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RESEARCH ARTICLE

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Key Points:

- Greenspace is associated with lower mental health prevalence among young people
- Greenspace interventions need to consider community structures, specifically rurality
- The highest prevalence of substance use disorders occurred in communities with low greenspace quantity and low greenspace accessibility

Supporting Information:

Supporting Information may be found in the online version of this article.

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Advancing Understanding on Greenspace and Mental Health in Young People

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Abstract Mental distress among young people has increased in recent years. Research suggests that greenspace may benefit mental health. The objective of this exploratory study is to further understanding of place-based differences (i.e., urbanity) in the greenspace-mental health association. We leverage publicly available greenspace data sets to operationalize greenspace quantity, quality, and accessibility metrics at the community-level. Emergency department visits for young people (ages 24 and under) were coded for: anxiety, depression, mood disorders, mental and behavioral disorders, and substance use disorders. Generalized linear models investigated the association between greenspace metrics and community-level mental health burden; results are reported as prevalence rate ratios (PRR). Urban and suburban communities with the lowest quantities of greenspace had the highest prevalence of poor mental health outcomes, particularly for mood disorders in urban areas (PRR: 1.19, 95% CI: 1.16–1.21), and substance use disorders in suburban areas (PRR: 1.35, 95% CI: 1.28–1.43). In urban, micropolitan, and rural/isolated areas further distance to greenspace was associated with a higher prevalence of poor mental health outcomes; this association was most pronounced for substance use disorders (PRRUrban: 1.31, 95% CI: 1.29–1.32; PRRMicropolitan: 1.47, 95% CI: 1.43–1.51; PRRRural 2.38: 95% CI: 2.19–2.58). In small towns and rural/isolated communities, poor mental health outcomes were more prevalent in communities with the worst greenspace quality; this association was most pronounced for mental and behavioral disorders in small towns (PRR: 1.29, 95% CI: 1.24–1.35), and for anxiety disorders in rural/isolated communities (PRR: 1.61, 95% CI: 1.43–1.82). The association between greenspace metrics and mental health outcomes among young people is place-based with variations across the rural-urban continuum.

Plain Language Summary Poor mental health outcomes are increasing among young people, stressing the need for community-level mental health interventions. This analysis explored the association between greenspace and mental health prevalence among young people. Our analysis found that greenspace is associated with lower mental health prevalence. However, the most effective greenspace interventions (i.e., improving greenspace access, increasing greenspace quantity) may vary with rurality. Greenspace quantity interventions may be most beneficial in urban and suburban neighborhoods; greenspace accessibility interventions may benefit mental health in urban, micropolitan, and rural/isolated areas, and greenspace quality interventions aimed at increasing biodiversity should focus on small towns and rural/isolated communities.

1. Introduction

Poor mental health among adolescents, including depression (Keyes et al., 2019; Thorisdottir et al., 2017), anxiety (Duffy et al., 2019; Eisenberg, 2019; Thorisdottir et al., 2017), self-harm, and suicide (Duffy et al., 2019; Eisenberg, 2019) have increased substantially in recent years in the United States. Observed increases in poor mental health outcomes among children, adolescents, and young adults have been especially pronounced for females (Keyes et al., 2019; Mercado et al., 2017; Thorisdottir et al., 2017), individuals who identify as LGBTQ+ (Fish et al., 2021; Ormiston & Williams, 2022), adolescents of color (Lindsey et al., 2019), and Hispanic individuals (Runkle et al., 2021). To better inform targeted mental health interventions, additional research into widely available community mental health resources, such as greenspace, are needed for this population.

Past greenspace mental health research among the general population (i.e., individuals of all ages) has found greenspace is associated with population-level reductions in anxiety (Beyer et al., 2014; de Vries et al., 2016; Nutsford et al., 2013), depression (Beyer et al., 2014; McEachan et al., 2016), mood disorders (de Vries et al., 2016; Nutsford et al., 2013) and general mental health and wellbeing (mental illness) (Feng & Astell-Burt, 2017a; Houlden et al., 2019; Wheeler et al., 2015; Zhang et al., 2020). Additionally, increases in greenspace

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quantity may be beneficial for addiction treatments and helping reduce addiction-related cravings (Berry et al., 2021; Martin et al., 2019). Among children, recent research has focused on investigating the associations between greenspace exposure and childhood mental well-being through the lens of attention and behavior (Bijnens et al., 2022; Luque-García et al., 2022). Findings suggest greenspace is associated with better attention, both in terms of focusing on one specific task and the ability to continue focusing despite external distractions, among adolescents (ages 13–17) (Bijnens et al., 2022). Further research suggests that contact with greenspace may be beneficial for child neurological development (Luque-García et al., 2022), and prolonged exposure to greenspace in childhood and adolescence is associated with a lower risk of developing psychiatric disorders in adulthood (Engemann et al., 2019). Contextual factors (e.g., back-yard, perceived safety) (Mueller et al., 2023; Zhang et al., 2020, p. 202) impact this association, stressing the need for place-based greenspace and mental health analyses.

A growing body of research considering multiple greenspace metrics (i.e., greenspace quality, quantity, accessibility) suggests that greenspace quality (measured as user-perceived) (Feng & Astell-Burt, 2017a, 2017b; Feng et al., 2020; Lyons et al., 2018), and accessibility (measured as availability of greenspace) (Markevych et al., 2014; Zach et al., 2016) may be more important than neighborhood greenspace quantity for children, adolescents and young adults mental wellbeing. Findings further indicate that the association between greenspace and mental health may change as individuals age through adolescence and young adulthood. Feng and Astell-Burt (2017a) suggest that the mental health benefits of greenspace for young people strengthen as youth transition into adolescence and young adulthood, and that greenspace quality is especially important in this relationship.

Greenspace analyses investigating the role of the rural-urban continuum suggest that urban areas have far better accessibility to public greenspaces (Wolff et al., 2020). In contrast, rural communities tend to have a higher prevalence of private home gardens and backyards (Dennis & James, 2017). Furthermore, Shanahan et al. (2017) found that urban communities with more public greenspaces tended to use greenspace at higher rates and reported more satisfaction with the public greenspaces than urban communities with a lower prevalence of public greenspaces. Among children, higher quantities of public greenspace in urban areas were associated with higher intelligence and lower prevalence of externalizing behaviors (e.g., aggression). However, this association was not significant in suburban or rural communities, suggesting place may play an important role (Bijnens et al., 2022). Little research has been conducted investigating the mental health of young people with regard to greenspace across the rural-urban continuum.

This ecological study aims to further the understanding of the greenspace-mental health association among young people in five distinct urbanities (i.e., urban, suburban, micropolitan, small towns, rural/isolated). We apply publicly available greenspace data sets, which were used to generate greenspace quantity, quality, and accessibility metrics. We hypothesize that place plays an essential role in the greenspace-mental health association among young people; such that neighborhoods with higher quantities and better accessibility of greenspace will be associated with a lower prevalence of poor mental health outcomes; particularly in urban and metropolitan neighborhoods. We further hypothesize that neighborhoods in small towns and rural communities with better greenspace quality will lower the prevalence of poor mental health outcomes among young people. The exploration of multiple greenspace metrics, in addition to an administrative emergency-department mental health data set, furthers understanding of the greenspace-mental health association. Furthermore, considering a suite of mental health outcomes (i.e., mood disorders, anxiety, substance use disorders) provides important context for targeted health interventions. Given that greenspace may function as widely available and publicly accessible preventative mental health care, a better understanding of these associations and how they vary with rurality is critical.

2. Methods

2.1. Study Area

North Carolina is a state in the southeastern United States characterized by a humid climate, with hot summers and moderately cold winters (Kunkel, 2022) and varied topography, with the Appalachian Mountains in the western region of the state, and the Atlantic Ocean on the eastern edge of the state. North Carolina is home to 10.4 million residents, of which 62.2% are white, 20.5% are Black or African American, and 10.7% identify as Hispanic or Latino (US Census, 2022). Young people (individuals 24 and under) make up 33.8% of the state population (US Census, 2022). In North Carolina, mental health providers can meet only 13% of the state's mental health care needs, compared to 27.7% nationally (KFF, 2021), further highlighting the need for community-level mental health interventions to reduce these mental health care needs.

2.2. Health Data

Mental health outcomes were derived from emergency department (ED) visit data, which were obtained from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) (NC DETECT, 2021) for 2016–2019 through an ongoing data use agreement. NC DETECT provides complete spatial coverage (includes data from all EDs in North Carolina) and temporal coverage (includes patients' date of admission to the ED) of ED visits in North Carolina (NC DETECT, 2021). NC DETECT data has been used in a variety of studies, including identifying spatial trends in mental health (Ryan et al., 2022; Sugg et al., 2022), extreme heat and ED visits (Fuhrmann et al., 2016; Kovach et al., 2015; Sugg et al., 2016), and investigating air mass type and migraine risk (Elcik et al., 2017). NC DETECT data has been validated as an accurate state-wide health data set (Hakenewerth et al., 2009). For this analysis, data were restricted to ED visits of individuals aged 24 and younger, producing a data set of 5,357,703 total ED visits between January 2016 and December 2019, of which 575,536 (10.7%) were related to a mental health or behavioral concern.

Using the provided International Classification of Diseases 10-CM codes (ICD-10), ED data were coded (SM Table 1) to isolate five mental health outcomes: (a) anxiety, (b) depression, (c) mental and behavioral disorders (an aggregated category including any mental health or behavioral concern), (d) mood disorders, and (e) substance use disorders. Substance use disorders included any substance-related ED visit (i.e., alcohol, opioids, etc.). Mental and behavioral disorders include any mental-health related concern, such as anxiety, depression, mood disorder, and substance use disorder visits.

The unit of analysis was the Zip Code Tabulation Area (ZCTA) level, which is the finest spatial resolution available for the NC DETECT health data set. ZCTA's are a US Census Bureau spatial geography relating to mailing postal codes, which do not always have a spatial component (i.e., P.O. Box zip codes) (US Census Bureau, 2022). As such, individual ED data was converted from zip code (U.S. postal service) to ZCTA (U.S. Census geography) when appropriate (AAFP, 2022). ZCTAs are considered a categorization of a neighborhood when examining neighborhood and health associations (Duncan & Kawachi, 2018), and have been shown to capture community health patterns more accurately, compared to county-level analyses (Jones & Kulldorff, 2012). In NC, there are 802 ZCTAs, which have a median area of 115 km^2 (SD 147 km^2). Mental health outcomes were coded in RStudio, version 2022.07.1 (RStudio Team, 2022).

2.3. Greenspace Data

For this analysis, greenspace was identified using two publicly available greenspace data sets: the Protected Area Database of the United States (PAD-US) (USGS, 2020) and the Trust for Public Land's ParkServe data set (The Trust for Public Land, 2021) (Figure 1). PAD-US is a spatial shapefile data set with polygons delineating the boundaries of all government-managed lands (e.g., wildlife refuges, national forest land, historical sites); data was collected in 2019. Following guidance from Browning et al. (2022), greenspace selection was restricted to remove any non-public greenspaces (e.g., military bases, indigenous lands) from the spatial data set, producing a data set of publicly accessible government-managed greenspaces (Browning et al., 2022; Runkle, Matthews, et al., 2022). ParkServe is a spatial shapefile data set comprising polygons outlining the boundaries of all public parks (e.g., local and city parks) (The Trust for Public Land, 2021); data was collected in 2020. No additional selection criteria were applied to the ParkServe data set. Both data sets were combined to create one spatial greenspace data set, depicting the boundaries of all publicly accessible greenspaces in NC, in ArcGIS Pro 3.0.0 (ESRI, 2022) (Figure 1). This combined spatial data set was used to generate the following greenspace metrics for each community (i.e., ZCTA):

1. **Greenspace quantity** considers the total amount of public greenspace per ZCTA. For this analysis, greenspace quantity was operationalized as two metrics: (a) *Percent Greenspace* and (b) *Greenspace per person* (Runkle, Matthews, et al., 2022) (Table 1). Calculations were made in ArcGIS Pro 3.0.0 (ESRI, 2022).
2. **Greenspace accessibility** was operationalized as one metric: *Greenspace distance* (Table 1), determined as the distance to the nearest greenspace from the population-weighted mean center of each ZCTA. Calculations were made in ArcGIS Pro 3.0.0 (ESRI, 2022).

Table 1
Summary of Greenspace Metrics Considered in This Analysis

Greenspace Metric	Operationalized at ZCTA[a]	Calculated Using	Data Source(s)	Exclusion Criteria	Hypothesized Association
Greenspace quantity					
Percent Greenspace	Percent greenspace land cover	Tabulate Intersection	PAD-US and ParkServe	Excluded due to multicollinearity with Greenspace per Person	Higher quantities of percent greenspace will be associated with a lower incidence of poor mental health
Greenspace per Person	Greenspace area/individual 24 and younger	Tabulate Intersection; total area of greenspace divided by total population (24 and younger)	PAD-US, ParkServeACS 2018		Higher quantities of greenspace per person will be associated with a lower incidence of poor mental health
Greenspace Accessibility					
Greenspace Distance	Distance to nearest greenspace from population weighted mean center	Euclidean Distance	PAD-US and ParkServe		Shorter distances to greenspace will be associated with a lower incidence of poor mental health
Greenspace quality					
Average Google Review	Average of available google reviews (0–5) of greenspaces	Reviews manually retrieved from google.com; averaged	Google	Included in state-wide model, excluded from stratified, effect modification analyses; not standardized	Higher average google reviews will be associated with a lower incidence of poor mental health
Nearest Google Review	Google review (0–5) of nearest greenspace from population weighted centroid	Reviews manually retrieved from google.com	Google, PAD-US and ParkServe	Included in state-wide model, excluded from stratified, effect modification analyses; not standardized	Higher near google reviews will be associated with a lower incidence of poor mental health
Perimeter Area Ratio (PAR)	Ratio of total greenspace perimeter to total greenspace area	Determined the perimeter using Summarize Within, divided the perimeter by the area of public greenspace	PAD-US and ParkServe		Lower PAR values (higher quality) will be associated with a lower incidence of poor mental health

[a]ZCTA: All operationalized metrics are calculated for each Zip Code Tabulation Areas (ZCTA) unit.

3. **Greenspace quality** was operationalized as three metrics: (a) *Perimeter: Area Ratio (PAR)*, (b) *Average Google Review*, and (c) *Nearest Google Review* (Table 1). The PAR was included to capture greenspace patchiness (Fonseca, 2008), which serves as a proxy for biodiversity, with a lower PAR indicating less greenspace patchiness, which can benefit flora and fauna in natural spaces (Helzer & Jelinski, 1999). For this analysis, a low PAR value was considered indicative of higher quality greenspace—as the perimeter length is substantially less than the area—suggesting the greenspace is not disrupted with intermittent development (e.g., road). ZCTAs with no public greenspace were categorized as poor quality. The *average Google review* was calculated by averaging all available average greenspace Google reviews for each ZCTA, producing one value for each ZCTA. The *nearest Google review* was determined by identifying the nearest greenspace's average Google review from the population-weighted mean center of each ZCTA (see greenspace accessibility) (Table 1) (SM Figure 3).

2.4. Covariates

Analyses were adjusted for ZCTA race and socio-economic status using the Index of the Concentration of Extremes (ICE) (Krieger et al., 2016), a series of indicators derived by analyzing the spatial distribution of income and race using US Census Data (US Census, 2018), producing community-level race and income metrics (Krieger et al., 2016). The first metric, **ICE: Income**, measures community income extremes by comparing how many

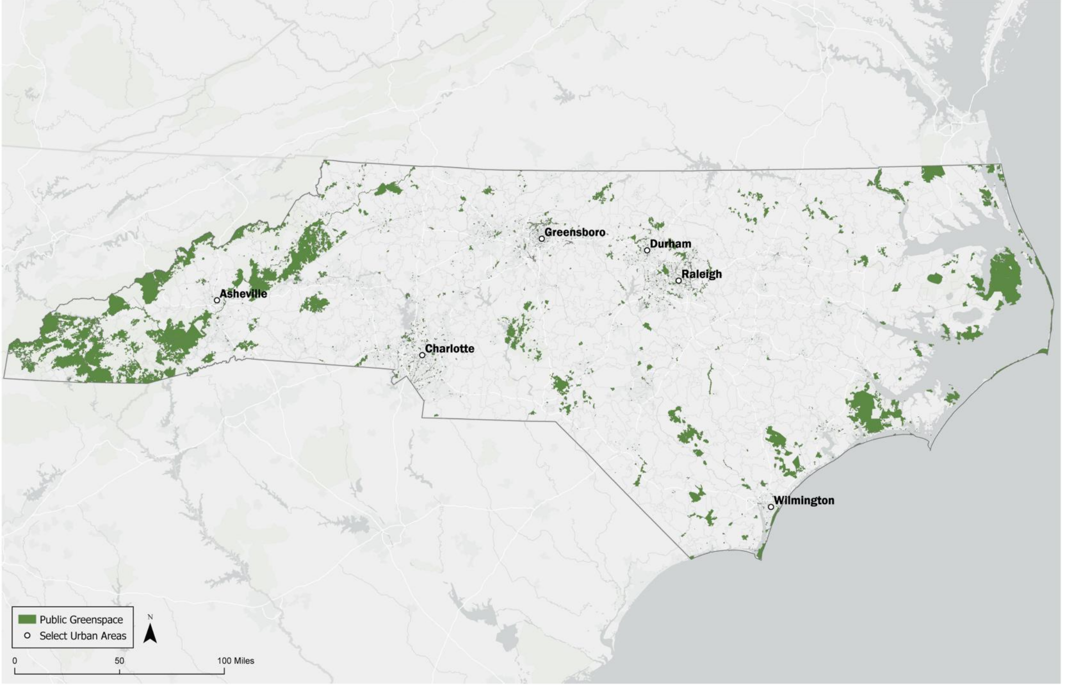

Figure 1. Map depicting the spatial distribution of public greenspace in North Carolina. Greenspace data is from the Protected Area Database of the United States (PAD_US) and the Trust for Public Land's ParkServe data set.

households make over $100,000 per year to how many make under $25,000 per year. The second metric, **ICE: Race**, captures the racial composition of a community by comparing the number of Black residents to the number of white residents. ICE metrics were operationalized as tertiles (Dyer et al., 2022; Krieger et al., 2016; Wallace et al., 2019): (a) predominately low income (ICE: Income) and predominately Black (ICE: Race), (b) mixed-income (ICE: Income) and mixed race (ICE: Race), and (c) predominantly high income (ICE: Income) and predominantly white (ICE: Race) (SM Figure 1).

Mental Health Professional Shortage Areas (MHPSA) (Health Resources & Services Administration, 2023) data was included to adjust for community mental health care access. MHPSA data was included as a binary variable, where each ZCTA is either located in an MHPSA (1) or not (0) (SM Figure 2).

The greenspace-mental health association may vary with rurality (Jiang et al., 2021; Ryan et al., 2023). Rurality was included using Rural-Urban Commuting Area (RUCA) codes at the ZCTA-level. RUCA codes range from 1 to 10. This analysis followed RUCA divisions provided by the U.S. Department of Agriculture (USDA) and operationalized rurality with five classifications, where RUCA code 1 was considered urban, RUCA codes 2–3 were considered suburban, RUCA codes 4–6 were considered micropolitan, RUCA codes 7–9 were considered small towns, and RUCA code 10 was considered rural/isolated (USDA, 2020) (Figure 2).

Age categories were considered to see if the greenspace-mental health association changes with age (Feng & Astell-Burt, 2017a). Three age categories, based on US Census age categories (US Census Bureau, 2020), were created to capture childhood (ages 14 and under), adolescence (ages 15–17), and young adulthood (ages 18–24).

Sex was included, where data were categorized as ED visits among males and ED visits among females to see if sex influences the greenspace-mental health association (Sillman et al., 2022).

2.5. Variable Importance

Machine learning was employed to quantify variable importance. Variable importance was determined using the generalized linear model (GLM) elastic net regression (GLMNET) function from the “caret” package in RStudio version 2022.07.1 (RStudio Team, 2022). GLMNET models were run with a Poisson distribution and included greenspace area per person, distance to nearest greenspace, and the perimeter: area ratio; the tune Length was set

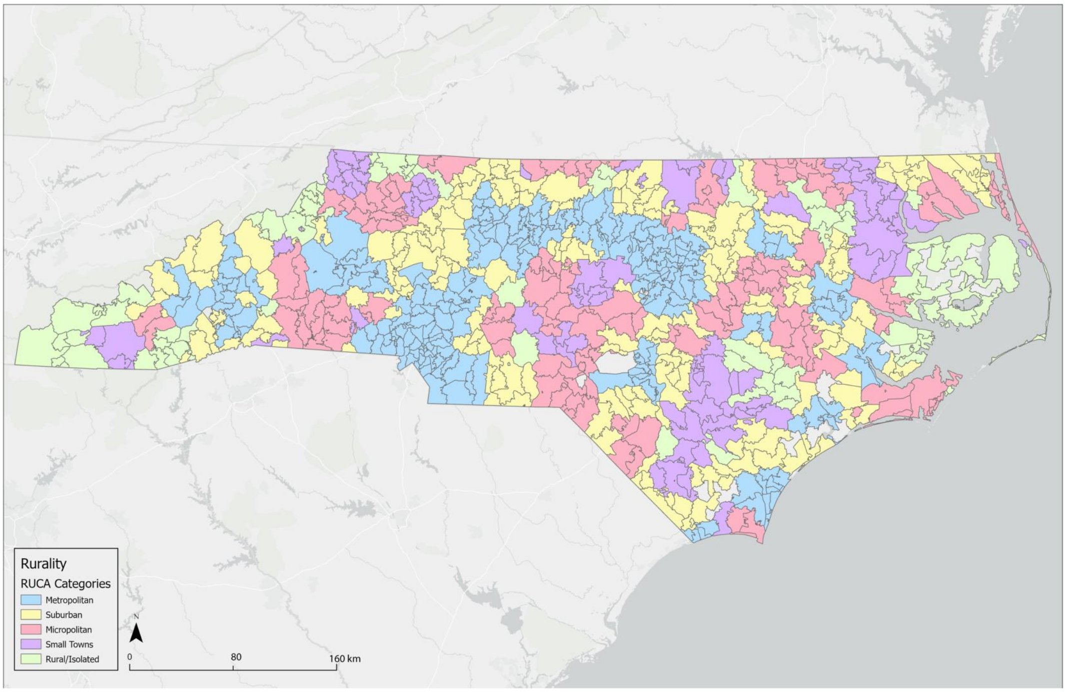

Figure 2. Map indicating the spatial distribution of urban, suburban, micropolitan, small towns, and rural/isolated Zip Code Tabulation Areas. Rurality designations were determined using U.S. Department of Agriculture Rural-Urban Commuting Area codes.

to three as there were three independent variables. Figure S4 in Supporting Information S1 depicts GLMNET results.

2.6. Statistical Analysis

This analysis employed GLMs with a Poisson distribution to analyze the association between community-level mental health prevalence (i.e., total cases per ZCTA, 2016–2019) and greenspace quantity, quality, and accessibility in North Carolina. Stratified analyses were employed to investigate the presence of effect modification by (a) Rurality, (b) Age, and (c) Sex.

GLMs were run to assess if greenspace is associated with community-level mental health outcomes among individuals aged 24 and younger. All five greenspace metrics were considered in the state-wide analysis, and one model was run for each mental health outcome, producing five total models. Models were run such that communities with poor or moderate greenspace quantity, quality and accessibility were compared to those with high greenspace quantity, quality, and accessibility (reference) (Table 1), so as to assess the changing prevalence of mental health outcomes at the community level. High, moderate, and low greenspace metrics were determined by creating tertiles. Due to multicollinearity, percent greenspace was removed from these models in favor of greenspace per person. The Google review-based quality metrics were included in the state-wide analysis but excluded from effect modification analyses as the availability of Google review data was skewed to urban areas.

Stratified GLMs were run to investigate the effect modification of rurality. Age and sex-stratified models were included as a supplemental analysis. Models were run for each rurality designation and each mental health outcome (30 models); each age group and each mental health outcome (18 models); and each sex and mental health outcome (12 models). For the stratified effect-modification analyses, Average Google review and Nearest Google review were removed in favor of the PAR metric, as it is a more standardized measure of greenspace quality.

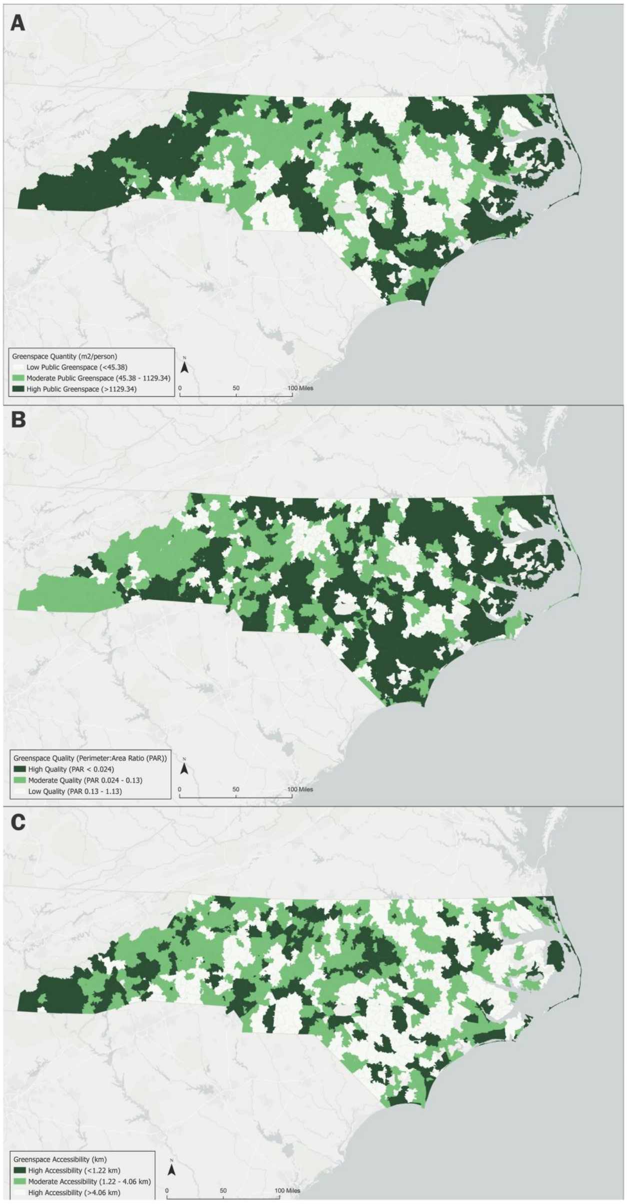

Figure 3. Distribution of greenspace quantity, quality and accessibility. Greenspace metrics are displayed in tertiles.

All GLMs were adjusted for race, income, population, and MHPSA designation. All greenspace metrics and the ICE index metrics were included in the GLMs as tertiles to improve interpretation. MHPSA data was included as a binary, and the population was included as a continuous variable.

Multicollinearity was considered by calculating the Variance Inflation Factor to identify the best model (VIF < 2) (Craney & Surles, 2002; James et al., 2013). The percent greenspace metric was removed for violating the assumption of independence. Models considering all greenspace metrics and sociodemographic factors had the lowest AIC values (Bozdogan, 1987).

3. Results

3.1. Demographic Summary

Table 2 summarizes the demographic characteristics for all ED visits and for each mental health-related ED visit. Overall, there were 5,357,703 total ED visits. ED visits for any mental health concern were highest among females (51.5%–67.7%), white individuals (60.7%–69.6%), and young adults aged 18–24 (48%–92.2%). The most prevalent mental health outcome was substance use disorder followed by anxiety and depression. SM Table 2 reports mental health prevalence by rurality.

3.2. Greenspace Metric Distribution

Throughout North Carolina, greenspace quantity is highest in the western and eastern regions of the state (Figure 3). Southwestern NC and the urban centers of Charlotte, Durham, and Greensboro have the best community-level greenspace access, and many ZCTAs in eastern NC have the worst greenspace access. Greenspace quality, operationalized as the perimeter: area ratio, is the best in eastern NC (smaller PAR values) and worst in western NC (higher PAR values).

3.3. Generalized Linear Models

Table 3 reports state-wide GLM results; all results are reported as prevalence rate ratios (PRRs), indicating the prevalence of each mental health outcome with relation to the variables of interest, compared to the reference group (i.e., communities with high greenspace quantities, better greenspace accessibility, high greenspace quality). PRRs are the equivalent of odds ratios for cohort studies (Tamhane et al., 2016). All five greenspace metrics were included in the state-wide analyses. ZCTAs with low or moderate greenspace quantity (greenspace area/person) were associated with higher PRRs for all mental health outcomes; depression was associated with up to 1.37 (CI: 1.34–1.40) higher prevalence as compared to the ZCTAs with the greatest quantity of public greenspace. Living in ZCTAs with moderate greenspace accessibility were associated with higher prevalence of all mental health outcomes; this increase was highest for anxiety (PRR: 1.28, CI: 1.26–1.30). Moderate greenspace quality was significantly associated with anxiety (PRR: 1.03, CI: 1.01–1.05). ZCTAs with lower reviews of the nearest greenspace were associated with higher PRRs across all mental health outcomes; substance use disorder had the largest PRR values (PRR: 1.33, CI: 1.32–1.34).

3.3.1. Rurality-Stratified

In both urban and suburban ZCTAs, ZCTAs with less greenspace quantity were associated with higher PRRs for all mental health outcomes, as compared to ZCTAs with more greenspace quantity (Table 4). In urban areas, mood disorders saw the greatest increase in prevalence, with mood disorders 19% higher (PRR: 1.19, CI: 1.16–1.21) in ZCTAs with little to no greenspace, and 33% higher (PRR: 1.33, CI: 1.30–1.35) in ZCTAs with moderate

Table 2
Demographic Characteristics of All Emergency Department (ED) Visits and Mental Health-Related ED Visits Among Individuals Ages 24 and Younger Who Visited a North Carolina ED (2016–2019)

	All ED visits *n* (%)	Anxiety *n* (%)	Depression *n* (%)	Mental and behavioral disorder *n* (%)	Mood disorder *n* (%)	Substance use disorder *n* (%)
ED visits	5,357,703 (100%)	97,447 (1.82)	86,924 (1.62)	575,536 (10.7)	119,434 (2.23)	350,277 (6.54)
Average age (SD)	12.49 (8.19)	19.02 (3.96)	18.43 (3.78)	19.13 (4.5)	18.56 (3.89)	21.03 (2.54)
Year						
2016	1,378,846 (25.7)	22,864 (23.5)	19,572 (22.5)	124,878 (21.7)	27,280 (22.8)	72,254 (20.6)
2017	1,371,847 (25.6)	24,300 (24.9)	22,512 (25.9)	150,371 (26.1)	30,745 (25.7)	94,530 (27.0)
2018	1,300,575 (24.3)	25,441 (26.1)	22,496 (25.9)	154,648 (26.9)	30,750 (25.7)	95,531 (27.3)
2019	1,306,435 (24.4)	24,842 (25.5)	22,344 (25.7)	145,639 (25.3)	30,659 (25.7)	87,962 (25.1)
Sex						
Male	2,427,180 (45.3)	31,962 (32.8)	28,581 (32.9)	270,723 (47.0)	42,711 (35.8)	169,465 (48.4)
Female	2,922,642 (54.6)	65,359 (67.1)	58,237 (67.7)	303,969 (52.8)	76,583 (66.7)	180,323 (51.5)
Other/unknown	7,881 (0.1)	126 (0.1)	106 (0.1)	58 (0.0)	140 (0.1)	488 (0.2)
Race						
Indigenous American	74,586 (1.5)	1,104 (1.2)	869 (1.0)	7,524 (1.4)	1,693 (1.5)	5,073 (1.5)
Asian/Pacific Islander	46,042 (0.9)	683 (0.7)	677 (0.8)	3,195 (0.6)	881 (0.8)	1,551 (0.5)
Black	1,902,890 (37.3)	21,098 (22.5)	20,305 (24.3)	175,678 (31.7)	29,168 (25.4)	111,377 (33.0)
White	2,556,293 (50.1)	65,187 (69.6)	56,585 (67.7)	338,448 (61.1)	76,668 (66.7)	204,927 (60.7)
Other	523,995 (10.3)	5,538 (5.9)	5,196 (6.2)	29,214 (5.3)	6,568 (5.7)	14,706 (4.4)
Age group						
Under 15	2,796,174 (52.2)	13,196 (13.5)	14,949 (17.2)	84,031 (14.6)	19,948 (16.7)	4,365 (1.2)
15–17	529,510 (9.9)	16,808 (17.2)	20,215 (23.3)	69,161 (12.0)	25,401 (21.3)	22,943 (6.5)
18–24	2,032,019 (37.9)	67,443 (69.2)	51,760 (59.5)	422,344 (73.4)	74,085 (62.0)	322,969 (92.2)

Note. Data is from NC DETECT.

greenspace quantity. Suburban areas indicate that as greenspace quantity decreases, mental health outcome prevalence increases. In suburban ZCTAs, the association with greenspace quantity was most pronounced for substance use disorders, with a 1.35 (CI: 1.28–1.43) higher prevalence of substance use disorders in ZCTAs with no greenspace, compared to those with the highest quantities of greenspace.

In urban, micropolitan, and rural/isolated areas, increasing distance to the nearest greenspace was associated with higher PRRs across all mental health outcomes. For urban and rural/isolated neighborhoods, this association was most pronounced for substance use disorders, with a 1.31 (CI: 1.29–1.32) higher prevalence in urban areas and a 2.38 (CI: 2.19–2.58) higher prevalence in rural/isolated areas. In micropolitan areas, poor and moderate greenspace accessibility were associated with higher PRRs; this association was greatest for substance use disorders, with 47% (CI: 1.43–1.51) higher prevalence of substance use disorders in ZCTAs with the worst greenspace accessibility, compared to those with the best greenspace accessibility (Table 4).

Both small towns and rural/isolated ZCTAs with worse greenspace quality (higher PAR values) were significantly associated with higher PRRs for all mental health outcomes, compared to ZCTAs with better greenspace quality. In small towns, this association was most substantial for substance use disorders, with 1.4 (CI: 1.33–1.47) higher PRR of substance use disorders in ZCTAs with the worst greenspace quality. In rural/isolated ZCTAs, this association was most pronounced for anxiety, with a 1.61 (CI: 1.53–1.82) higher prevalence of anxiety in ZCTAs with worse greenspace quality, as compared to ZCTAs with better greenspace quality (Table 4).

Table 3
State-Wide Generalized Linear Model Results Investigating the Relationship Between Greenspace Quantity, Quality and Accessibility, and Mental Health Outcomes Among Individuals Ages 24 and Under

	Anxiety		Depression		Mood		Mental and behavioral disorders		Substance Use disorder	
	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI
Greenspace quantity: area/person										
Low quantity (0–45.38 m^2)	0.91	0.89–0.93	0.89	0.87–0.92	0.93	0.91–0.95	0.89	0.88–0.89	0.84	0.83–0.85
Moderate quantity (45.92–1,129 m^2)	1.29	1.26–1.31	1.37	1.34–1.40	1.36	1.33–1.38	1.27	1.26–1.28	1.21	1.20–1.23
Reference: high quantity (>1,147 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (1.23–4.06 km)	1.28	1.26–1.30	1.21	1.19–1.23	1.2	1.18–1.22	1.22	1.22–1.23	1.21	1.20–1.22
Poor accessibility (4.09–21.6 km)	1	0.98–1.02	0.93	0.91–0.95	0.95	0.93–0.96	1.06	1.05–1.07	1.1	1.08–1.11
Reference high accessibility (0–1.22 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0.01–0.035)	1.03	1.01–1.05	1.01	0.99–1.03	0.99	0.97–1.00	0.97	0.97–0.98	1	0.99–1.01
Low quality (0.035–1.13)[a]	0.75	0.73–0.76	0.79	0.78–0.81	0.76	0.74–0.77	0.75	0.75–0.76	0.76	0.75–0.77
Reference: high quality (0–0.01)										
Greenspace quality: near review										
Low quality (0–4.6)	1.17	1.15–1.19	1.19	1.16–1.21	1.18	1.16–1.20	1.25	1.24–1.26	1.33	1.32–1.34
Moderate quality (4.6–4.8)	0.98	0.96–1.00	1.04	1.02–1.07	1.02	1.01–1.04	0.98	0.97–0.99	0.99	0.98–1.00
Reference: high quality (4.8–5)										
Greenspace quality: average review										
Low quality (0–4.05)	1.07	1.06–1.09	1.1	1.08–1.11	1.07	1.05–1.08	1.07	1.06–1.07	1.07	1.06–1.08
Moderate quality (4.06–4.55)	1.23	1.21–1.25	1.21	1.19–1.23	1.23	1.21–1.25	1.2	1.19–1.21	1.26	1.24–1.27
Reference: high quality (4.56–5)										
ICE: Income										
Low income	1.48	1.45–1.50	1.39	1.36–1.42	1.5	1.47–1.52	1.85	1.83–1.86	2.1	2.08–2.13
Mixed income	1.44	1.42–1.47	1.4	1.38–1.43	1.46	1.44–1.48	1.72	1.71–1.73	1.93	1.91–1.94
Reference: high income										
ICE: Race										
Predominately Black	0.81	0.79–0.82	0.88	0.86–0.90	0.96	0.94–0.97	1.05	1.04–1.06	0.97	0.96–0.98
Mixed race	1.08	1.06–1.10	1.13	1.10–1.15	1.16	1.14–1.18	1.19	1.18–1.20	1.13	1.11–1.14
Reference: predominately white										
MHPSA	1.14	1.08–1.20	1.14	1.08–1.20	1.16	1.11–1.22	1.2	1.17–1.23	1.29	1.25–1.34
Observations: 808										

[a]Includes ZCTAs with no public greenspace.

3.3.2. Age and Sex-Stratified

SM Table 3 reports age-stratified GLM results for the entire state of NC. Across all three age groups (14 and under, 15–17, and 18–24), ZCTAs with less public greenspace quantity (greenspace area per person) were significantly associated with higher prevalence of all mental health outcomes, compared to ZCTAs with more greenspace quantity. SM Table 4 reports sex-stratified GLM results for the entire state of NC. No substantial differences in the greenspace-mental health association were noted between males and females. A detailed explanation of age and sex results can be found in Supporting Information S1.

Table 4
Rurality-Stratified Generalized Linear Model Results Investigating the Association Between Greenspace Quantity, Quality, and Accessibility, and Mental Health-Related Emergency Department Visits Among Individuals Ages 24 and Under With Consideration of Urban, Suburban, Micropolitan, Small Towns, and Rural/Isolated Communities in NC (2016–2019)

	Anxiety		Depression		Mood		Mental and behavioral disorders		Substance use disorder	
	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI
Urban										
Greenspace quantity: area/person										
Low quantity (0–3.33 m^2)	1.13	1.10–1.15	1.17	1.14–1.19	1.19	1.16–1.21	1.14	1.13–1.15	1.17	1.16–1.18
Moderate quantity (4.49–136.9 m^2)	1.29	1.26–1.32	1.24	1.21–1.27	1.33	1.30–1.35	1.24	1.23–1.25	1.3	1.29–1.32
Reference: high quantity (>137 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (0.56–1.82 km)	1.01	0.99–1.03	0.98	0.96–1.00	0.98	0.97–1.00	1.11	1.11–1.12	1.12	1.11–1.13
TLow accessibility (1.89–10.7 km)	1.15	1.13–1.17	1.08	1.06–1.10	1.09	1.07–1.11	1.28	1.27–1.29	1.31	1.29–1.32
Reference high accessibility (0–0.53 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0.025–0.064)	1	0.99–1.02	0.97	0.95–0.99	0.99	0.98–1.01	1.04	1.03–1.04	1.08	1.07–1.09
Low quality (0.066–1.02)	0.8	0.79–0.82	0.77	0.76–0.79	0.77	0.76–0.79	0.82	0.81–0.83	0.83	0.82–0.84
Reference: high quality (0–0.02)										
ICE: Income										
Low income	1.72	1.68–1.76	1.64	1.60–1.68	1.75	1.71–1.78	2.23	2.20–2.25	2.71	2.67–2.75
Mixed income	1.25	1.22–1.28	1.19	1.16–1.22	1.26	1.24–1.29	1.45	1.44–1.47	1.68	1.66–1.70
Reference: high income										
ICE: Race										
Predominantly Black	0.79	0.78–0.81	0.95	0.93–0.98	1	0.98–1.02	1.16	1.15–1.18	1.11	1.10–1.13
Mixed race	0.85	0.83–0.87	0.95	0.92–0.97	0.96	0.94–0.98	0.99	0.98–1.00	0.97	0.96–0.98
Reference: predominantly white										
MHPSA	1.08	1.02–1.14	1.15	1.08–1.22	1.17	1.11–1.23	1.08	1.06–1.11	1.12	1.08–1.16
Observations: 254										
Suburban										
Greenspace quantity: area/person										
Low quantity (0 m^2)	1.28	1.15–1.43	1.23	1.09–1.38	1.27	1.15–1.40	1.29	1.23–1.34	1.35	1.28–1.43
Moderate quantity (0–1,280.6 m^2)	1.01	0.97–1.06	1.05	1.00–1.10	1.06	1.02–1.11	1.21	1.19–1.23	1.22	1.19–1.25
Reference: high quantity (>1,340.8 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (2.52–6.49 km)	0.76	0.73–0.79	0.72	0.69–0.76	0.73	0.70–0.76	0.79	0.78–0.80	0.81	0.79–0.83
Low accessibility (6.56–17.19 km)	0.66	0.63–0.70	0.67	0.63–0.71	0.7	0.66–0.73	0.74	0.73–0.76	0.74	0.72–0.76
Reference: high accessibility (0–2.5 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0–0.021)	1.11	1.06–1.15	1.08	1.03–1.12	1.11	1.07–1.15	1.03	1.02–1.05	1.04	1.02–1.06
High quality (0.022–1.13)	0.78	0.70–0.86	0.77	0.69–0.86	0.74	0.67–0.81	0.81	0.78–0.84	0.78	0.75–0.83
Reference: low quality (0)										
ICE: Income										
Low income	1.38	1.31–1.45	1.25	1.18–1.32	1.4	1.33–1.46	1.61	1.57–1.64	1.82	1.77–1.87

Table 4
Continued

	Anxiety		Depression		Mood		Mental and behavioral disorders		Substance use disorder	
	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI
Mixed income	1.53	1.46–1.60	1.5	1.43–1.57	1.49	1.43–1.56	1.55	1.52–1.58	1.62	1.58–1.67
Reference: high income										
ICE: Race										
Predominantly Black	0.59	0.56–0.62	0.63	0.60–0.66	0.68	0.65–0.71	0.77	0.76–0.79	0.71	0.69–0.73
Mixed race	0.62	0.59–0.65	0.67	0.64–0.70	0.7	0.67–0.73	0.71	0.70–0.73	0.67	0.65–0.69
Reference: predominantly white										
MHPSA										
Observations: 202										
Micropolitan										
Greenspace quantity: area/person										
Low quantity (0–12.4 m^2)	0.67	0.62–0.73	0.54	0.50–0.60	0.5	0.51–0.59	0.55	0.54–0.57	0.48	0.46–0.50
Moderate quantity (19.1–1,050.7 m^2)	0.98	0.94–1.02	0.89	0.85–0.93	0.9	0.87–0.94	0.92	0.91–0.94	0.88	0.86–0.89
Reference: high quantity (>1,091.7 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (1.78–5.09 km)	1.48	1.43–1.54	1.49	1.43–1.55	1.53	1.48–1.58	1.39	1.37–1.41	1.37	1.34–1.40
Low accessibility (5.09–20.2 km)	1.35	1.28–1.42	1.32	1.25–1.39	1.36	1.30–1.43	1.4	1.37–1.43	1.47	1.43–1.51
Reference high accessibility (0–1.78 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0.008–0.025)	0.78	0.75–0.82	0.74	0.71–0.77	0.73	0.70–0.76	0.66	0.65–0.67	0.6	0.59–0.61
Low quality (0.025–0.56)	0.52	0.48–0.57	0.53	0.48–0.58	0.55	0.51–0.60	0.6	0.58–0.62	0.64	0.61–0.67
Reference: high quality (0–0.006)										
ICE: Income										
Low income	1.71	1.63–1.79	1.45	1.38–1.52	1.52	1.46–1.59	1.58	1.55–1.61	1.77	1.73–1.81
Mixed income	1.64	1.57–1.72	1.53	1.46–1.61	1.53	1.47–1.59	1.74	1.71–1.77	1.95	1.91–2.00
Reference: high income										
ICE: Race										
Predominantly Black	0.99	0.95–1.04	0.99	0.94–1.03	1.15	1.10–1.20	1.2	1.18–1.23	1.06	1.04–1.09
Mixed race	1.38	1.32–1.44	1.36	1.30–1.42	1.47	1.42–1.53	1.59	1.56–1.61	1.46	1.43–1.50
Reference: predominantly white										
MHPSA	1.32	1.08–1.63	1.09	0.89–1.35	1.25	1.04–1.53	1.67	1.52–1.84	2.55	2.20–2.97
Observations: 173										
Small town										
Greenspace quantity: area/person										
Low quantity (0–59.87 m^2)	0.9	0.82–1.00	0.91	0.81–1.02	0.93	0.85–1.03	0.92	0.88–0.96	0.96	0.91–1.01
Moderate quantity (62.11–3,120.2 m^2)	0.72	0.67–0.77	0.78	0.72–0.85	0.75	0.70–0.80	0.84	0.82–0.87	0.87	0.84–0.91
Reference: high quantity (>4,560.2 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (2.36–6.07 km)	0.74	0.69–0.80	0.64	0.59–0.70	0.71	0.66–0.76	0.76	0.73–0.78	0.75	0.72–0.78
Low accessibility (6.16–21.03 km)	0.54	0.48–0.59	0.48	0.43–0.54	0.47	0.43–0.52	0.48	0.46–0.50	0.44	0.42–0.47

Table 4
Continued

	Anxiety		Depression		Mood		Mental and behavioral disorders		Substance use disorder	
	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI
Reference high accessibility (0–2.34 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0.008–0.027)	1	0.93–1.07	0.99	0.92–1.08	0.97	0.91–1.04	1	0.97–1.03	1.03	0.99–1.07
Low quality (0.027–0.23)	1.15	1.04–1.28	1.17	1.05–1.31	1.12	1.02–1.23	1.29	1.24–1.35	1.4	1.33–1.47
Reference: high quality (0–0.007)										
ICE: Income										
Low income	1.25	1.14–1.37	1.27	1.15–1.42	1.4	1.28–1.53	1.34	1.29–1.39	1.38	1.32–1.45
Mixed income	1.61	1.49–1.74	1.53	1.40–1.66	1.68	1.56–1.81	1.67	1.62–1.73	1.72	1.65–1.79
Reference: high income										
ICE: Race										
Predominantly Black	0.97	0.90–1.05	0.85	0.77–0.93	0.85	0.79–0.91	1.13	1.10–1.17	1.2	1.16–1.25
Mixed race	0.79	0.73–0.86	0.64	0.58–0.70	0.67	0.62–0.72	0.7	0.68–0.73	0.65	0.62–0.67
Reference: predominantly white										
MHPSA	0.55	0.42–0.73	0.35	0.26–0.46	0.43	0.34–0.56	0.61	0.54–0.70	0.91	0.75–1.12
Observations: 85										
Rural/Isolated										
Greenspace quantity: area/person										
Low quantity (0–7,774.03 m^2)	0.55	0.46–0.64	0.66	0.56–0.79	0.7	0.59–0.81	0.61	0.57–0.64	0.54	0.50–0.58
Moderate quantity (8,804.1–49,9595.1 m^2)	1.05	0.93–1.19	1.19	1.03–1.36	1.22	1.08–1.39	1.04	0.99–1.09	0.95	0.89–1.00
Reference: high quantity (>59,922.6 m^2)										
Greenspace accessibility: distance										
Moderate accessibility (0.55–3.19 km)	1.77	1.56–2.02	1.77	1.53–2.05	1.71	1.51–1.95	1.71	1.63–1.80	1.81	1.70–1.92
Low accessibility (3.41–21.56 km)	2.09	1.76–2.49	2.09	1.72–2.53	2.16	1.83–2.56	2.28	2.13–2.44	2.38	2.19–2.58
Reference high accessibility (0–0.45 km)										
Greenspace quality: perimeter: area ratio										
Moderate quality (0.01–0.037)	1.11	0.98–1.27	1.05	0.91–1.21	1.05	0.93–1.20	1.17	1.11–1.23	1.21	1.14–1.28
Low quality (0.041–1.1)	1.61	1.43–1.82	1.27	1.11–1.44	1.3	1.16–1.45	1.23	1.18–1.29	1.19	1.12–1.26
Reference: high quality (0–0.01)										
ICE: Income										
Low income	1.3	1.15–1.48	1.18	1.03–1.35	1.19	1.06–1.34	1.13	1.08–1.18	1.12	1.05–1.18
Mixed income	1.25	1.10–1.41	1.04	0.91–1.18	1.08	0.97–1.22	1.4	1.34–1.47	1.54	1.46–1.63
Reference: high income										
ICE: Race										
Predominantly Black	1.10	0.93–1.29	1.14	0.95–1.37	1.25	1.07–1.48	1.23	1.15–1.31	1.22	1.13–1.32
Mixed race	1.82	1.58–2.10	2.21	1.88–2.6	2.4	2.07–2.78	2.17	2.05–2.30	2.38	2.22–2.55
Reference: predominantly white										
MHPSA										
Observations: 94										

Note. Ruralities were determined using USDA Rural Urban Commuting Area (RUCA) Codes.

4. Discussion

This exploratory study investigated the association between three distinct greenspace metrics: greenspace quantity, quality, and accessibility, and population-level mental health outcomes among children, adolescents, and young adults in North Carolina. Most greenspace-mental health research among children, adolescents, and young adults has focused on behavioral and attention problems. Less focus has been directed at additional mental health outcomes (Vanaken & Danckaerts, 2018); papers report conflicting findings, especially for young adults and adolescents (Mueller et al., 2023; Vanaken & Danckaerts, 2018; Zhang et al., 2020). Most mental disorders develop between the ages of 14 and 24 (American Psychiatric Association, 2023), stressing the need for a better understanding of potential community-based mental health interventions like greenspace for this population. Our analysis found that higher greenspace quantity was associated with a lower prevalence of poor mental health outcomes (i.e., anxiety, depression, mood disorders, substance use disorders and mental and behavioral disorders) in urban and suburban neighborhoods, whereas better greenspace accessibility was associated with a lower prevalence of poor mental health outcomes in urban, micropolitan and rural/isolated areas. Poor mental health prevalence was lower in small towns and rural/isolated communities with higher greenspace quality (operationalized as the PAR). Our findings suggest that greenspace may be protective of a wide suite of mental health outcomes among young people, and this association varies substantially with rurality. These results can help guide targeted, place-based greenspace interventions to lower the prevalence of poor mental health outcomes among young people.

Past research indicates that greenspace quantity is protective for mental health (including neurocognitive development) in urban areas (Bezold et al., 2018; Bijnens et al., 2022; Engemann et al., 2019; Islam et al., 2020; Madzia et al., 2019; P. Wang et al., 2019; R. Wang et al., 2021). Our analysis corroborates these findings, where all five mental health outcomes included in this analysis were more prevalent in urban communities with lower quantities of greenspace. While we cannot derive causal pathways, past studies indicate that higher quantities of greenspace in urban areas can benefit mental health by offering avenues for social cohesion, recreation, and restorative experiences (Liu et al., 2022; R. Wang et al., 2021). Increased greenspace quantity can also help alleviate air pollution and poor mental health attributed to air pollution (Bloemsma et al., 2022). Furthermore, our results contribute to new knowledge that this association remains true in suburban areas. In urban areas, mood disorders were 19% higher in communities with poor greenspace quantities; in suburban areas, substance use disorders were 35% higher in communities with poor greenspace quantities. Untreated mood disorders may be a precursor of adolescent suicide (Runkle, Yadav, et al., 2022); emphasizing the importance of mood disorder interventions among adolescents.

Recent research corroborates our substance use disorder findings; suggesting greenspace may be associated with lower rates of binge drinking and tobacco-use among adolescents and young adults (Wiley et al., 2022) and the general public (Berry et al., 2021; Ryan et al., 2023). Our analysis highlights the protective role of greenspace quantity for young people's mental health in urban and suburban neighborhoods. Higher quantities of greenspace may help reduce rates of binge drinking and tobacco use, as exposure to greenspace can alleviate stress, reduce pain, and encourage informed decision-making (Berry et al., 2021). Findings highlights that higher quantities of public greenspaces may be protective of mental health among young people in both urban and suburban neighborhoods.

Better greenspace accessibility was associated with a lower prevalence of poor mental health outcomes in urban, micropolitan, and rural/isolated neighborhoods. Our results corroborate past research, which found greenspace accessibility was significantly associated with lower mental health burdens among young people in urban communities (Markevych et al., 2017; Zach et al., 2016), and contribute new knowledge that this association is also present in micropolitan and rural communities. For all three ruralities (i.e., urban, micropolitan, rural/isolated), this association was most pronounced for substance use disorders, which were 31% more prevalent in urban neighborhoods with the worst greenspace access, 47% more prevalent in micropolitan neighborhoods with the worst greenspace access, and 138% more prevalence in rural communities with the worst greenspace access. Greenspace accessibility may indicate better opportunities for social cohesion (Dimitrova et al., 2017; Jennings & Bamkole, 2019). Community, family, and social cohesion may be a protective factor against adolescent and young adult substance use (Cleveland et al., 2008; Maclin-Akinyemi et al., 2021; Pei et al., 2020). Furthermore, many of the major outdoor recreation opportunities in North Carolina (e.g., Pisgah National Forest, DuPont State Forest, Cape Hatteras) are in rural and isolated areas. Therefore, our findings may indicate an association between mental health and economic opportunities afforded by public greenspaces (Bikomeye et al., 2021). Our findings add evidence that greenspace interventions, both quantity and accessibility, may reduce community substance use burdens (Berry et al., 2021; Wiley et al., 2022). Our analysis identified accessibility at the community-level; future research is needed to identify if improved residential accessibility to greenspace at an individual-level can benefit mental health outcomes.

In both small towns and rural and isolated areas, worse greenspace quality, when operationalized as the PAR, was associated with a higher prevalence of poor mental health outcomes. This association was particularly pronounced for substance use disorders, which were 40% more prevalent in small towns with poor greenspace quality, and anxiety disorders, which were 61% more prevalent in rural communities with poor greenspace quality. One of the mechanisms through which greenspace can help alleviate poor mental health is by offering avenues for mindfulness, restorative experiences, and stress reduction (Hedblom et al., 2019; Liu et al., 2022; R. Wang et al., 2021), which can reduce the likelihood of substance use (Berry et al., 2021; Masterton et al., 2022), and can help alleviate symptoms related to anxiety (Song & Lindquist, 2015; Strohmaier et al., 2021). More diverse greenspaces have been reported to provide more restorative experiences, as compared to less biodiverse greenspaces (Wheeler et al., 2015). The PAR is an indicator of biodiversity, which could suggest that in small towns and rural/isolated communities' higher quality (more biodiverse) greenspaces may help alleviate poor mental health outcome prevalence through restorative experiences. As substance use disorders were also significantly associated with greenspace quantity and accessibility, these findings highlight that greenspace interventions; whether in the form of increasing greenspace quantity, accessibility, or quality, may be beneficial for reducing the community substance use disorder burden; these associations are dependent on place. Our findings regarding a higher prevalence of anxiety in rural communities with poor greenspace quality corroborate other analyses, which suggests that one of the main pathways through which greenspaces benefits mental health is via restorative experiences which promote stress reduction (Liu et al., 2022; R. Wang et al., 2021). Our quality metric (PAR) is used as a proxy for habitat fragmentation and biodiversity (Helzer & Jelinski, 1999). Access to more biodiverse greenspaces can aid in promoting overall well being (Carrus et al., 2015; Mavoa et al., 2019). Based on our findings, greenspace interventions in rural areas and small towns should emphasize development of high-quality greenspaces aimed at improving biodiversity (e.g., greenspaces connected to one another, protection of local habitat).

In this exploratory analysis, we hypothesized that place plays an important role in the greenspace-mental health association among young people. Our results suggest that this is true, as the associations between greenspace metrics and mental health prevalence varied among the five ruralities. We further hypothesized that neighborhoods with higher quantities, and better accessibility of greenspace will be associated with a lower prevalence of poor mental health outcomes, particularly in urban and metropolitan neighborhoods. Our results for urban areas support these findings, but our findings in micropolitan areas suggest that the prevalence of poor mental health outcomes is lowest in communities with the least amount of public greenspace. These conflicting findings might highlight the different community structures of semi-urban areas, with micropolitan communities bridging the gap between rural and urban areas (Dabson, 2019). In both small towns and rural/isolated communities mental health prevalence was also lowest in ZCTAs with the least amount of greenspace, which may be because rural areas tend to have higher quantities of private greenspaces (e.g., agricultural fields, home gardens, back yards, etc.) (Ekkel & de Vries, 2017). Past research suggests that private greenspace may also benefit community mental health (Ryan et al., 2023; Verheij et al., 2008), which could help explain our greenspace quantity findings in micropolitan, small town and rural/isolated communities. Our results indicate that with regards to greenspace interventions, micropolitan areas may benefit more from increased accessibility of greenspace, rather than increased greenspace quantity.

4.1. Implications

Our results suggest that greenspace interventions for the mental health of young people vary with place (i.e., urbanity) and greenspace metrics (i.e., quantity, quality, accessibility) (Figure 4). Greenspace quantity interventions may be most beneficial in urban and suburban neighborhoods; greenspace accessibility interventions may benefit mental health in urban, micropolitan, and rural/isolated areas, and greenspace quality interventions aimed at increasing biodiversity should focus on small towns and rural/isolated communities.

Figure 4. Summary of place-based greenspace and mental health findings. Blue boxes indicate a negative association between greenspace and mental health; dark blue boxes indicate the most substantial associations (i.e., largest prevalence rate ratios). Red boxes indicate no association.

Substance use disorders were often associated with the greatest increase in prevalence in communities with poor greenspace accessibility (urban, micropolitan and rural/isolated), quantity (suburban) and quality (small towns). These compelling findings suggest that greenspace interventions, regardless of rurality, may help alleviate the community mental health burden of substance use.

Studies have shown greenspace development is not equitable; such that primarily white and primarily high income communities (Mears & Brindley, 2019) and cities (Rigolon et al., 2018) often have the best access to ample, high quality greenspaces. In the past, greenspace developments in minority neighborhoods have often led to gentrification (Kim & Wu, 2022; Triguero-Mas et al., 2022); with the most affluent benefiting from increased greenspaces; while minority residents and low-income residents face social exclusion and rising housing costs (Cole et al., 2019). Future greenspace interventions need to ensure the development of greenspaces that serve all community members, without leading to displacement and gentrification.

4.2. Strengths and Limitations

Our study has a number of strengths. First, while past studies have relied primarily on self-reported, or parent-reported well-being questionnaires to quantify mental health (Vanaken & Danckaerts, 2018), our analysis employed an objective mental health data set with state-wide coverage, allowing for analysis at the neighborhood scale (i.e., ZCTA). Second, many studies do not consider multiple greenspace metrics (i.e., quality, quantity, accessibility); relying on NDVI to quantify greenspace (Collins et al., 2020; Vanaken & Danckaerts, 2018), or self-reported questionnaires relating to neighborhood greenspace quantity, quality and/or accessibility (Vanaken & Danckaerts, 2018). This analysis considered multiple public greenspace metrics, investigating greenspace quantity, quality, and accessibility, contributing important knowledge for future greenspace-mental health interventions. Third, there is less focus on mental health concerns, such as mood disorders or substance use disorders, with more attention targeted at childhood and adolescent behavior, hyperactivity, and attention (Vanaken & Danckaerts, 2018). This analysis considered a suite of five mental health outcomes (i.e., mood disorders, anxiety disorders, depression disorders, mental and behavioral disorders and substance use disorders). Finally, greenspace-health research is most often conducted in urban settings, consideration of rurality on a spectrum, including suburban, micropolitan and small-town designations, provides location-specific results that can guide future greenspace interventions.

Our study is also limited. Our analysis was conducted at the neighborhood-level, using ZCTAs as our definition of a neighborhood. ZCTA-level analyses may not capture all of the variability within a community and neighborhood scale analyses can result in inflated associations (Kwan, 2021). Furthermore, we did not consider the activity patterns of individuals, and we were unable to account for additional greenspace exposure opportunities outside of the immediate community (i.e., ZCTA); which can lead to exposure misclassification (Kwan, 2021). Third, ED data spans 2016 to 2019, while greenspace data was collected cross-sectionally in 2019 (PAD_US) and 2020 (ParkServe). Fourth, our mental health data, ED administrative data, only captures one cohort of individuals, representing some of the most vulnerable young people in the state (i.e., individuals who may not have mental health care resources outside of the ED) (Schall et al., 2020;

Theriault et al., 2020). With our data set, we may not capture young people who sought mental health care through school counselors, private mental health providers, or those at residential treatment facilities, among others. Fifth, our accessibility metric does not capture accessibility from individual residences; future studies should investigate more accurate accessibility metrics. This analysis was exploratory in nature; given the high number of statistical tests, our results may be subject to Type 1 error. Finally, this analysis did not consider how the greenspace mental health association varies with race, nor did we consider the interaction between greenspace metrics; future studies should consider how race modifies the greenspace mental health association, and the interplay between greenspace metrics.

5. Conclusions

This analysis investigated place-based differences in the association between greenspace metrics (i.e., quantity, quality, and accessibility), and population-level mental health outcomes among young people in North Carolina. Results reveal that greenspace metrics, are associated with population-level mental health benefits, and this association varies with place, such that increasing quantities of greenspace were associated with lower mental health prevalence in urban and suburban communities. We further observe that increasing greenspace accessibility was associated with lower mental health prevalence in urban, micropolitan and rural/isolated communities, and higher quality (i.e., more biodiversity) greenspaces were associated with lower mental health prevalence in small towns and rural/isolated communities. Often, substance use disorders were associated with the greatest increase in prevalence with decreasing greenspace quantity or accessibility. These compelling findings highlight that greenspace interventions, regardless of rurality, may help alleviate the community mental health burden of substance use and mental and behavioral disorders (e.g., anxiety, mood disorders). Place-based results provide important information for targeted mental health interventions.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

Health data was obtained through an ongoing data use agreement with the North Carolina Department of Health and Human Services (NC Department of Health and Human Services, 2021). Greenspace data was obtained from The Trust for Public Lands—ParkServe (The Trust for Public Land, 2021) and the Protected Area Database of the United States—PADUS (USGS, 2020). Mental Health Professional Shortage Areas—MHPSA data was obtained from the Health Resource and Services Administration (Health Resources & Services Administration, 2023). Rural Urban Commuting Area—RUCA Code data was obtained from the U.S. Department of Agriculture (USDA, 2020). The Index of the Concentration of Extremes (ICE) metrics were calculated using American Community Survey 5-year estimates (US Census, 2018).

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