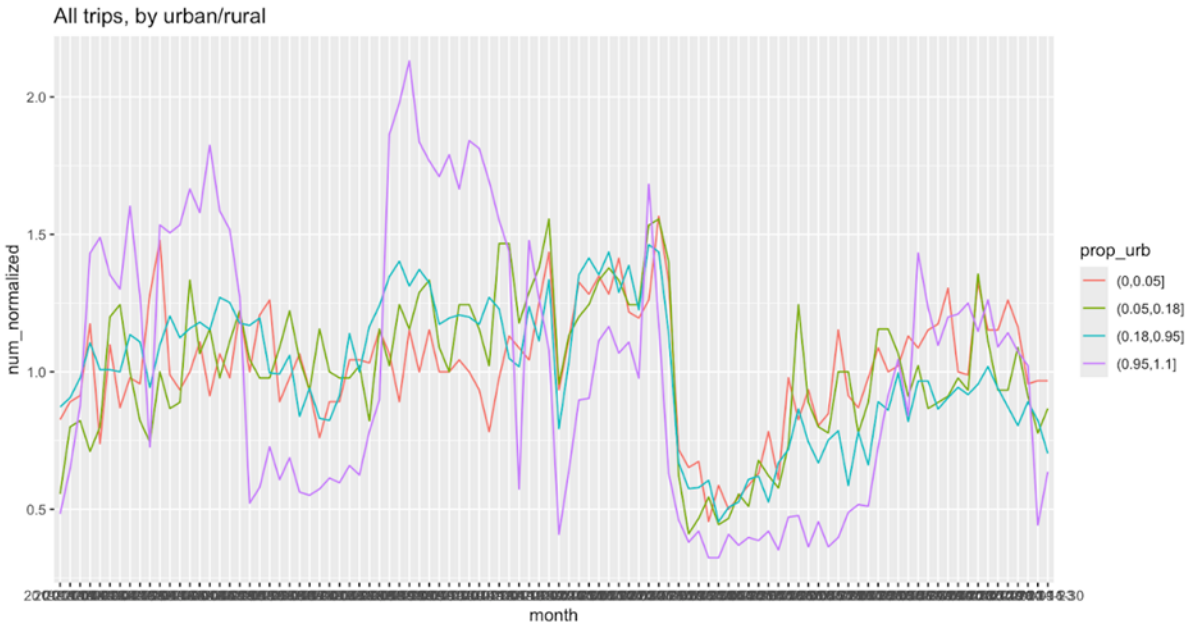
Spatial and regression analyses further elucidated differences between healthcare-specific and general mobility. Multivariate regression revealed that trips to healthcare facilities decreased most

substantially in urbanized areas, whereas overall trips to non-healthcare destinations increased in the same regions.



This divergence indicates that essential and non-essential mobility responded differently to pandemic conditions. A longitudinal comparison of healthcare and general trips, stratified by urbanization, demonstrated that healthcare visits remained relatively stable across urban and rural areas, while general trips varied considerably depending on urban density.





Collectively, these findings highlight that proximity to healthcare facilities alone did not guarantee access during the pandemic; behavioral responses and structural limitations both played critical roles.

Discussion

The results of this study indicate that the COVID-19 pandemic disrupted healthcare accessibility across the NRV in significant and spatially heterogeneous ways. The marked reductions in healthcare visits observed in April 2020 underscore the vulnerability of both urban and rural communities to mobility restrictions and perceived infection risk. By May 2020, partial recovery

in healthcare visits suggests that individuals adapted their behavior, resuming essential care while continuing to limit discretionary travel, a pattern that persisted through September 2020.

Regression analyses provide further insight into the determinants of mobility patterns. Healthcare trips decreased most sharply in urban areas, while overall trips increased in the same regions (Figure 4), revealing a decoupling of essential and non-essential mobility behaviors. This pattern is consistent with Andersen's Behavioral Model, highlighting the role of enabling factors, such as transportation availability and socioeconomic resources, alongside perceived risk in shaping

healthcare-seeking behavior. Comparison of healthcare trips to general trips over time, stratified by urbanization, reinforces the conclusion that essential healthcare utilization remained relatively stable across urban and rural areas, whereas general mobility was highly sensitive to urbanization and local pandemic conditions.

These findings have important implications for understanding spatial inequities in healthcare access. While urban areas experienced the largest relative declines, rural areas continued to face structural challenges, including limited facility density and longer travel distances. Together, these results suggest that interventions to support healthcare accessibility must account for both structural and behavioral barriers. Strategies such as targeted transportation support, telehealth expansion, and prioritization of resources for high-burden communities are essential to mitigate disparities during public health crises.

Conclusion

This study demonstrates that healthcare accessibility in the New River Valley was significantly affected by the COVID-19 pandemic, with the sharpest reductions occurring in April 2020, followed by partial recovery in subsequent months. The analysis highlights both temporal and spatial heterogeneity in mobility patterns, as well as a divergence between healthcare-specific trips and general mobility. Urban areas, despite higher facility density, experienced larger proportional declines in healthcare visits, whereas rural areas continued to encounter persistent access challenges. Socioeconomic factors, vehicle ownership, and travel distance further influenced healthcare utilization, illustrating the compounded effects of structural and behavioral determinants.

These findings provide actionable guidance for public health planning and policy. Expanding telehealth services, providing targeted transportation support, and allocating resources to high-need communities are essential strategies to enhance healthcare accessibility and resilience during crises. By integrating spatial, behavioral, and socioeconomic perspectives, this research contributes to a more nuanced understanding of healthcare access in rural regions and underscores the importance of equity-focused interventions to maintain essential healthcare services during public health emergencies

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