Title: Spatial analysis of greenspace and mental health in North Carolina: Consideration of rural and urban neighborhoods

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Abstract

Background and Objectives

Greenspace positively impacts mental health. Previous research has focused on the greenspace mental health relationship in urban areas. Yet, little work has looked at rural areas, despite rural communities reporting similar rates of poor mental health outcomes and higher rates of suicide mortality compared with urban areas. This ecological research study examined the following research questions: (1) Do public and/or private greenspace affect the spatial distribution of mental health outcomes in North Carolina? (2) Does this relationship change with rurality?

Methods

Emergency department data for six mental health conditions and suicide mortality data from 2009-18 were included in this analysis. Spatial error and ordinary least squares regressions were used to examine the influence of public and private greenspace quantity on mental health in rural and urban communities.

Results

Results suggest greenspace benefits mental health in rural and urban communities. The strength of this relationship varies with urbanity and between public and private greenspaces, suggesting a more complex causal relationship.

Conclusions

Given the high case counts and often lower density of mental health care facilities in rural areas, focusing attention on low-cost mental health interventions, such as greenspace, is important when considering rural mental health care.

Keywords: Spatial analysis, spatial regression, suicide, greenspace, mental health, green space

1. Introduction

Greenspace positively impacts mental health and is a low-cost nature-based intervention that encourages physical activity and social cohesion. Neighborhood greenspace quantity has been associated with population-level improvements in mental health and well-being, including a reduction in psychological stress levels, depressed mood, prescription rates, and enhanced emotional well-being.[1–3] Greenspace can be defined as public, which are openly accessible natural spaces[6,7] or private greenspaces, which encompasses all green or natural land cover in an area.[8,9] Few studies differentiate between public and private greenspace.[10] Furthermore, the distribution and development of greenspaces is often not equitable.

Greenspaces are most common in high-income, predominantly white communities (cite). However, the positive health benefits of greenspace have been found to be strongest among low-income groups and the socially marginalized, like older adults.4,5 Despite this observed relationship, low-income, and socially marginalized communities often have far less access to this low-cost health intervention (cite). Furthermore, greenspace development in these priority areas can often lead to gentrification; meaning low-income and socially marginalized peoples continue to have less access to greenspaces (cite).

Four main pathways have been identified through which greenspace benefits mental health; stress reduction, social cohesion, pollution reduction and outdoor recreation.[12,13] Stress reduction occurs due to the restorative properties of nature, such as breathing fresh air or intentionally taking time to relax, which may be achieved in public and private greenspaces.[12,13] Social cohesion occurs through interactions with community members, such as attending sporting events or participating in outdoor group activities.[12,13] This pathway requires engagement in public greenspaces and is less likely to occur in private greenspaces.[11] Pollution reduction occurs from the physical properties of plants found in greenspaces, and the general public has reported an appreciation for having access to greenspace, either public or private, for this specific reason.[12,13] The fourth pathway is recreation opportunities. Recreation opportunities are of particular interest due to their role as a causal pathway, by offering opportunities for physical exercise and social cohesion[12], and due to the additional mental health benefits physical activity offers.[14] Outdoor recreation is more likely to occur in accessible public greenspaces (e.g. trail networks, athletic fields)[15], though private greenspace can also provide recreation opportunities.

In addition to the type of greenspace and the pathways in which greenspace benefits mental health, rurality may also contribute to the greenspace mental health relationship[16]. Most research to date has focused on greenspace in urban communities.[2] Studies focusing on greenspace and mental health in urban areas suggest that high quantities of greenspace, both public parks, and all vegetated land cover, benefit mental health.[13,17,18] It is unclear, however, how urbanity influences the greenspace-mental health relationship. Some studies suggest the relationship is different in rural areas[19], though others find no difference, with greenspace benefiting mental health equally in urban and rural communities.[16] Yet, the type and quantity of greenspace varies with

rurality.[19,20] In rural areas, private greenspaces, such as agricultural fields and general countryside greenness, are much more common than in urban areas.[20] Additionally, the definitions of 'rural' and 'urban' vary greatly, from regional to international scales.[21] As such, adequately addressing the rural-urban greenspace relationship is difficult. Thus, further consideration of public and private greenspaces in both rural and urban communities is needed to understand better if and how greenspace type and rurality influence the greenspace mental health relationship.

While rates of poor mental health outcomes are similar in rural and urban areas[22], access to mental health care is not.[23] This remains true for North Carolina and the Southern US in general, which has fewer rural mental health care practitioners per capita compared to other regions in the US.[24] Overwhelmingly, rural areas tend to have fewer mental health care facilities and fewer mental health care specialists than urban areas.[23] More consideration of the mental health benefits of low-cost nature-based interventions, such as greenspace, in rural neighborhoods, is needed.

This study aims to investigate the greenspace mental health relationship in both urban and rural communities of North Carolina, with additional consideration given to the type of greenspace (public or private). This study has two guiding research questions (1) Does greenspace benefit mental health in North Carolina?, and (2) Does rurality and/or type of greenspace (public vs. private) influence this relationship? This work furthers foundational knowledge on the impacts of greenspace quantity and type on the greenspace-mental health relationships in both rural and urban neighborhoods.

2.Methods

2.1 Study Area

North Carolina (NC) is located in the southeastern US. Composed of 3 main regions: the mountains, the piedmont, and the coast, NC is home to a diversity of land covers, climates, and land uses (Figure 1). There are multiple urban centers in the state, including Raleigh, Charlotte, and Winston-Salem, all of which are located in the piedmont, as well as cities in the mountains, including Asheville and the coastal plain; Fayetteville and Wilmington (Figure 1). Additionally, there are regions of varying rurality, most notably in the western mountains and the coastal plain. Greenspace also varies greatly throughout the state. Forested areas dominate the western mountains, whereas city and local parks are common in the piedmont and the eastern coast is predominantly marshy coastal greenspaces. [INSERT FIGURE 1 HERE]

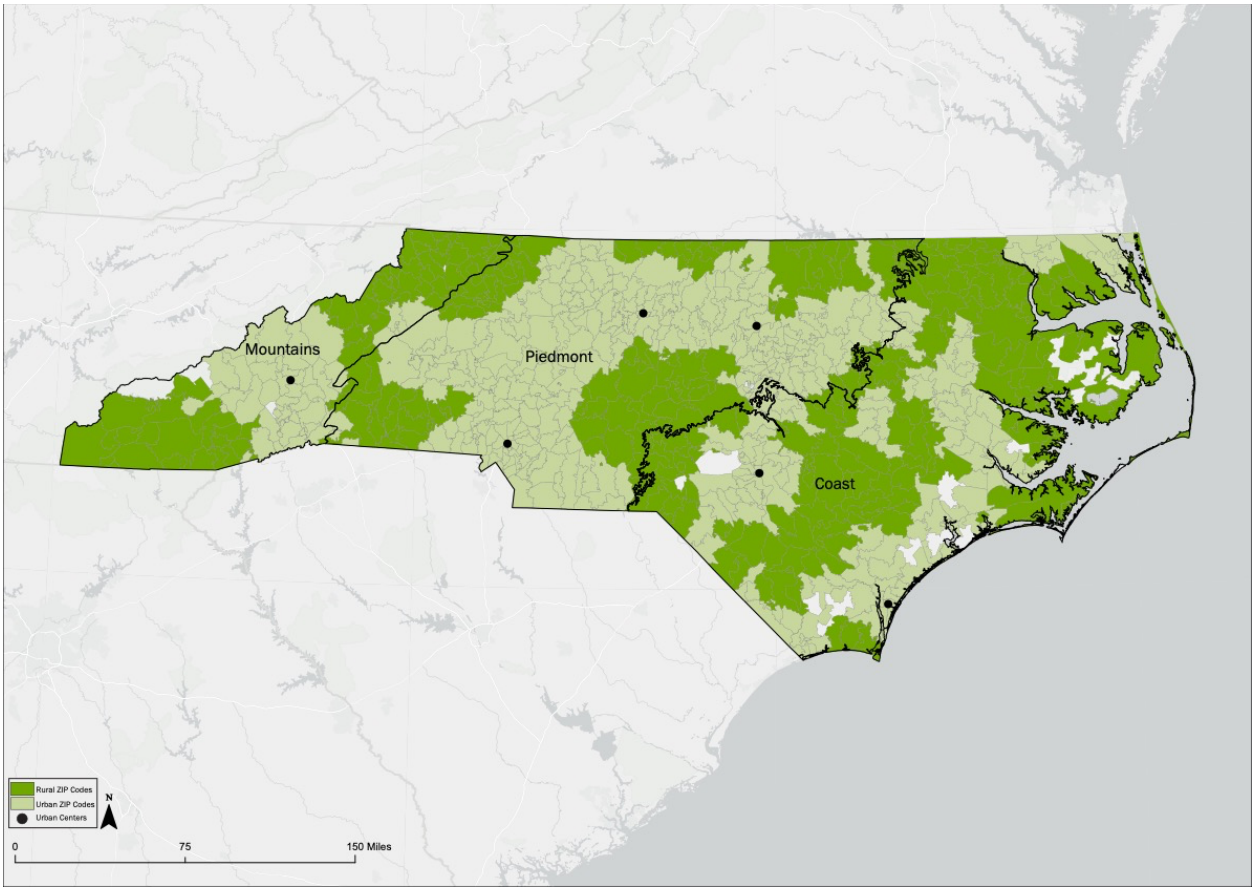

Figure 1: Map of North Carolina illustrating rurality, select urban centers and the 3 dominant regions: mountains, piedmont and coast.

North Carolina is ranked 31st out of 50 for mental health care service, meaning the state has higher than average poor mental health occurrence and fewer mental health facilities compared to other states.[25] Suicide mortality in the state is comparable to the average US rates for common mental illnesses, such as substance abuse and anxiety.[26] Given that North Carolina, as with many places in the US, does not have sufficient mental health care providers, the investigation into low-cost mental health care is crucial.

2.2 Mental Health Data

Data on suicides were obtained from the NC Violent Death Reporting System (NC VDRS) (Table 1) from 2009-18. NC VDRS provides comprehensive reporting of violent deaths and contains additional contextual factors (e.g., manner of death, mental health history).[27] Emergency department (ED) data on mental health outcomes were obtained from the NC Disease Event Tracking and Epidemiologic Collection Tool (NC-DETECT) (Table 1) from 2009-18. NC-DETECT provides complete spatio-temporal coverage of mental health diagnoses from all 120 emergency departments throughout NC.[28] The six mental health outcomes considered in this analysis were (1) anxiety (ICD-9: 300.00, ICD-10 CM: F41.9), (2) major depressive disorders (MDD) (ICD-9: 296.2 and 296.3, ICD-10 CM: F32-F33), (3) mood disorders (ICD9: 296, 300.0, 300.2,300.3, 300.7, 300.4, 309, 311; ICD10:F30-F39), (4) mental illness (ICD9: 290-319; ICD10: F0-F99), (5) substance abuse (ICD9: 291, 292, 303, 304, 305, 964; ICD10:F10-F19) and (6) self-injury (ICD-9: E950-959, ICD-10 CM: R45.841, T36-T65 + T7, T14.91, X60-X84). NC-DETECT provides basic demographic information and insurance. Both datasets provide the individuals' ZIP Code, the unit of analysis for this study. [INSERT TABLE 1 HERE]

Table 1. Mental Health cases by Rural and Urban locations

	Anxiety	Depression	Mental Illness	Mood	Self Injury	Substance Abuse	Suicide
Urban							
Total Cases	829585	590131	5123867	1434260	119539	3438364	8425
Annual Cases	92176.11	65570.11	569318.6	159362.2	13282.11	382040.4	936.1111
Annual Cases per 100,000 People	1,171.8	833.5	7,237.3	2,025.8	168.8	4,856.6	11.9
Rural							
Total Cases	335063	223743	2139801	554530	43261	1468081	3118
Annual Cases	37229.22	24860.33	237755.7	61614.44	4806.778	163120.1	346.4444

Annual Cases per 100,000 People	1,626.3	1,086.0	10,386.1	2,691.6	210.0	7,125.7	15.1

Urban Population: 7,866,458
Rural Population: 2,289,166

2.3 Greenspace Data and Definitions

Greenspace was defined as (1) public and (2) private to gain a better understanding of how public and private greenspace may influence the greenspace mental health relationship in rural and urban communities.

Public greenspace was defined using the Trust for Public Land's ParkServe definition of free and openly accessible to the public.[29] ParkServe[29] and The Protected Area Database of the United States (PAD_US) from 2020[30] were used for the identification of public greenspaces.[31,32] ParkServe is a dataset comprising all public parks. All parks in the ParkServe dataset are free and open to the public, therefore, no additional selection criteria were needed. PAD-US is a spatial dataset of all government-managed greenspaces. Only free, open-access greenspaces with conservation easements and future development restrictions (GAP status 1-3) were selected from the PAD-US dataset. This selection excluded military lands, most notably, as they are not openly accessible to the public. In addition, Great Smoky National Park was excluded from this analysis as it has no year-round population and occurs at the border of North Carolina and Tennessee. All parks and public greenspaces selected from these two datasets were combined to form one public greenspace dataset (Figure 2). [INSERT FIGURE 2 HERE]

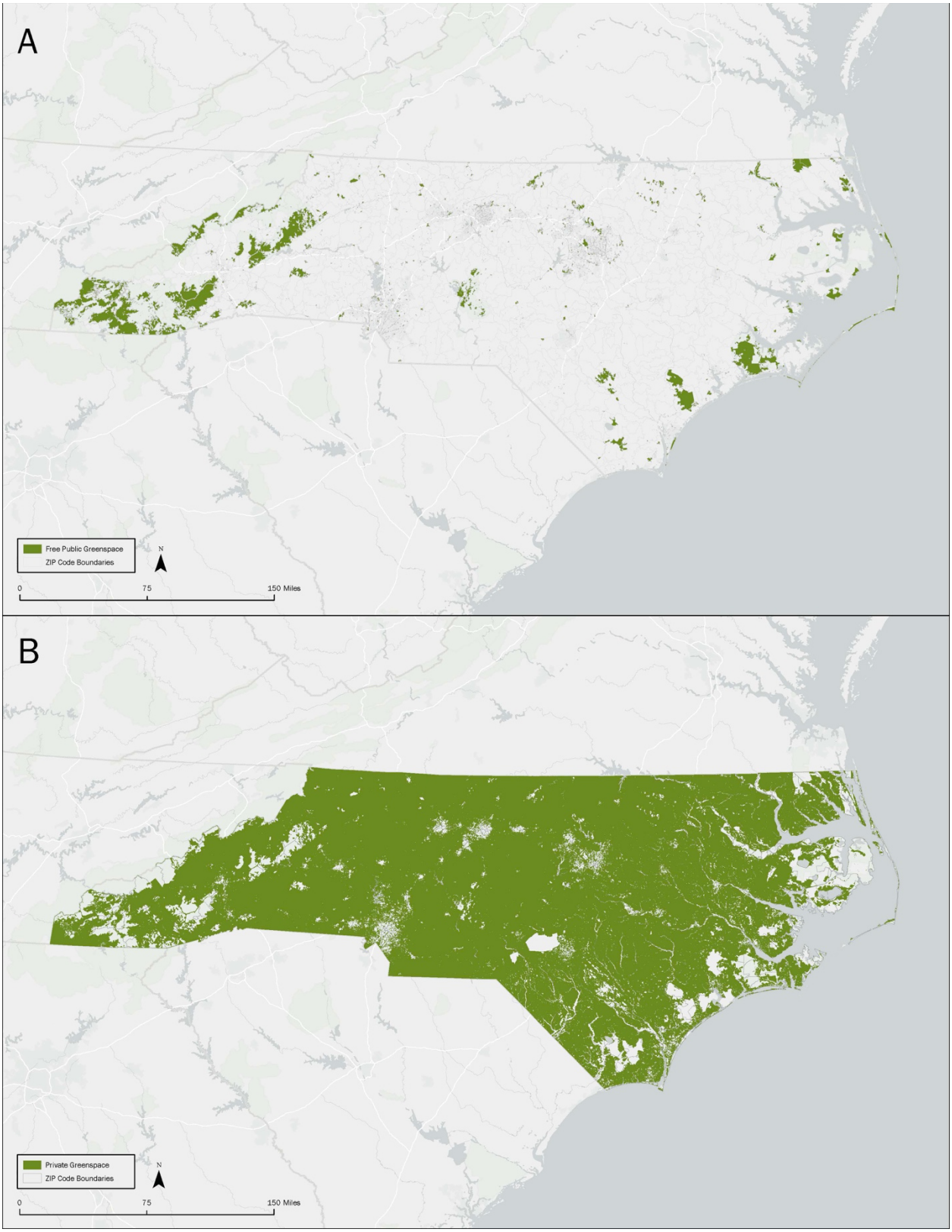

Figure 2. Map of (A) public greenspace and (B) private greenspace in North Carolina.

Private greenspace was defined as all greenspace and natural land cover that was not included in the public greenspace definition. National Land Cover Data (NLCD)[10,33] from 2019 was classified as natural vegetation, and all other land cover types were designated as 'unclassified'. The public greenspaces were removed from the classified land cover dataset, creating a dataset of private greenspace, defined as all vegetated land cover in NC that is not free and openly accessible to the public (Figure 2). All spatial analysis was performed in ArcGIS Pro 2.9.0.[34]

To be consistent with mental health datasets, total private and public greenspace area was calculated in acres/ZIP Code[35], and the population was accounted for by calculating greenspace/person in each ZIP Code. Separate models were performed for 1) total public greenspace per person in rural communities; 2) total public greenspace per person in urban communities; 3) total private greenspace per person in rural communities, and 4) total private greenspace per person in urban communities.

2.4 Covariates

The relationship between mental health and greenspace is influenced by race[35] and income[36], with predominantly white, upper class communities typically having greater access to greenspaces.[37] We included race (% white residents) and income (% of households making more than $125,000/year), as covariates, using 5-year American Community Survey estimates.[38] Greenspace, mental health outcomes, and covariates were analyzed as continuous variables.[6]

2.5 Rurality

Rurality and urbanity were determined using Rural-Urban Commuting Area (RUCA) codes.[8] RUCA codes consider the distance and direction of the primary commutes from each ZIP Code.[39] RUCA codes range from 1, most urban, to 10, most rural.[39] For this analysis codes 1-3 were considered urban (including suburban ZIP Codes), and codes 4-10 were considered rural. Micropolitan ZIP Codes (RUCA codes 4-6)[39] were considered rural as many are town centers in rural areas; which differentiates them from urban centers. Out of 802 populated ZIP Codes in North Carolina (excludes PO ZIP Codes), 349 were considered rural, and 453 were considered urban (Figure 1).

2.6 Analysis

Mental health outcomes and greenspace distribution were tested for spatial autocorrelation. Moran's I was used to assess the spatial autocorrelation of mental health outcomes and greenspace in urban and rural areas for both public and private greenspaces at a significance level of $p<0.05$. *P*-values at or below 0.05 indicate spatial autocorrelation and indicate spatial dependence pointing to the need to perform spatial regression.[41,42] Rural greenspace and mental health were spatially autocorrelated.

For spatially autocorrelated variables, the Lagrange multiplier diagnostics for spatial dependence test was conducted. This test illustrates which spatial regression (i.e., spatial error, SARMA, or spatial lag) is best for the spatially autocorrelated variables. The spatial regression with the lowest *p*-value was selected. For this analysis, the spatial error model was the most significant model across all spatially autocorrelated variables (Robust Lagrange: 0.89-3.33). Spatial error

models account for spatial autocorrelation by including it as an error term in the regression equation.[43]

For mental health outcomes that were not spatially autocorrelated, Ordinary Least Squares (OLS) regression was used to determine if greenspace influenced mental health outcomes.[6] For all regressions, both OLS and spatial error, the population was accounted for by using the metric of greenspace/person/ZIP Code. All mental health outcomes were log-transformed for regression analysis to achieve normal distributions.[44] This ecological analysis examined the association between a) total public greenspace per person and b) total private greenspace per person for each mental health outcome separately and adjusted for area-level racial and economic composition. All statistical analyses were performed in RStudio 2021.9.2.[45]

3. Results

3.1 Mental Health Outcomes

Mental health outcomes are distributed throughout the state, with higher case counts occurring in the western mountains across all mental health outcomes, except for self-injury, which has high case counts in the southeast (Figure 3). More mental health ED visits occurred per 100,000 people per year in rural communities than in urban ones (Table 1). Mental illness (i.e., any mental health diagnosis) had the highest annual occurrence per 100,000 people in both rural and urban communities, while suicide had the lowest annual occurrence per 100,000 people (Table 1). [INSERT FIGURE 3 HERE]

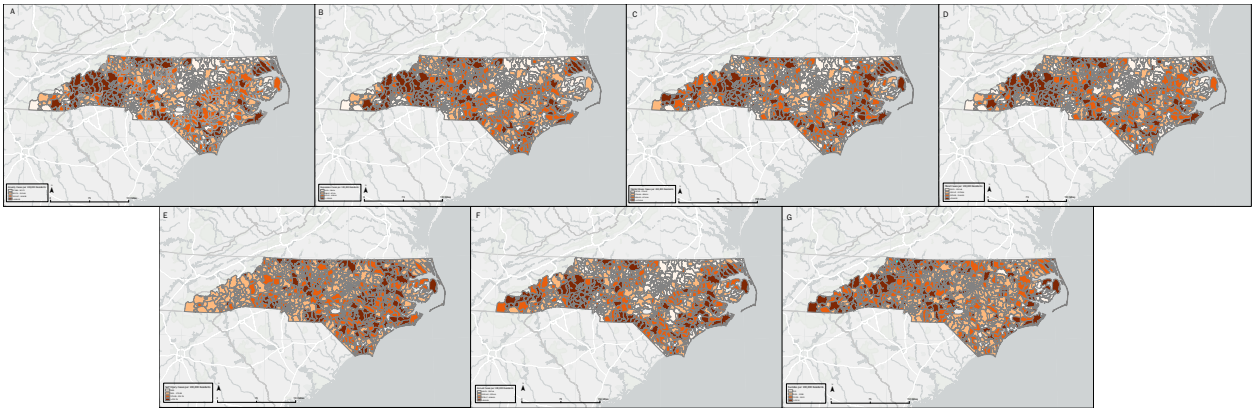

Figure 3. Annual mental health outcomes per 100 000 people for (A) anxiety, (B) depression, (C) mental illness, (D) mood disorders, (E) self-injury, (F) substance use disorder, and (G) suicide.

3.2 Greenspace

Western and Eastern NC have the highest density of public greenspace (Figure 2). Western NC is home to the Pisgah National Forest while Eastern NC has Croatan National Forest and multiple Fish and Wildlife and Game preserves.[30] Private greenspace is dispersed more evenly throughout the state. The highest density of private greenspace occurs in the central region of the state, where there is less identified public greenspace (Figure 2). Throughout the state, 203 ZIP Codes do not have any identified public greenspace and one ZIP Code does not have identified private greenspace.

3.3 Rurality

Rural and urban ZIP Codes are distributed throughout the state (Figure 1). The majority of populated ZIP Codes in NC (453 out of 802) were classified as urban neighborhoods, while slightly fewer (349 out of 802) were identified as rural. Central NC has the highest density of urban ZIP Codes, corresponding to the three major urban centers in the state. Eastern NC has the highest density of rural ZIP Codes, though western NC also has large rural pockets (Figure 1).

3.4 Regression analysis

Rural greenspace and mental health outcomes were spatially autocorrelated. Spatial error regression illustrated that greenspace benefits mental health in rural communities after adjusting for population, income, and race (Table 2). Given that all regression coefficients are negative, this indicates that per unit increase in greenspace/person, mental health case counts decrease. Examining the magnitude of the regression coefficients, we see that private greenspace had a stronger influence on all mental health outcomes in rural communities, though increases in public greenspace/person still corresponded with reduced case counts across mental health indicators. In rural neighborhoods, when comparing across the seven indicators, self-injury case counts decreased the most with an increase in public greenspace (B=-0.028, p-value<0.001), while substance abuse decreased the most with an increase in private greenspace (B=-1.661, p-value<0.001). An increase in both public and private greenspace also reduced suicide mortality in rural communities, with private having a stronger influence (B=-0.972, p-value<0.001) than public (B=-0.012, p-value<0.001). R^2 values highlight that the quantity of public greenspace per person explains 1.2-10.6% of the variability in all mental health ED visits in rural communities, while the quantity of private greenspace per person explains 9.9-21.2% of ED visit variability, with greenspace quantity explaining the most variability in self-injury case counts (Table 2).

[INSERT TABLE 2 HERE]

Table 2. OLS and spatial error regression results for greenspace per person and mental health outcomes, adjusted for race (% white) and income (% households making >= $125,000/year).

	Urban Private	Urban Public	Rural Private	Rural Public
Anxiety				
Estimate	-2.572	-0.212	-1.530	-0.025
Standard Error	0.284	0.088	0.243	0.009

Z Value	-	-	-7.322	-2.906
R^2	0.165	0.026	0.147	0.039
P Value	<0.001	0.016	<0.001	0.004
Depression				
Estimate	-2.560	-0.210	-1.504	-0.026
Standard Error	0.283	0.087	0.218	0.009
Z Value	-	-	-6.940	-2.920
R^2	0.175	0.037	0.132	0.036
P Value	<0.001	0.016	<0.001	0.004
Mental Illness				
Estimate	-2.482	-0.209	-1.591	-0.023
Standard Error	0.279	0.086	0.217	0.009
Z Value	-	-	-7.841	-2.647
R^2	0.182	0.050	0.178	0.053
P Value	<0.001	0.015	<0.001	0.008
Mood Disorders				
Estimate	-2.607	-0.223	-1.628	-0.027
Standard Error	0.282	0.087	0.211	0.009
Z Value	-	-	-7.707	-3.034
R^2	0.179	0.037	0.165	0.048
P Value	<0.001	0.011	<0.001	0.002
Self Injury				
Estimate	-2.599	-0.286	-1.523	-0.028
Standard Error	0.273	0.084	0.198	0.008
Z Value	-	-	-7.708	-3.289
R^2	0.251	0.122	0.212	0.106
P Value	<0.001	<0.001	<0.001	<0.001
Substance Abuse				
Estimate	-2.467	-0.204	-1.661	-0.021
Standard Error	0.284	0.087	0.205	0.009
Z Value	-	-	-8.115	-2.420
R^2	0.179	0.052	0.183	0.046
P Value	<0.001	0.019	<0.001	0.016
Suicide				
Estimate	-2.021	-0.138	-0.972	-0.012
Standard Error	0.224	0.069	0.159	0.007
Z Value	-	-	-6.110	-1.860
R^2	0.187	0.047	0.099	0.012
P Value	<0.001	0.046	<0.001	0.063

Urban greenspace and mental health outcomes were not spatially autocorrelated. OLS regression found that greenspace benefits all mental health outcomes in urban communities (Table 2). As with rural areas, the relationship was stronger with private greenspace, though public greenspaces still significantly benefited mental health in urban neighborhoods. In urban neighborhoods, mood disorder occurrence decreased the most with increased private greenspace/person (B=-2.607, p-value<0.001), and self-injury decreased the most as public greenspace/person increased (B=-0.286, p-value<0.001). Both public and private greenspace reduced suicide morality in urban communities. Increased private greenspace reduced suicide mortality more (B=-2.021, p-value<0.001) than public (B=-0.138, p-value: 0.046). R^2 values illustrate that the quantity of public greenspace per person explains 2.6-12.2% of variability in mental health ED case counts, while quantity of private green space per person explains 16.5-25.1% of the variability in ED visit variability (Table 2).

5. Discussion

Similar to prior research, our findings demonstrate that greenspace, identified as either public or private, benefits mental health in both rural and urban neighborhoods in North Carolina.[8,46,47] The greenspace-mental health relationship was strongest in urban areas, with private greenspace having the greatest influence on mental health outcomes. In rural areas, private greenspace was also found to be more beneficial for mental health outcomes than public greenspaces.

In urban neighborhoods, private greenspace was associated with a reduced mental health burden for all outcomes compared to public greenspace per person. This finding is surprising, as past research has illustrated that public, or usable, greenspaces are especially important for mental

health outcomes in urban communities.[18,48] Public greenspace still proved to be beneficial for all mental health outcomes in urban neighborhoods, though the relationship was not as strong as that for private greenspace. The strong relationship with private greenspace in urban communities could partly be explained by the development pattern of North Carolina cities. North Carolina cities, as with many cities in the Southeast, are automobile-dominated.[49,50] As such, most commuters drive in their cars rather than biking or walking.[49] It is possible that urban dwellers in NC interact with and access more private greenspaces than residents in non-car dominated cities, such as those in the United Kingdom and the Netherlands, where a majority of greenspace research has been conducted.[2] Despite illustrating a slightly different public greenspace-mental health relationship, this analysis illustrates that increasing quantity of greenspace corresponds to significant reductions in poor mental health outcomes and suicide mortality in urban neighborhoods.

A similar relationship was present in rural neighborhoods, with private greenspace benefiting mental health outcomes more than public. This finding supports previous research illustrating that private greenspace benefits mental health in rural communities.[10,20,51] Ekkel and de Vries[20] hypothesize this is because of the large amount of private greenspace in rural neighborhoods, including agricultural fields and private lawns, which provide many of the benefits associated with public greenspaces. Additional literature has corroborated that agricultural lands[51], and forested land cover[10] benefit mental health in rural areas. As such, public greenspace is thought to have less of an impact on mental health in rural areas because of the wide availability of private greenspaces.

Past greenspace mental health research has considered anxiety[8,46,52], depression[8,53], mood disorders[46,52] and general mental health and wellbeing (mental illness)[6,54–56] as indicators of mental health. This analysis found similar relationships between quantity of greenspace and a reduction in any mental health diagnosis; mood or anxiety disorders, depression, and mental illness, in addition to less commonly studied indicators, such as substance abuse, self-injury, and suicides, adding further evidence to the protective nature of greenspace for mental health.

This study considered mental health outcomes not regularly studied in the literature, including substance abuse, self-injury, and suicide. These mental health outcomes decreased with an increased quantity of greenspace, both public and private. In urban neighborhoods, self-injury had the greatest decrease in ED visits with increased public greenspace, which suggests that greenspace has the greatest protection for extreme mental health outcomes, though strong protective effects were observed for all included mental health indicators. We observed a similar protective benefit for rural public greenspace. This finding is further supported by the observed decrease in suicides as quantity of both public (significant at $p<0.10$) and private greenspace increased.[19,57] For urban private greenspace, substance abuse had the strongest relationship. Substance abuse case counts also decreased the most with increased private greenspace in rural communities. This finding supports recent research illustrating that greenspace, in conjunction with pharmacotherapy, can be effective as treatment for addiction[58], and that greenspace may reduce addiction-related cravings.[59] These findings suggest that, in urban and rural communities, increased quantities of both public and private greenspace benefit multiple mental health outcomes, including those not often considered in greenspace analyses.

5.1 Implications

The quantity of private and public greenspace per person across urban and rural communities explained a significant portion of the variability in mental health-related ED visits in NC. These results support greenspace as a low-cost nature-based intervention in urban and rural neighborhoods. Given that North Carolina has a current shortage of mental health care facilities per person, indicating an under addressed unmet need for more mental health services[25], consideration of low-cost mental health interventions is important. As this analysis demonstrated; greenspace may act as a low-cost mental health intervention and can explain a substantial amount of the variability observed in neighborhood mental health burdens. As such, policy-makers in NC need to focus on developing greenspaces in low-income, predominantly minority communities to ensure equitable access to this mental health resource; in both urban and rural communities. Particular attention should be directed to ensuring greenspace development does not result in the displacement of residents. This analysis illustrates the importance of both public and private greenspaces for reducing the burden of mental health outcomes throughout the state.

5.2 Strengths and Limitations

This article is strengthened by the inclusion of multiple mental health indicators and the consideration of rurality and greenspace type. We were able to move beyond subjective survey responses that are privy to recall bias and measure mental health diagnosis using a universal standardized coding classification. Little research has addressed greenspace and mental health in rural communities, and as this analysis illustrates, greenspace may serve as a protective factor or buffer of mental health in both rural and urban communities. Consideration of greenspace type

(public vs private) illustrates that type of greenspace is important to consider, as the strength of relationships varied between public and private greenspaces.

This study is also limited. Given that private greenspace was defined as all green land cover not identified in the public greenspace analysis, it is possible that private greenspace has been overestimated in this study. This may further explain the stronger relationships observed with private greenspace, in both urban and rural settings. This is an ecological analysis and therefore did not consider additional individual-level factors that may influence the greenspace-mental health relationship. Future analyses should include additional measures of greenspace (e.g. accessibility and quality), in addition to community level variables (e.g. structural racism, economic disparity), and individual-level factors (e.g. race and ethnicity, age). In addition, this analysis considered rurality as a binary (rural vs urban). To better understand the intricacies of the greenspace-mental health relationship, future research should further investigate this relationship with consideration of suburban neighborhoods, micropolitan areas, and small towns, in addition to urban centers and rural communities.

6. Conclusions

This analysis illustrates that greenspace is a protective factor in reducing the risk of ED visits for extreme mental health conditions, such as self-injury and suicide, addiction-related mental health outcomes, like substance abuse, and more common mental health indicators, including anxiety, depression, and mental illness in North Carolina. This association remained true for both public and private greenspaces in rural and urban neighborhoods. Private greenspace had the strongest relationship with mental health outcomes, though public greenspaces also benefited mental

health, more so in urban areas than rural. This analysis provides new knowledge on the greenspace mental health relationship, specifically for less frequently studied mental health indicators, including self-injury, suicide, and substance abuse. Our work illustrates the importance of both public and private greenspaces as low-cost mental health interventions. These findings can be applied to public policy and help illustrate the importance of low-cost, nature-based mental health interventions.

Figure Legend

Figure 1. Map of North Carolina illustrating rurality, select urban centers and the 3 dominant regions: mountains, piedmont, and coast.

Figure 2. Map of (A) public greenspace and (B) private greenspace in North Carolina.

Figure 3. Annual mental health outcomes per 100,000 people for (A) anxiety (B) depression (C) mental illness (D) mood disorders (E) self-injury (F) substance abuse and (G) suicide.

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