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Original article

Place-Based Differences in the Association Between Greenspace and Suicide-Related Outcomes Among Young People

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A B S T R A C T

Purpose: This study investigated place-based differences in the association between greenspace and suicide-related outcomes (SROs) among young people, guided by the following two objectives: (1) Contextualize place-based differences in the association between greenspace and SRO prevalence among young people at the community level in five different urbanities (urban, suburban, micropolitan, small towns, and rural/isolated communities) and (2) identify which greenspace metrics (quantity, quality, or accessibility) are most protective for SROs at the community level.
Methods: Publicly available greenspace datasets were used to derive greenspace quantity, quality, and accessibility metrics. SRO emergency department visits for young people were identified from 2016–2019 in North Carolina, USA. Generalized linear models investigated the association between greenspace metrics and community-level drivers of SRO prevalence. Shapely additive explanations confirmed the most important greenspace variables in accurately predicting community-level SRO prevalence.
Results: The prevalence of SROs was highest in communities with the least amount of public greenspace; this association was most pronounced in suburban communities, with SROs 27% higher in suburban communities with low quantities of greenspace (PRR_{Urban}: 1.11, confidence interval [CI]: 1.08–1.13; $PRR_{Suburban}$: 1.27, CI: 1.10–1.46; $PRR_{SmallTowns}$: 1.21, CI: 1.05–1.39), and in communities with the worst greenspace accessibility (i.e., furthest distance to nearest greenspace) (PRR_{Urban}: 1.07, CI: 1.04–1.10; $PRR_{Rural\&Isolated}$: 1.95, CI: 1.54–2.49).
Discussion: Our analysis provides place-based, community-specific findings to guide targeted greenspace interventions aimed at addressing the rising prevalence of SROs among young people. Our findings suggest that greenspace quantity interventions may be most effective in urban, suburban, and small-town communities, and greenspace accessibility interventions may be most useful in urban and rural/isolated communities.

IMPLICATIONS AND CONTRIBUTION

These results indicate that greenspace interventions for child, adolescent, and young adult mental health in urban and nonurban areas should focus on improving equitable greenspace quantity and accessibility.

The prevalence of suicide-related outcomes (SROs) is increasing in the United States [1]. This increase is especially pronounced among young people, with trends for adolescents and young adults depicting a notable rise in self-injury (47% increase), suicidal ideation (76% increase), and suicide attempts

Conflicts of interest: The authors have no conflicts of interest to declare.

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(58% increase) during the 2010s [1]. Given this widespread, sustained increase, additional research is needed to identify and better understand community-level mental health interventions.

Past research among the general public suggests greenspace can function as a health intervention. Greenspaces are theorized to benefit mental health by providing avenues for social cohesion, stress reduction, physical recreation, and restorative experiences [2]. Findings indicate greenspace may have protective implications for numerous mental health outcomes, including anxiety [3–5], depression [6], mood disorders [4,5], general mental health and wellbeing [7,8], suicide [9,10], and substance use disorders [11,12]. Among young people, exposure to greenspace is associated with benefits to child neurological development and behavioral outcomes (i.e., attention deficit disorder, attention deficit hyperactive disorder) [13].

Greenspace research focused on the mental health of young people remains understudied [14]. Available research suggests young adults and adolescents may be more likely to use greenspaces with recreation opportunities and less likely to use greenspace for relaxation [14,15], while children are more likely to enjoy greenspaces that provide opportunities for active play [16]. Furthermore, results suggest adolescents who spend extended periods of time in natural spaces reported higher rates of self-satisfaction and social cohesion compared to adolescents who spent little time in natural spaces [17], while children are associated with better memory and a reduction in inattentiveness [18].

These compelling findings suggest that greenspace can help alleviate community-level mental health burdens. However, most greenspace and health research is conducted in urban areas (e.g., [19]), with little focus across the rural-urban continuum or in the most rural locations. Furthermore, few studies have investigated the association between greenspace metrics (i.e., greenspace quantity, greenspace quality, and greenspace accessibility) and the prevalence of SROs (e.g., self-harm, suicide ideation, suicide attempt) among young people.

This study aims to contribute new knowledge regarding the association between greenspace and SROs. Our research is guided by two main objectives: (1) Investigate place-based differences in the association between greenspace and SRO prevalence among young people at the community level in five different urbanities (urban, suburban, micropolitan, small towns, and rural/isolated communities) and (2) identify which greenspace metrics (quantity, quality, or accessibility) are most protective for SROs at the community level. The consideration of multiple greenspace metrics, in addition to a population-based emergency department (ED) dataset for SROs, furthers our understanding of how greenspace can function as a health intervention.

Methods

Health data

ED visit data were obtained from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) [20] for 2016–2019. NC DETECT provides complete spatiotemporal coverage of ED visits in North Carolina [20]. For this analysis, data were restricted to ED visits of individuals aged 24 years and less. ED data were coded using the International Classification of Diseases 10 Clinical Modification codes to isolate SRO cases (International Classification of Diseases 10 codes: X71-X838, R45851, R4588, T1491-T1491XS) [21]. SROs include the following: intentional self-harm, self-poisoning and toxic effects, suicidal ideation, and asphyxiation [21]. ED data were coded in RStudio, version 2022.07.1. Data were exempt under human subjects' category #4 for secondary data from Appalachian State University's Institutional Review Board (IRB#19-0270).

For this analysis, communities were defined at the Zip Code Tabulation Area (ZCTA) level [22], with individual ED data converted from zip code to ZCTA when applicable [23]. ZCTAs are a US Census Bureau spatial geography relating to mailing postal codes; in North Carolina, ZCTAs have a median area of 115 km^2. ZCTA is the finest spatial resolution available for the NC DETECT health dataset.

Greenspace data

Public greenspaces in North Carolina were identified using the Protected Area Database of the United States (PAD-US) [24], and the Trust for Public Land's ParkServe datasets [25] (Figure 1). PAD-US is a spatial dataset containing all government-managed greenspaces (e.g., national forest land, national parks, and historical sites). Any nonpublic greenspaces (e.g., military bases) were removed to ensure selected greenspaces were publicly accessible [26,27]. ParkServe is a spatial dataset of all public parks (e.g., local and city parks) [25]. PAD-US and ParkServe data were combined to create one spatial greenspace dataset (Figure 1), which was used to generate the following greenspace metrics for each neighborhood (i.e., ZCTA) in ArcGIS Pro 3.0.0.

(1) *Greenspace quantity*, operationalized as *Greenspace per person* [27] (Table S1) captures the total amount of public greenspace per ZCTA.
(2) *Greenspace accessibility* was operationalized as *Greenspace distance* (Table S1).
(3) *Greenspace quality* was operationalized using an ecologic metric as the *Perimeter area ratio (PAR)* (Table S1). The PAR was included to capture greenspace patchiness [28]. Natural landscape patchiness is often a proxy for biodiversity, as patchier natural spaces tend to have higher edge effects, which can harm flora and fauna [29]. Past research suggests the psychological benefits of greenspace increase with biodiversity [30,31]. ZCTAs with no public greenspace were categorized as poor quality.

Covariates

Important covariates included in this analysis included individual-level factors, notably age group and sex, as well as community-level factors that capture residential segregation, economic segregation, mental health professional shortage areas, and rurality.

Age [7] and sex [32] were considered to see if the association changes based on these demographic factors. Following census age categories, SRO ED visits were categorized as childhood (ages 14 and less), adolescence (ages 15–17), and young adulthood (ages 18–24) (American Community Survey, 2018). To investigate the influence of sex, ED data were categorized as visits among males and visits among females (Table S2).

Regression analyses were adjusted for ZCTA race and socioeconomic status using the Index of the Concentration of Extremes (ICE) [33]. ICE metrics analyze the spatial distribution of extreme concentrations of economic and racial privilege and deprivation using US Census Data, producing community-level

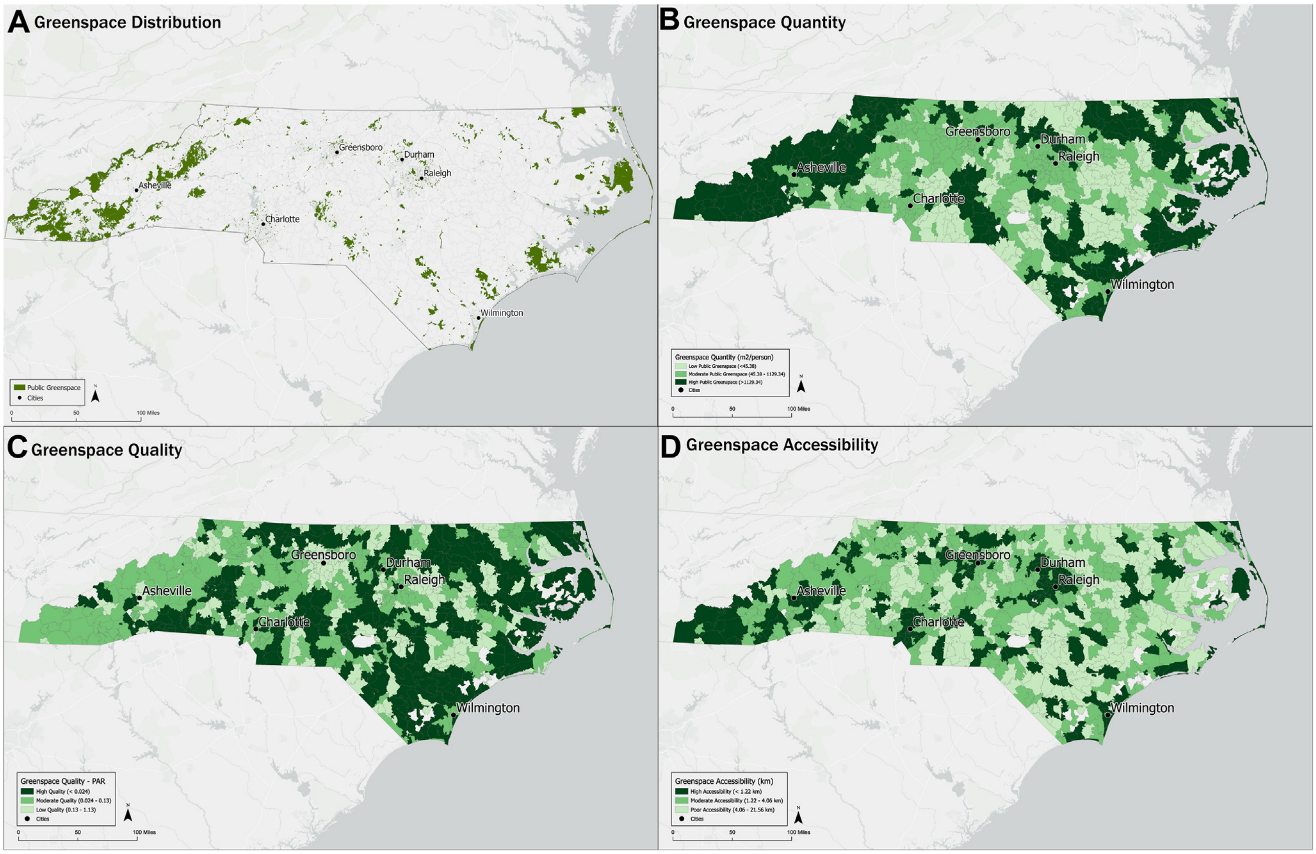

Figure 1. Map depicting the spatial distribution of public greenspace in North Carolina (A), and the distribution of greenspace quantity (B), quality (C), and accessibility (D). Greenspace metrics are displayed in tertiles. Greenspace data are from the Protected Area Database of the United States (PAD_US) and the Trust for Public Land's ParkServe dataset.

race and income metrics [33]. *ICE:Income* measures ZCTA income extremes by comparing how many households make more than $100,000 per year to how many make less than $25,000 per year. *ICE:Race* captures racial segregation of a community by comparing the number of Black residents to the number of white residents. For this analysis, ICE metrics were computed as tertiles. The use of tertiles was adapted to improve the interpretability of the regression results [34,35], where Tertile 1 corresponds to predominately low income (ICE:Income) and predominately Black (ICE:Race), Tertile 2 corresponds to mixed income (ICE:Income) and mixed race (ICE:Race), and Tertile 3 corresponds to predominantly high income (ICE:Income) and predominantly white (ICE:Race) (Figure S1). American Community Survey 2018 five-year estimates were used to calculate the ICE metrics. ICE metrics have been used in past United States–based research to investigate the role of privilege and deprivation in infant mortality [34] and pregnancy-associated mortality [35], among other health outcomes.

Community mental healthcare context was accounted for using Mental Health Professional Shortage Areas (MHPSA), which was included as a binary with ZCTAs designated as MHPSA or non-MHPSA [36] (Figure S2).

To understand place-based differences, rurality was included using Rural-Urban Commuting Area (RUCA) codes at the ZCTA level. RUCA codes range from 1–10, and each RUCA code was assigned an urbanity (Table S3) (Figure 2) [37].

Statistical analysis

Generalized linear models (GLMs) with a Poisson distribution were performed to identify the association between ZCTA SRO prevalence and greenspace quantity, quality, and accessibility in North Carolina. Models were run for each rurality designation, each age group, and for both males and females. All models were adjusted for community-level race, income, total ZCTA population of individuals aged 24 years and less, and MHPSA designation. Population was included as a continuous variable, and MHPSA data were included as a binary.

Statistical models were designed to compare the prevalence of SROs with relation to greenspace quantity, quality, and accessibility. Communities were divided into three groups to identify and compare the prevalence of SROs among communities with low, moderate, and high greenspace quantity, quality, and accessibility. We hypothesize that communities with high greenspace quantity will have lower SRO prevalence compared to communities with low greenspace quantity [7,9], and communities with high greenspace quality (low PAR value) will have a lower prevalence of SROs compared to communities with low greenspace quality (high PAR) [31]. Finally, communities with the highest greenspace accessibility (i.e., shortest distances to the nearest greenspace) will be associated with a lower prevalence of SROs compared to communities having to travel farther distances to access the nearest greenspace [38] (Table 1).

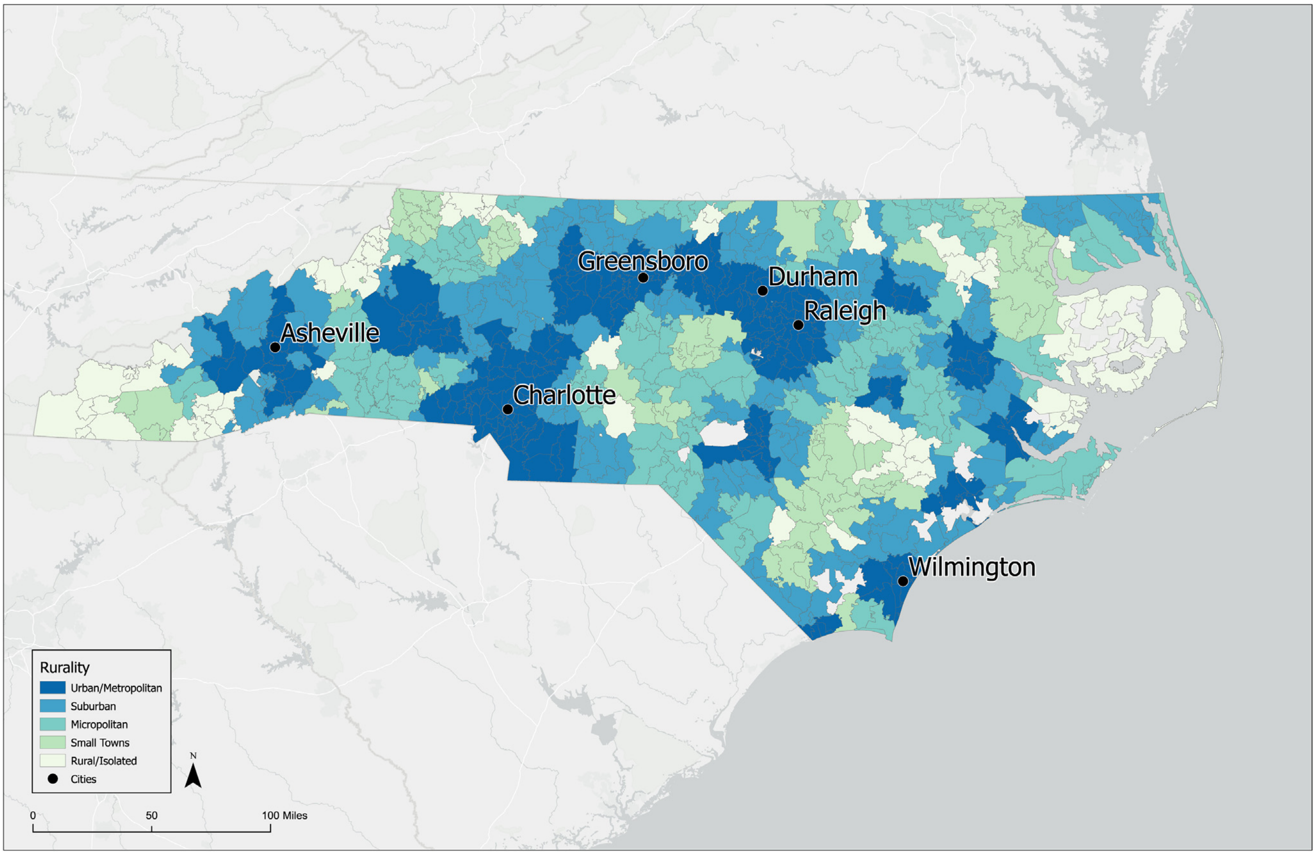

Figure 2. Map indicating the spatial distribution of urban, suburban, micropolitan, small towns, and rural/isolated ZCTAs. Rurality designations were determined using United States Department of Agriculture (USDA) Rural-Urban Commuting Area (RUCA) codes.

Table 1
Demographic characteristics of all Emergency Department (ED) visits and mental health–related ED visits among individuals aged 24 and younger who visited a North Carolina ED (2016–2019)

	All ED visits n (%)	Suicide-related outcomes (SROs) n (%)
ED visits	5,357,703 (100%)	59,999 (1.12)
Average age (SD)	12.49 (8.19)	17.35 (4.1)
Year		
2016	1,378,846 (25.7)	11,256 (18.8)
2017	1,371,847 (25.6)	14,239 (23.7)
2018	1,300,575 (24.3)	16,826 (28.0)
2019	1,306,435 (24.4)	17,678 (29.5)
Sex		
Male	2,427,180 (45.3)	25,461 (42.4)
Female	2,922,642 (54.6)	34,435 (57.4)
Other/Unknown	7,881 (0.1)	103 (0.2)
Race		
Indigenous American	74,586 (1.5)	726 (1.3)
Asian/Pacific Islander	46,042 (0.9)	563 (1.0)
Black	1,902,890 (37.3)	15,003 (25.9)
White	2,556,293 (50.1)	37,422 (64.5)
Other	523,995 (10.3)	4,317 (7.4)
Age group		
Under 15	2,796,174 (52.2)	15,813 (26.4)
15–17	529,510 (9.9)	15,374 (25.6)
18–24	2,032,019 (37.9)	28,812 (48.0)

Data are from NC DETECT.
SD = standard deviation; ED = emergency department.

Multicollinearity was considered by calculating the Variance Inflation Factor to identify the best model (Variance Inflation Factor < 2) [39]. Models considering all greenspace metrics and sociodemographic factors had the lowest Akaike information criterion values.

Variable contribution—SHAP

As a supplement to our GLM analysis, we employed Shapley models to quantify variable contribution (SHAP values) in accurately predicting SRO prevalence at the community level. The objective of SHAP is to provide an explanation for the model's prediction by considering variable values and their contributions to the final outcome [40]. Shapley models quantify how each variable contributes to model performance globally (average variable contribution) and locally (how each variable value contributes to model predictions) [40]. The inclusion of Shapley models in this analysis provides context, not only of which variables are associated with SROs, but also which variables are most important in predicting SRO prevalence at the community level. Shapley model results help inform which greenspace and socioeconomic variables drive mental health prevalence, while GLMs provide prevalence rate ratios to compare risk among communities. Shapley models were run using a GLM model with a Poisson distribution to be consistent with statistical models and created using the 'shapr' package in RStudio [41].

Results

Demographic summary

Overall, there were 5,357,703 total ED visits, of which 59,999 are SRO ED visits (Table 1). SRO visits were highest among females (57.4%), white individuals (64.5%), and young adults aged 18–24 years (48%). The proportion of ED visits for SROs increased throughout the study period, with 29.5% of visits occurring in 2019.

Greenspace metric distribution

Figure 1 illustrates the distribution of greenspace metrics in North Carolina. Greenspace quantity is highest in western and eastern North Carolina. Greenspace accessibility varies throughout the state; southwestern North Carolina and the urban centers of Charlotte, Durham, and Greensboro have the best community-level greenspace access (shortest distance to nearest greenspace) while many ZCTAs in eastern North Carolina have the worst greenspace access (furthest distance to nearest greenspace). Greenspace quality is highest in eastern North Carolina (smallest PAR values) and worst in western North Carolina (highest PAR values).

Generalized linear models

Table 2 reports state-wide GLM results. ZCTAs with low or moderate greenspace quantity were associated with higher prevalence rate ratios (PRRs) (1.73, confidence interval [CI]: 1.67–1.78), compared to the ZCTAs with the greatest quantity of public greenspace (reference). Living in ZCTAs with moderate greenspace accessibility was associated with a 12% higher prevalence of SROs (PRR: 1.12, CI: 1.10–1.14) compared to ZCTAs with the best greenspace access (i.e., short distances to nearest greenspace, reference). ZCTAs with moderate greenspace quality were associated with a 5% higher prevalence of SROs (PRR: 1.05, CI; 1.03–1.07) compared to ZCTAs with high greenspace quality (low PAR, low greenspace patchiness, reference).

Rurality-stratified. Table 2 reports GLM results for rurality-stratified models. In urban, suburban, and small-town communities, SROs exhibited the highest PRR in ZCTAs with the least amount of public greenspace per person, compared to ZCTAs with the highest greenspace quantity. SROs were 11% higher in urban areas with the least amount of greenspace (PRR_{Urban}: 1.11, CI: 1.08–1.13), 27% higher ($PRR_{Suburban}$: 1.27, CI: 1.10–1.46) in suburban areas with the lowest quantities of greenspace, and 21% higher ($PRR_{SmallTown}$: 1.21, CI: 1.05–1.39) in small towns with low greenspace quantity, compared to urban, suburban, and small-town communities with the highest greenspace quantity. In rural/isolated communities, residence in ZCTAs with moderate greenspace quantity was associated with a 46% higher prevalence of SROs ($PRR_{Rural/Isolated}$: 1.46, CI: 1.21–1.76), as compared to ZCTAs with the highest greenspace quantity.

In urban and rural/isolated areas, further distance to the nearest greenspace (poor accessibility) was associated with increased prevalence in SROs. In urban areas, SROs were 7% more

Table 2
State-wide and RUCA-stratified GLM results investigating the relationship between greenspace quantity, quality and accessibility, and suicide-related outcomes among individuals aged 24 and under with consideration of urban, suburban, micropolitan, small towns, and rural/isolated communities in North Carolina (2016–2019)

	Statewide[b]		Urban		Suburban		Micropolitan		Small towns		Rural/Isolated	
	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI	PRR	CI
Greenspace Quantity: Area/Person												
Low Quantity (0–45.38 m2)	1.56	1.51–1.61	1.11	1.08–1.13	1.27	1.10–1.46	0.72	0.65–0.81	1.21	1.05–1.39	0.96	0.76–1.20
Moderate Quantity (45.92–1,129 m2)	1.73	1.67–1.78	1.08	1.05–1.11	1.21	1.14–1.29	1.01	0.95–1.06	1.05	0.95–1.17	1.46	1.21–1.76
Reference: High Quantity (> 1,147 m2)												
Greenspace Accessibility: Distance												
Moderate Access (1.23–4.06 km)	1.12	1.10–1.14	0.97	0.94–0.99	0.77	0.73–0.82	1.15	1.09–1.21	0.7	0.63–0.79	1.44	1.19–1.74
Low Access (4.09–21.6 km)	0.76	0.74–0.78	1.07	1.04–1.10	0.83	0.77–0.88	0.95	0.88–1.02	0.6	0.53–0.69	1.95	1.54–2.49
Reference: High Access (0–1.22 km)												
Greenspace Quality: Perimeter:Area Ratio												
Moderate Quality (0.01–0.035)	1.05	1.03–1.07	0.98	0.95–1.00	1.05	0.99–1.11	0.72	0.68–0.76	1.02	0.92–1.13	1	0.84–1.19
Low Quality (0.035–1.13)[a]	0.77	0.75–0.79	0.83	0.80–0.85	0.74	0.65–0.84	0.51	0.46–0.58	0.77	0.66–0.89	0.87	0.74–1.02
Reference: High Quality (0–0.01)												
ICE:Income												
Majority Low Income	1.25	1.22–1.28	1.47	1.43–1.51	1.08	1.01–1.16	1.28	1.20–1.36	0.89	0.78–1.01	1.06	0.90–1.26
Mixed Income	1.31	1.28–1.34	1.09	1.06–1.12	1.22	1.15–1.29	1.31	1.24–1.39	1.05	0.94–1.17	0.92	0.78–1.09
Reference: Majority High Income												
ICE:Race												
Predominately Black	1.07	1.04–1.10	1.19	1.16–1.23	0.81	0.76–0.87	1.24	1.17–1.32	1.03	0.92–1.16	1.1	0.86–1.40
Mixed Race	1.19	1.16–1.25	1.11	1.08–1.15	0.78	0.74–0.83	1.42	1.34–1.51	0.75	0.67–0.84	2.49	2.01–3.10
Reference: Predominately White												
MHPSA	1.07	1.01–1.13	0.93	0.87–0.99			1.27	0.99–1.66	0.47	0.34–0.65		
Observations												
	808		254		202		173		85		94	

Ruralities were determined using United States Department of Agriculture (USDA) Rural Urban Commuting Area (RUCA) codes.
MHPSA = Mental Health Professional Shortage Areas; ICE = Index of the Concentration of Extremes; PRR = prevalence rate ratio; CI = confidence interval; GLM = generalized linear model.
[a] Includes ZCTAs with no public greenspace.
[b] Reported greenspace ranges (i.e., low, moderate, high), reflect state-wide greenspace tertiles. Rurality-stratified models re-computed tertiles to reflect the communities included in each model (i.e., urban, micropolitan).

prevalent (PRR_{Urban}: 1.07, CI: 1.04–1.10) in communities with the worst greenspace access compared to those with the best greenspace access; in rural/isolated areas, SROs were associated with a 95% higher prevalence ($PRR_{Rural/Isolated}$: 1.95, CI: 1.54–2.49) in communities with the worst greenspace access, compared to those with the best accessibility (i.e., shortest distances to nearest greenspace). In micropolitan areas, moderate greenspace accessibility was associated with a 15% higher prevalence of SROs ($PRR_{Micropolitan}$: 1.15, CI: 1.09–1.21) compared to micropolitan communities with the best accessibility.

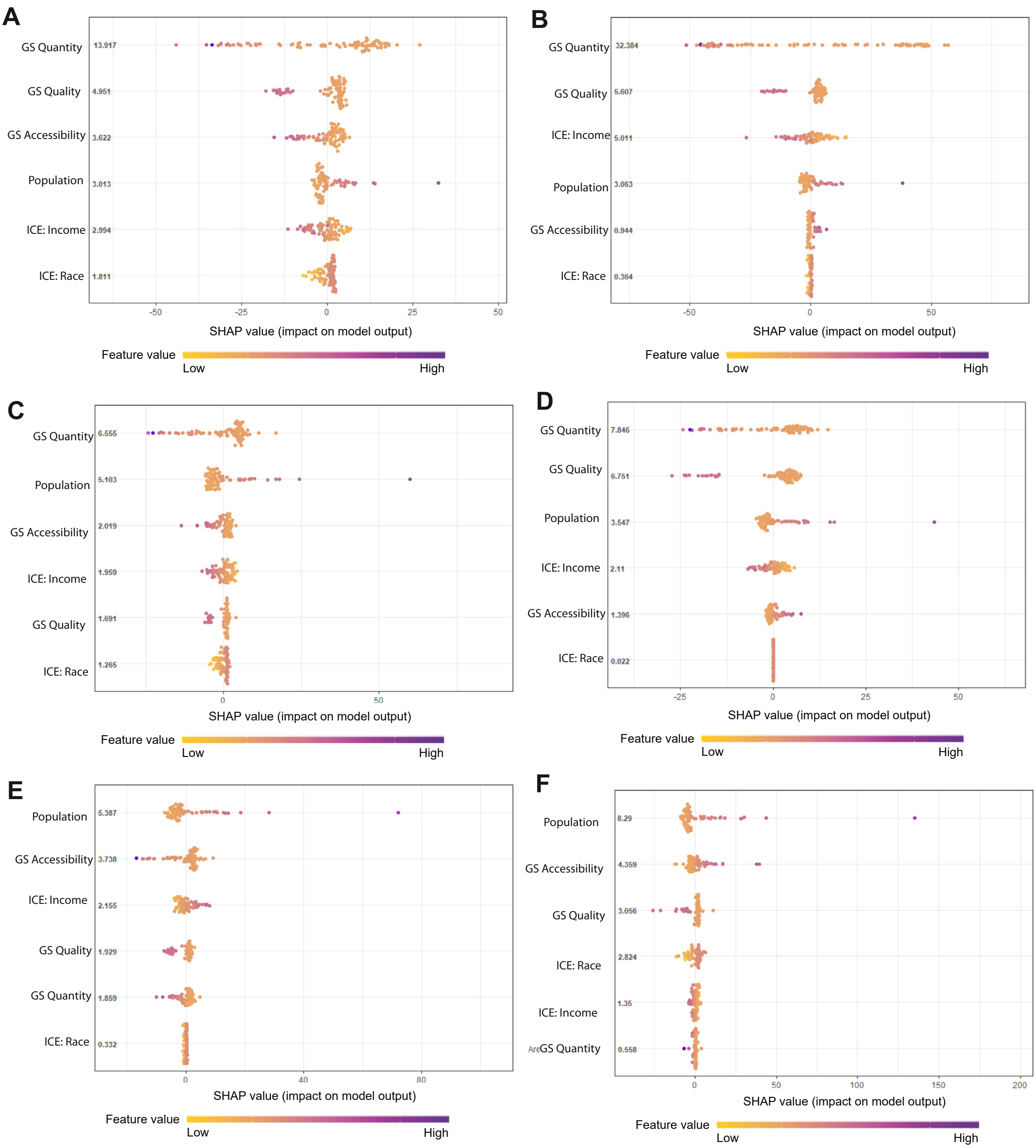

Figure 3. SHAP model contribution results for (A) statewide, (B) urban, (C) suburban, (D) micropolitan, (E) small town, and (F) rural/isolated communities.

Age-stratified and sex-stratified. For children (ages 14 and less) (PRR: 1.53, CI: 1.40–1.60), young adults (ages 18–24) (PRR: 1.2, CI: 1.16–1.23), and both males (PRR: 1.55, CI: 1.50–1.61) and females (PRR: 1.56, CI: 1.51–1.61) residing in communities with low greenspace quantity was associated with the highest prevalence of SROs (Table S4). Mixed-income (ICE:Income) communities were associated with the highest prevalence of SROs across all age groups and for both males and females. Mixed-race (ICE:Race) communities exhibited the highest PRR of SROs among males (PRR: 1.31, CI: 1.26–1.36), females (PRR: 1.31, 1.27–1.35), children (ages 14 and less) (PRR: 1.26, CI: 1.20–1.32), and adolescents (ages 15–17) (PRR: 1.29, CI: 1.23–1.35); predominantly Black communities were associated with the highest risk of SROs among young adults (ages 18–24) (PRR: 2.35, CI: 2.27–2.43).

Variable contribution—SHAP

Figure 3 summarizes SHAP variable contribution results; SHAP values show the average effect of each variable on SROs. Statewide and in urban, suburban, and micropolitan communities, greenspace quantity proved to be the highest contributing variable (i.e., most important in accurately predicting SRO prevalence), with lower quantity values resulting in higher SROs. In small towns and rural/isolated areas, population was the most important variable in predicting SRO prevalence in rural communities, followed by greenspace accessibility. SHAP values for greenspace quality highlight that a selected number of ZCTAs drive the direct association (e.g., higher biodiversity, higher mental health burden).

Discussion

Despite escalating rates of SROs [1], few studies have considered the association between neighborhood greenspace and SROs among young people. This study investigated the association between three distinct greenspace metrics: greenspace quantity, quality, and accessibility, and population-level SRO prevalence among children, adolescents, and young adults in North Carolina. Our results suggest that increasing greenspace quantity may be protective for SROs, and this association remained robust for urban, suburban, small town, and rural/isolated neighborhoods and across age-stratified and sex-stratified analyses. These findings support previous work, which found that greenspaces were associated with protective effects for SROs [10], and suicides [9,10] in urban and rural communities. Our findings also corroborate past research, which found higher quantities of greenspace were associated with lower odds of serious psychological distress [42] and depression [6] among adolescents, and exposure to high quantities of greenspace in childhood and adolescence may reduce the likelihood of developing psychiatric disorders in young adulthood [43]. Our SHAP model contribution results further highlight the importance of greenspace quantity in accurately predicting SRO prevalence among young people at the community level, especially in urban and suburban communities.

Our analysis found that greenspace accessibility can also function as a mental health intervention for SROs, specifically in urban, micropolitan, and rural/isolated areas. To the author's knowledge, this study is one of the first analyses to investigate greenspace accessibility in relation to mental health outcomes in nonurban settings (i.e., micropolitan, rural). Our results indicate that in addition to increasing greenspace quantity, many communities benefit from having better access to public greenspaces, and our SHAP model results highlight better access to greenspaces (i.e., shorter distances) is particularly important in accurately predicting lower SRO prevalence in small towns and rural/isolated areas. In urban and micropolitan areas, better access to greenspace can make the beneficial aspects of greenspace, such as stress reduction and social cohesion [2,44], more readily available. In rural areas, better access to greenspaces may provide opportunities for social cohesion, a pathway through which greenspace benefits mental health [2,44]. Recent research further indicates that better access to greenspaces during the pandemic was associated with a higher prevalence of mental health resilience [38]. Our findings add to the growing body of research linking greenspace accessibility to population-level mental health benefits. These compelling findings highlight the importance of developing equitable and accessible greenspaces.

Our regression analysis did not find SROs significantly associated with mental health benefits from greenspace quality when operationalized as a biodiversity proxy (perimeter:area ratio). Recent research has focused on assessing greenspace quality with surveys to understand user-perceived greenspace quality and safety of access [2,7]. Results from these analyses suggest that users who perceive their neighborhood greenspace as safe and of high quality are often associated with lower self-reported poor mental health [2,7]. Further research suggests that the type of greenspace (i.e., sports complex, nature path) may mediate the association between greenspace quality and mental health [45], with adolescents and young adults far more likely to access greenspaces with recreation opportunities [14,15], and children more likely to use greenspaces with playground facilities [16]. Our analysis relied on ED visit data and state-wide greenspace metrics; collecting survey data on this scale is not feasible. While our quality metric of the PAR proved insignificant in relation to SROs, we recommend future research investigate additional greenspace quality metrics that can be generated across a large spatial area (i.e., state-wide) to better understand what characteristics and types of greenspaces are most beneficial for reducing SRO prevalence at the community level among young people.

Model contribution (SHAP) results confirm the importance of greenspace metrics, notably greenspace quantity, in predicting SRO prevalence. Unlike more traditional models, which assess how much variance is predicted by greenspace metrics, SHAP results use game theory to understand the contribution of all observations to each variable by fairly distributing "gains" and "costs" for all locations. As such, additional information can be derived from these results. Interestingly, greenspace quality often proved important for model estimation despite showing a negative and often insignificant association. Furthermore, the SHAP models indicate that selected locations may influence regression results for greenspace quality statewide and across all five ruralities. These results highlight the need for further consideration of greenspace quality metrics, and the PAR metric may not be appropriate for all locations. We recommend qualitative data collection across rural and urban communities to identify what features of greenspace may be most beneficial in helping reduce SRO prevalence among young people. Greenspace accessibility was identified as a key contributor in model prediction for small towns and rural/isolated communities, supporting past literature which has found better accessibility of greenspace may translate to better mental health outcomes among adolescents [8]. Our results further highlight the potential importance of equitable greenspace access as a mental health intervention to reduce community-level SRO prevalence.

Research indicates that greenspace development is not equitable, with primarily white and primarily high-income communities [46] often seeing the greatest quantity, accessibility, and/or quality of public greenspaces. Historically, the development of greenspaces in minority neighborhoods has led to rising housing costs [47,48] and social exclusion for low-income and minority residents [49]. Planning efforts need to be aware of these realities and ensure the active participation of all residents when it comes to greenspace development to guarantee the planning process equitably benefits all residents. Our results further highlight the high prevalence of SROs in mixed-race communities, and among individuals aged 24 years and younger who live in predominately Black neighborhoods. Predominantly Black and mixed-race communities with a large youth population should be given priority for greenspace interventions.

Strengths and limitations

Our study has numerous strengths. We employed an administrative health dataset with state-wide coverage, allowing for analysis at the neighborhood scale (ZCTA). Second, this analysis considered three distinct public greenspace metrics generated for the entire state: accessibility, quantity, and quality, contributing important place-based findings that can guide future greenspace–mental health interventions. Third, this analysis considered SROs, an understudied mental health outcome with regard to young people and greenspace. Finally, this is one of the only greenspace–mental health analyses to consider multiple ruralities (e.g., suburban, micropolitan) rather than operationalizing rurality as a binary; our work provides location-specific results that can guide future mental health interventions.

Our study is also limited. First, we did not consider the interaction between greenspace metrics; future research should consider the interplay between greenspace metrics to further understanding of the greenspace mental health relationship. Second, we conducted this analysis at the neighborhood level. Neighborhood scale analyses can result in inflated relationships [50]. Furthermore, mental health data were derived from patients' ZCTA of residence, residential location does not necessarily reflect activity patterns, and we were unable to account for additional greenspace exposure opportunities (e.g., school); this may lead to exposure misclassification [50]. Third, greenspace metrics were collected cross-sectionally in 2019 (PAD-US) and 2020 (ParkServe), whereas mental health outcome data span 2016–2019; greenspace exposure may have changed during this time period. However, the authors are unaware of any major greenspace developments during the study period. Fourth, our mental health data are ED administrative data; we only captured one cohort of individuals, which may not be representative of the entire state. However, our cohort of mental health data is for the most vulnerable residents. Therefore, our results depict the association between greenspace and mental health among North Carolina's most vulnerable children, adolescents, and young adults. Fifth, our greenspace quality metric was derived using spatial analysis to generate the PAR rather than using self-reported quality data (e.g., [8]), and as such, we did not access additional quality metrics, such as available greenspace facilities or user-perceived greenspace quality. We recommend future analyses incorporate these greenspace quality metrics. Finally, this analysis did not consider how the greenspace mental health association varies with race; future studies should consider how race modifies the greenspace mental health association.

Conclusions

This analysis investigated the association between greenspace quantity, quality, and accessibility, and population-level SROs among children, adolescents, and young adults in North Carolina. Results reveal that greenspace metrics, most notably greenspace quantity and greenspace accessibility, are associated with population-level mental health benefits; this association varies with rurality. Increasing greenspace quantity in urban areas may serve as an intervention for SROs, which was 58% higher in urban communities with poor greenspace quantity. Greenspace quantity interventions may be most effective in urban, suburban, and small-town communities, and greenspace accessibility interventions may be most useful in urban and rural/isolated communities. Our analysis provides community-specific findings to guide targeted greenspace interventions aimed at reducing the prevalence of SROs.

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Supplementary Data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jadohealth.2024.03.014.

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