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How tree canopy cover can reduce urban suicide attempts: A geospatial analysis of the moderating role of area deprivation

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A B S T R A C T

A lack of knowledge about the benefits of urban trees on mental health is addressed by exploring the association between tree canopy coverage, suicide attempts and the levels of neighborhood deprivation. Although the positive association between tree canopy cover and mental health as well as a negative association between neighborhood socioeconomic status and suicide attempts are well-known, it remains largely unclear how both area deprivation and tree canopy cover can help predicting local suicide attempts. Using the local suicide records (n = 3442) between 2015 and 2019 in the city of Cincinnati, OH, we analyzed if the number of local suicide attempts was related to the tree canopy cover at the census block group level (n = 275). After adjusting for control variables, we found that as the deprivation level gets a one-percentage point higher, the number of attempted suicide rate significantly increases by 1.05 %, while a one-percentage point increase in tree canopy coverage significantly decreases the attempted suicide rate by 0.9 %. Additionally, the level of area deprivation showed a moderating effect on the association between overall tree canopy and attempted suicide. Our findings suggest that local tree canopy cover could be a useful tool to improve local mental health including suicide attempts. More importantly, the benefit of tree canopy cover was stronger in less disadvantaged areas than in highly disadvantaged areas, which provides a new insight that interventions to qualitatively improve green space may be important for improving mental health in left-behind areas as a form of environmental justice.

1. Introduction

Suicide is a significant public health challenge. Approximately, more than 700,000 people die by suicide annually worldwide (World Health Organization 2019). In the U.S. alone, suicide is the 10th leading cause of death (Ahmad & Anderson, 2021), much more people developed suicide plans or had serious thoughts about suicide, and over 1.4 million people reported suicide attempts among those over the age of 18 (Substance Abuse and Mental Health Services Administration, 2020). Suicide attempts could eventually progress to suicide and also impact the well-being among those in the close social environment (Suominen et al., 2004). Suicide attempts not only affect the bereaved, surviving family and friends, but also those living in the nearby community (Chapman & Dixon-Gordon, 2007). Experiences of shock and feelings of guilt or responsibility can also put a burden on mental health as well as future suicides and suicide attempts. At the same time, psychological

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well-being is known to curb against suicide as a resilience factor (Teismann et al., 2019) and may even moderate the relationship between suicide ideation and suicide attempts (Brailovskaia et al., 2019). A comprehensive public health approach and multidimensional efforts are required to support healthy communities with resilient individuals to prevent suicide.

Strategies to reduce stress are critical to support community mental health. Previous studies found that spending time in urban, local green spaces is a key source of wellbeing promoting mental health (van den Berg et al., 2017; Van den Berg et al., 2016) and even decreasing suicide mortality (Jiang et al., 2021). Areas in greater proximity to more green spaces were not only found to be associated with less mental fatigue or stress (Van den Berg et al., 2010), but also with less crime and higher social cohesion (Beyer et al., 2014). Accessible and usable green space was also found to be associated with decreased anxiety/mood disorder (Nutsford et al., 2013). More green spaces had been associated with lower rates of death due to stress-related illnesses (Mitchell & Popham, 2008). Higher exposure to residential green space and lower mood disorder medication sales were found in urban areas in a nationwide ecological study in Belgium (Aerts et al., 2022). However, relatively few studies investigated the association between tree canopy cover and mental health. Tiako et al. (2021) found that residential tree canopy cover was associated with lower prenatal stress among women with anxiety or depression. Another study found that older adults with exposure to 30 % or more tree canopy were less likely to experience psychological distress compared to those exposure to 0 % to 9 % tree canopy (Astell-Burt & Feng, 2019). Especially during the COVID-19 pandemic, a study in Beijing found that more tree canopy in residential areas was shown to be related to better mental health (Zhang et al., 2022).

Despite the mental health benefits of tree canopy cover in urban areas, little is known about how the socioeconomic status (SES) of a neighborhood may impact the observed associations. It is well-documented that the amount of tree canopy is not equal across neighborhoods (Schwarz et al., 2015) and the density of tree canopy cover was found to be positively correlated with the income of a neighborhood (Iverson & Cook, 2000). One study of urban heat risk found that racially more segregated neighborhoods had less tree canopy and more impervious surface cover (Jesdale et al., 2013), and another study showed that an unequal distribution of tree canopy cover varied along the lines of the residents' socioeconomic status thereby exacerbating health inequalities (Astell-Burt & Feng, 2019). Besides the mere amount of available green space, its quality and maintenance also matter (Mitchell & Popham, 2008). Less well-maintained, deprived neighborhoods usually have less access to green space, and if available, the green space is of lower quality, and in conjunction with safety concerns (Astell-Burt&Feng, 2019).

Additionally, SES is also an important predictor of suicide attempts and death. Ecological studies found that suicides as well as suicide attempts oftentimes concentrate in disadvantaged neighborhoods (Rehkopf & Buka, 2006). Collectively, people with lower SES are more vulnerable to suicide attempts than individuals with higher SES (Kim et al., 2016), and more likely to be exposed to forms of social and psychological deprivation (Stack, 2000). High unemployment and poverty contributes to a sense of social isolation, despair, and nihilism at the community level that can contribute to suicide even across different levels of SES (Kubrin et al., 2006). Across the board, more affluent neighborhoods tend to have better quality medical services that are better suited to lower the death toll from attempted suicides (Neumayer, 2003).

In sum, although several studies found a positive association between tree canopy cover and mental health as well as a negative association between neighborhood SES and suicide attempts, it remains largely unclear how both neighborhood SES and tree canopy cover can help predicting local suicide attempts. The present study aims at filling this gap using a combination of the secondary datasets, including the Area Deprivation Index (ADI) to measure the relative neighborhood SES and satellite imagery data for tree canopy cover, and objectively captured suicide attempts through the Emergency Medical Services (EMS) calls in the City of Cincinnati, Ohio. We explored how the association between green space and suicide attempts can be explained by levels of neighborhood deprivation at the Census block group levels. Given that the amount and quality of trees is distributed unequally across the city, we postulated that the protective impact of a higher tree canopy cover on local suicide attempts will be more pronounced in less advantaged areas.

2. Methods

2.1. This study

This study is based on data from the City of Cincinnati, Ohio, USA. The city has a land area of 206.07 km^2 with a population of 309,317 (2020 U.S. Census), which is the 3rd largest city in the State of Ohio. Importantly, Cincinnati was much larger in 1950 with a population of 503,998. Although Cincinnati is situated in the former Rust Belt, a region of the Northeastern and Midwestern U.S. that has experienced much industrial decline in the past, Cincinnati is currently growing slowly at an annual growth rate of 0.5 % and has increased by 3.5 % between 2010 and 2020. For this study, we included Census block groups with ≥90 % of the area within the city boundaries (n = 275). Data on local suicide attempts was extracted from a database that included the City of Cincinnati, and excluded the enclave municipalities of Norwood, Elmwood Place and St. Bernard. The local suicide rate is 12.8 per 100,000 people in the City of Cincinnati, as compared to 13.3 per 100,000 people in the State of Ohio and 13.0 per 100,000 people in the entire U.S. given the data between 2012 and 2016 (The Cincinnati Health Department, 2020). Cincinnati is racially a primarily White (50.7 %) and Black or African American (42.3 %) city (US Census Bureau 2019). In terms of tree canopy, Cincinnati has been referred as a "city in a park" with a higher than the National average tree canopy coverage (38 %). However, local tree canopy coverage varied substantially by neighborhoods (City of Cincinnati, 2018). Finally, the unemployment rate in Cincinnati was 3.6 % (Ohio: 4.2 % and U.S.: 3.6 %), trended down after the 2007–2008 financial crisis and before the COVID-19 pandemic according to the U.S. Bureau of Labor Statistics.

2.2. Data collection and measurement

2.2.1. Suicide attempts

The dependent variable in this study is the count of suicide attempts in the City of Cincinnati, OH. Suicide attempt records for city was obtained from the Emergency Medical Services (EMS) calls, a service that collects and addresses geocodes of all incidents that is handled by the Cincinnati Fire Department. The City of Cincinnati's computer aided dispatch database is the source of this data, provided by the City of Cincinnati's Open Data Portal. Since patterns of suicide might have been influenced by the COVID-19 pandemic, we used suicide attempt records reported from 2015 to 2019, i.e., before the COVID-19 pandemic. During this 5-year period, a total of n = 3,442 suicide attempts was reported and in 42 % of them, a medical transport was dispatched. During the same time, a total of N = 529 suicides (12.9 rate per 100,000 population) were reported for Cincinnati's surrounding county Hamilton (Ohio Department of Health, 2020), and the average annual suicide rate for Cincinnati, OH between 2009 and 2018 was reported to be 11.9 (Mental Health & Addiction Advocacy Coalition, 2020). Therefore, the number of suicide attempts in Cincinnati, OH is much closer to the number of suicides than usually reported (one suicide for every 25 suicide attempts; see Suicide Awareness Voices of Education, 2021). We used the total number of suicide attempts at the Census block group level as the primary outcome of this study.

2.2.2. Area deprivation index

The Area Deprivation Index (ADI) comprises of 17 variables clustered in four categories: poverty (e.g., median family income, income disparity, and number of families below poverty level), housing (e.g., owner occupied housing units, median home value), employment (e.g., employed persons aged 16 and older in white collar occupations), and education indicators (e.g., population aged 26 and older with at least a high school education). The index was created using the 5-year estimates of the 2019 U.S. Census American Community Survey (Kind & Buckingham, 2018) and ranged from 0 = *low deprivation* to 100 = *high deprivation*. Higher levels of the Area Deprivation Index are associated with lower SES, whereas a lower ADI indicates higher SES. The ADI is available through the Neighborhood Atlas supported by the National Institute of Aging. We modified ADI unit from percentage to decimal to be consistent with the unit of other variables. We also created a binary variable to categorize Deprivation as either more disadvantaged (ADI $>$ 76) or less disadvantaged (ADI $\leq$ 76) in order to easily compare the variables between two areas. The cutoff (ADI = 76) was based on the median ADI score of all census block groups ($n = 275$) within the city of Cincinnati, OH.

2.2.3. Tree canopy cover

The main predictor was the urban tree canopy coverage. Urban tree canopy cover data were acquired from the Multi-Resolution Land Characteristics (MRLC) Consortium website as a geospatial raster dataset for the year of 2016 with a 30-meter resolution. We summarized the tree canopy cover data as the proportion of each Census block group that is covered by tree canopy. Since most suicides occur in residential areas (Tian et al., 2016), we first considered the overall tree canopy coverage rate and also broke it down by residential properties using the citywide parcel boundaries and land use information to measure residential tree canopy separately, compared to other tree canopy cover found in the other areas.

2.2.4. Environmental and Demographic characteristics

The role of green space for public mental health cannot be underestimated. In this study, we included the rate of park areas per block group as a variable to capture accessible green space that is known to be beneficial for mental health (Bixby et al., 2015; Min & Min, 2018; Min et al., 2017). We also considered using the publicly available land cover information to capture different types of green space (such as forests and shrubs) but eventually had to exclude from the analysis due to the high correlation with the tree canopy information. Moreover, we included variables representing neighborhood disorders that could affect mental health. Foreclosed properties and vacancy rate were taken into consideration to represent abandoned or empty houses that are typically considered physical eyesores that can negatively affect the perceived quality of life (Raleigh & Galster, 2015) with foreclosures being a known factor for suicidality (Fowler et al., 2015; Houle, 2014; Houle & Light, 2014). We have considered two aspects of housing vacancies: how long on average a foreclosed housing stays vacant and how many dwelling units are vacant in the area. To identify the average length of vacancies, we aggregated foreclosure information provided by the City of Cincinnati to the block group level by averaging the length of vacancies during the observation period. When measuring the proportion of vacancy by block group, instead of identifying the number of foreclosed properties, we used the American Community Survey (ACS) information on housing vacancy in an effort to capture the overall housing vacancy rates by block group regardless of their foreclosure status. While ACS vacancy may not represent housing abandonment, studies have used ACS to represent the percentage of empty units at the neighborhood level (Newman et al., 2019). Another aspect of neighborhood disorder is safety concerns. We considered violent crimes (e.g., aggravated assault, homicide, robbery) and property crimes (e.g., burglary, theft, motor vehicle theft, and arson) separately, but later we combined them into one measure of crime density to avoid multicollinearity. To capture the crime level, we calculated crime incidents per square kilometer during the observation period using the incident level crime data provided by the Cincinnati Police Department. Although it might be more conventional to calculate the crime rate per capita, we chose to calculate the crime rate per area instead to keep the unit consistent across variables that measure environmental factors. Population density was included as a separate variable to control for various population counts. The structural environment that could potentially affect perceptions of living quality was measured with the rate of older (50 years or older) versus newer structures (20 years or newer). Additionally, we included neighborhood SES variables that have not been already included as indicators of Area Deprivation. Assistant housing was included to control for areas with more institutional subsidies. To capture low SES that was not included in the ADI measure, non-white minority status was included from the 5-year estimate American Community Survey (2015–2019). Working age between 15 and 44 and female (over male) rates were also included (see Barbosa et al., 2014).

2.3. Statistical analysis

We used negative binomial regression models to determine whether tree canopy and suicide attempts were correlated. Because of the skewed distribution of the suicide attempt events over the block groups, we adopted using negative binomial regression, which has typically been used to estimate count models with over-dispersion. Since the number of suicide attempt events from 2015 to 2019 was used as the dependent variable, we included population (per 1,000 persons) of block group as an exposure variable, which was log transformed and its coefficient was 1. This approach allowed the outcome to be interpreted as a logged attempted suicide rate (i.e., number of suicide attempt events from 2015 to 2019 per 1,000 persons) within the block group in this study. We also included spatial lags of explanatory variables in the model in an effort to control the spatial autocorrelation of the model. Importantly, for our observations that are based on block groups, spatial independence between observations cannot be assumed. Due to the adjacency between block groups, an indirect or spillover effect of explanatory variables on neighboring block groups could exist. This is known as an SLX model that includes these spatial lag variables of the explanatory (or X) variables (Anselin, 2003; Halleck Vega & Elhorst, 2015). A spatial weight matrix was calculated using the inverse distance method in order to address these spatial lags. This weighting method assumes a stronger relationship among spatially clustered or closer observations. We have also conducted diagnostic tests to specify the extent of potential spatial interdependence. Moran's I on residuals indicated significant clustering ($p = .042$). The Lagrange multiplier (LM) test results indicated significant spatial lag on variables ($p = .009$). After controlling for the SLX variables calculated with the weight matrix, however, both the Moran's I and LM test results show no spatial interdependence justifying our model to include SLX variables to control for spatial interdependence. Overall, the diagnostic test supported our assumption of spillover effects of explanatory variables and the inclusion of SLX variables.

For data analysis, we first calculated descriptive statistics for attempted suicides, tree canopy cover, and environmental variables at the block group level and compared them between more and less disadvantaged groups – stratified by ADI. X^2 tests were used to assess significant differences between the two groups. For our regression models, we first explored the relationship of tree canopy cover and residential tree canopy and suicide attempts while controlling for ADI and other control variables. To check the model robustness, we examined both non-spatial models (Model 1) and SLX models (Model 2) and repeated the same analyses for overall and residential tree canopy cover. We then introduced the interaction term between tree canopy cover and ADI to the models in order to examine whether the relationships of overall tree canopy cover (Model 3–1) and residential tree canopy cover (Model 3–2) and suicide attempts was moderated by ADI. We checked for possible multicollinearity using the variance inflation factor (VIF)

but found no indication of multicollinearity in our results (all VIF values were<2.5). All statistical analyses were conducted using Stata version 17.0 (Stata Corp LLC). Statistical significance was considered for *p*-values lower than 0.05.

3. Results

3.1. Characteristics by Census block groups

Table 1 shows the descriptive statistics for all Census block groups (n = 275) and stratifies them by the median value of the Area Deprivation Index. Overall, we found M = 12.92 suicide attempts per 1,000 population between 2015 and 2019 at the block group level. We also found that the average ADI in decimal format was M = 0.68 and the average tree canopy coverage rate and residential tree canopy coverage rate were M = 0.20 and M = 0.21 at the block group level. Fig. 1 presents maps of Cincinnati with the spatial distribution of attempted suicides, ADI, and tree canopy as per selected block groups.

More-disadvantaged block groups as defined by lower ADI scores as per median split had about 1.8 times more attempted suicides, compared to less-disadvantaged areas (Mdis = 16.75 vs Mnon-dis = 9.12, p <.001). In terms of urban green space, we found no significant differences of the rates of tree canopy cover or park area between more- and less-disadvantaged areas. For built environments, average foreclosure days, housing vacancy rate, and density of violent crimes, there were significant differences between more- and less-disadvantaged areas (all p <.001). More-disadvantaged areas also tended to be older as measured by the percentage of structures built before 1970 (MΔ = -0.06, SE = 0.02, p =.01) while less-disadvantaged areas tended to have more structures built after 2000 (MΔ = 0.04, SE = 0.01, p =.002).

3.2. The effect of tree canopy cover and area deprivation on suicide attempts

We then examined the effects of tree canopy cover and area deprivation (measured with ADI) on suicide attempts. Table 2 shows that both the non-spatial model (Model 1) and the SLX model (Model 2). These two models showed equivalent significance level of the coefficients at the same significance level confirming the robustness of Model 2 when the spatial lag variables (SLX) are included in the model. From Table 2, we found that there is a significant association between ADI, tree canopy, and attempted suicide rate. Specifically, as the deprivation level gets a one-percentage point higher, the number of attempted suicide rate significantly increases by 1.05 % per block group.[1] For tree canopy, the increase in tree canopy coverage generally decreases the attempted suicide rate, yet the residential tree canopy (Model 2–2) turned out to be only marginally associated with the attempted suicide rate (p=<.1). For the overall tree canopy variable (Model 2–1), a one-percentage point increase in tree canopy coverage significantly decreases the attempted suicide rate by 0.9 %. While tree canopy shows a significant association, the effect size is larger for ADI potentially indicating that area deprivation is a stronger predictor of attempted suicide rate than the tree canopy is.

Additionally, some of the control variables turned out to be significant factors predicting the number of suicide attempts. The housing vacancy rate (β = 1.847, p = <0.001 in Model 2–1 and β = 1.902, p = <0.001 in Model 2–2), and crime density (β = 0.069, p =.018 in Model 2–1 and β = 0.074, p =.012 in Model 2–2) were significantly associated with the suicide attempts while the average days of foreclosure were not a significant factor. Lower population density (β = -0.188, p = <0.001 in Model 2–1 and β = -0.185, p = <0.001 in Model 2–2) and more assistant housing (β = 0.768, p =.001 in Model 2–1 and β = 0.774, p =.001 in Model 2–2) were significantly associated with suicide attempts.

3.3. Moderating effects of neighborhood deprivation on the association between tree canopy and suicide attempts

Since the quality of tree canopy cover varied across neighborhoods in terms of areal deprivation, we tested whether the relationship between tree canopy and attempted suicide rate was conditioned by the levels of areal deprivation (Table 3). The ADI variable was included by interacting with overall tree canopy (Model 3–1) and with residential tree canopy (Model 3–2), but only the interaction term between ADI and overall tree canopy turned out to be significant (β = 2.101p =.031). This indicates that the level of area deprivation has a moderating effect on the association between overall tree canopy and suicide attempts. Fig. 2 shows the predictive margins of ADI from Model 3–1. Accordingly, as the level of overall tree canopy increases, the predicted number of suicide attempts gradually decreases. However, when comparing areas with high ADI (or, more disadvantaged areas; 75th percentile value) and low ADI (or, less disadvantaged areas; 25th percentile value), the preventive effects of tree canopy cover is stronger in less disadvantaged areas as compared to more disadvantaged areas.

4. Discussion

The purpose of this study was to examine the role of urban tree canopy and neighborhood deprivation on suicide attempts occurred in the city of Cincinnati, OH (USA). This study addressed gaps in the literature in multiple ways. First, spatial analysis to explain suicide attempts has been virtually missing due to data availability, and relatively little attention has been paid to environmental factors in conjunction with it. Previous studies typically used self-reported measures of suicide ideation or attempts (de la Garza et al., 2021). Using actual suicide attempt records from EMS providers, this study offers a more objective and accurate view on local suicide attempts that integrates additionally available local information. Second, we expand on the beneficial effects of urban tree canopy cover and community mental health, specifically regarding suicidal behaviors. Due to the high comorbidity of suicide and mental disorders including depression (Park et al., 2018), we hypothesized that tree canopy cover would potentially be able to help locally mitigate attempted suicides. Third, we explored compositional and contextual effects on the number of suicide attempts. Specifically, we integrated a measure of areal deprivation and other environmental factors to investigate the association between urban tree canopy cover and suicide attempts at the block group level.

4.1. From the socio-ecological viewpoint: neighborhood environment and suicidal behaviors

Our findings add to the body of evidence on the role of tree canopy cover in promoting mental health and reducing risks for mental disorders and suicidality among urban residents. When considering residential trees, however, the suicide preventive effects of tree canopy was less significant, which indicates that the positive effects of tree canopy cover is not simply limited to residential areas but includes all trees in the whole community whether or not residents have direct access. Previous studies consistently found that exposure to green spaces and the degree of tree canopy cover can help reducing stress, improving community mental health (Ulmer et al., 2016), and even mitigating street violent crime (Lee, 2021). A recent study in Germany found that a higher density of street trees was associated with less frequent prescriptions of antidepressants (Marselle et al., 2020), similar to physiological and psychological benefits of forest therapy (Hansen et al., 2017). In fact, it seems as if simply seeing green spaces has a relaxing effect (Tsunetsugu et al., 2013) and promotes recovery (Ulrich, 1984). Roadside vegetation

[1] When interpreting the effects of ADI and tree canopy cover from the Negative Binomial Models, we have converted the current coefficients (ranged 0 – 1) to percentage (ranged 0 – 100) before exponentiating the coefficients. For ADI, $[\exp(1.04 \div 100) - 1] \times 100 = 1.05\%$

Table 1
Suicide attempts, foreclosed properties, crime, tree canopy, stratified by area deprivation levels.

	Total	Less-disadvantaged	More disadvantaged	Mean DIFF	*p*-value
	(n = 275)	(n = 138) Mean (S.E)	(n = 137) Mean (S.E)	Mean (S.E)	
Outcome					
Number of suicide attempt (2015–2019)	11.24 (0.51)	8.07 (0.59)	14.44 (0.74)	−6.37 (0.95)	<0.001
Suicide attempt rate (2015–2019) per 1,000 persons	12.92 (0.78)	9.12 (0.88)	16.75 (1.2)	−7.63 (1.49)	<0.001
Independent Variables					
Area deprivation index (ADI)	0.68 (0.02)	0.47 (0.02)	0.89. (0.06)	−0.41 (0.02)	<0.001
Tree canopy rate	0.20 (0.01)	0.21 (0.01)	0.19 (0.01)	0.18 (0.02)	0.353
Residential tree canopy rate	0.21 (0.01)	0.22 (0.01)	0.19 (0.01)	0.03 (0.02)	0.088
Environmental Characteristics					
Park area rate	0.13 (0.01)	0.12 (0.01)	0.13 (0.02)	−0.01 (0.02)	0.568
Foreclosure (average days)	331.97 (8.6)	298.54 (13.54)	365.65 (9.84)	−67.11 (16.75)	<0.001
Housing vacancy rate	0.16 (0.01)	0.12 (0.01)	0.19 (0.01)	−0.07 (0.01)	<0.001
Violent crime density (counts per 1,000 km2)	0.14 (0.01)	0.1 (0.02)	0.18 (0.02)	−0.08 (0.02)	<0.001
Property crime density (counts per 1,000 km)	0.64 (0.05)	0.59 (0.08)	0.69 (0.06)	−0.1 (0.1)	0.321
Crime density (counts per 1,000 km)	0.78 (0.07)	0.69 (0.1)	0.87 (0.07)	−0.18 (0.12)	0.129
Population density (1,000 persons per 1,000 km)	2.27 (0.09)	2.25 (0.12)	2.29 (0.13)	−0.05 (0.18)	0.793
Structures built before 1970 rate	0.76 (0.01)	0.73 (0.02)	0.79 (0.01)	−0.06 (0.02)	0.011
Structures built after 2000 rate	0.06 (0.01)	0.08 (0.01)	0.04 (0.01)	0.04 (0.01)	0.0012
Assistant housing rate	0.07 (0.01)	0.05 (0.01)	0.09 (0.02)	−0.04 (0.02)	0.056
Demographic characteristics					
Minority rate	0.52 (0.02)	0.38 (0.02)	0.66 (0.02)	−0.28 (0.03)	<0.001
Age between 15 and 44 rate	0.44 (0.01)	0.46 (0.01)	0.42 (0.01)	0.04 (0.02)	0.021
Female rate	0.51 (0.01)	0.51 (0.01)	0.52 (0.01)	−0.01 (0.01)	0.397

Note: A chi-square test was used to compare the results between the two groups; neighborhoods were grouped into 2 deprivation levels: neighborhoods with ADI values in the top 50% were classified as more disadvantaged while those in the lower 50% were classified as less disadvantaged.; and we changed ADI unit from percentage to decimal ranging between 0 and 1 to be consistent with the unit of other variables.

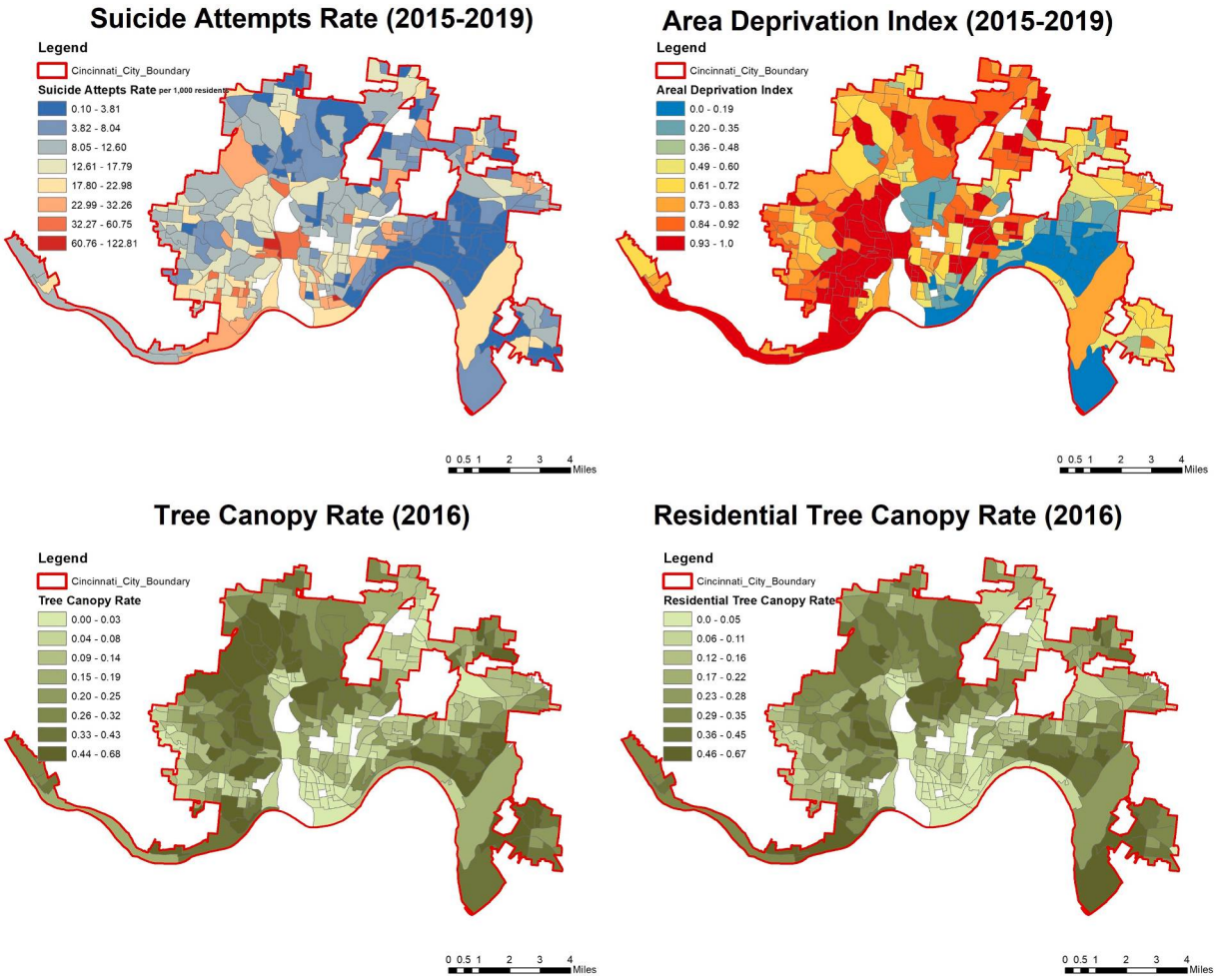

Fig. 1. Attempted suicide rates, ADI, tree canopy, and residential tree canopy by Census block group (n = 275).

Table 2
The effect of tree canopy and ADI on suicide attempts.

	Non-spatial model				SLX model			
	Model 1–1		Model 1–2		Model 2–1		Model 2–2	
VARIABLES	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
Direct effects								
Area deprivation index (ADI)	1.200***	(0.201)	1.160***	(0.201)	1.04***	(0.253)	1.045***	(0.259)
Overall tree canopy rate	−0.759**	(0.278)	–	–	−0.901**	(0.329)	–	–
Residential tree canopy rate	–	–	−0.681*	(0.31)	–	–	−0.682	(0.378)
Environmental Characteristics								
Park area rate	−0.033	(0.248)	−0.122	(0.243)	−0.075	(0.238)	−0.194	(0.231)
Foreclosure (days)	3.236	(1.911)	3.329	(1.921)	2.217	(1.936)	2.370	(1.945)
Housing vacancy rate	2.352***	(0.357)	2.373***	(0.358)	1.847***	(0.387)	1.902***	(0.389)
Crime density [a]	0.112***	(0.03)	0.114***	(0.031)	0.069*	(0.029)	0.074*	(0.029)
Population density	−0.171***	(0.034)	−0.17***	(0.034)	−0.188***	(0.033)	−0.185***	(0.033)
Structures built before 1970	−0.338	(0.243)	−0.31	(0.243)	−0.099	(0.245)	−0.052	(0.246)
Structures built after 2000	−0.142	(0.426)	−0.132	(0.429)	0.087	(0.425)	0.157	(0.431)
Assistant housing rate	1.012***	(0.238)	1.014***	(0.239)	0.768***	(0.230)	0.774***	(0.232)
Demographic characteristics								
Minority rate	−0.256	(0.17)	−0.238	(0.17)	−0.132	(0.204)	−0.112	(0.206)
Age between 15 and 44 rate	0.471	(0.305)	0.446	(0.308)	0.075	(0.313)	0.0470	(0.316)
Female rate	−0.641	(0.473)	−0.703	(0.475)	−0.474	(0.459)	−0.539	(0.462)
Indirect effects								
W × Area deprivation index					1.145	(0.791)	1.098	(0.804)
W × Tree canopy					1.624	(1.315)	2.232	(1.583)
W × Park area rate					0.662	(1.233)	0.524	(1.17)
W × Foreclosure (days)					−5.875	(10.34)	−4.503	(10.4)
W × Housing vacancy rate					−3.867*	(1.833)	−3.784*	(1.855)
W × Crime density					0.479**	(0.161)	0.495**	(0.162)
W × Population density					−0.269	(0.252)	−0.220	(0.26)
W × Structures built before 1970					0.117	(0.967)	0.0233	(0.946)
W × Structures built after 2000					3.120	(2.55)	3.837	(2.554)
W × Assistant housing rate					−1.055	(1.284)	−1.143	(1.316)
W × Minority rate					0.516	(0.513)	0.452	(0.516)
W × Age between 15 and 44 rate					0.456	(1.201)	0.375	(1.206)
W × Female %					−5.571*	(2.707)	−5.334*	(2.652)
lnalpha	−1.480	(0.132)	−1.465	(0.132)	−1.717	(0.145)	−1.692	(0.143)
Alpha	0.228	(0.03)	0.231	(0.03)	0.180	(0.026)	0.184	(0.026)
Constant	−4.973***	(0.403)	−4.948***	(0.415)	−3.034	(1.779)	−3.363	(1.878)
Pseudo R^2	0.101		0.099		0.122		0.12	
Observations	275				275			

Note: Standard errors in parentheses; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$[a]: We combined violent and property crime information to create a crime density variable due to the high correlation between the two types of crime data.

can be beneficial in reducing road rage (Cackowski & Nasar, 2003), and being exposed to greenery more long-term can contribute to developing resilience against suicide (Helbich et al., 2020).

The main underlying mechanism of the relationship between green spaces and mental health appears to be that tree canopy cover can mitigate some of the stressors that come with of urban life (Roe et al., 2017), promote recovery from stress and fatigue (Tiako et al., 2021). and even enhance social capital by promoting outside and street activities (Holtan et al., 2015). Tree canopy may also help reduce heat-related stress and potentially prevent pedestrian falls among older adults (Lee et al., 2022). Tree canopy, particularly near-road tree canopy can also buffer traffic-related air pollution and noise, which potentially prevent diseases such as childhood autism and Alzheimer's disease (Wu & Jackson, 2017; Wu & Jackson, 2021). Although there is some evidence that pollen peaks may be associated with suicide (Postolache et al., 2005), the benefits of tree canopy in preventing suicide attempts may outweigh possible pollen issues coming from the trees. Given the growing concerns in public health and increased stress levels in metropolitan areas and modern societies, our findings suggest that planting trees may be a cost-effective and natural health intervention to improve community mental health and to mitigate local suicidality.

More importantly, there are several social and built environmental factors that are associated with patterns of suicide attempts that this study confirms and that have been discovered in previous studies. For example, housing vacancy rate and crime density were consistently found to be risk factors for local suicide attempts in this study. This is in line with previous studies indicating that neighborhood disorders can be associated with suicide attempts (Pickover et al., 2021). People living in urban areas with increased traffic, noise, and threats from crime are more likely to suffer from psychological distress (Gruebner et al., 2017). Considering the significance of such neighborhood factors, interventions to improve the local living quality and safety might be most effective to mitigate suicidal behaviors and increase mental well-being and one of these measures could be the provision of more tree canopy coverage.

Some neighborhood characteristics, on the other hand, yielded mixed findings and were less clearly associated with suicide in the present study. For example, the average days of foreclosure did not significantly contribute to local suicidality. Perhaps, the number of vacancies, rather than the lingering effect of vacancies represented by the average foreclosed days, is more strongly linked to how a neighborhood is perceived. There was also an inverse relationship between population density and suicide attempts. Although previous studies reported that people who live in high-density cities show more mental health problems and a higher risk of substance abuse than those living in less densely populated areas, effects on suicide attempts were less clear-cut. The studies focusing on suicide attempts actually showed inconsistent findings on the relationship between density and suicide in that higher suicide rates have been reported in more sparsely populated, rural areas (Ivey-Stephenson et al., 2017; Page et al., 2007). As indicated by Vichi et al. (2020), higher suicide risk in less densely populated areas should

Table 3
The moderating effects of neighborhood deprivation on the association between tree canopy and suicide attempts.

	Model 3–1		Model 3–2	
VARIABLES	Coef.	S.E.	Coef.	S.E.
Direct effects				
Area deprivation index (ADI)	0.596	(0.323)	0.720*	(0.337)
Overall tree canopy	−2.433**	(0.781)	–	–
Residential tree canopy	–	–	−1.699*	(0.782)
ADI # Tree canopy	2.101*	(0.971)	–	–
ADI # Residential tree canopy	–	–	1.49	(1)
Environmental characteristics				
Park area rate	−0.071	(0.237)	−0.207	(0.231)
Foreclosure (days)	2.432	(1.925)	2.492	(1.94)
Housing vacancy rate	1.821***	(0.384)	1.88***	(0.388)
Crime density	0.065*	(0.029)	0.071*	(0.029)
Population density	−0.181***	(0.033)	−0.179***	(0.033)
Structures built before 1970	−0.122	(0.244)	−0.07	(0.246)
Structures built after 2000	−0.074	(0.429)	0.072	(0.433)
Assistant housing rate	0.758***	(0.229)	0.751**	(0.232)
Demographic characteristics				
Minority rate	−0.104	(0.203)	−0.084	(0.206)
Age between 15 and 44 rate	0.025	(0.311)	−0.009	(0.317)
Female rate	−0.522	(0.456)	−0.566	(0.461)
Indirect effects				
W × Area deprivation index	1.050	(0.788)	1.039	(8.041)
W × Tree canopy	1.351	(1.310)	2.452	(1.585)
W × Park area rate	0.940	(1.235)	0.558	(1.171)
W × Foreclosure	−4.036	(10.29)	−2.944	(10.44)
W × Housing vacancy rate	−2.970	(1.865)	−3.114	(1.904)
W × Crime density	0.367*	(0.169)	0.420*	(0.170)
W × Population density	−0.181	(0.254)	−0.137	(0.265)
W × Structures built before 1970	−0.242	(0.978)	−0.0759	(0.949)
W × Structures built after 2000	2.523	(2.541)	3.998	(2.547)
W × Assistant housing rate	−1.195	(1.274)	−1.391	(1.323)
W × Minority rate	0.341	(0.516)	0.343	(0.520)
W × Age between 15 and 44 rate	0.327	(1.194)	0.278	(1.206)
W × Female rate	−6.497*	(2.724)	−6.088*	(2.698)
lnalpha	−1.741	(0.146)	−1.702	(0.144)
Alpha	0.175	(0.026)	0.182	(0.026)
Constant	−1.89	(1.849)	−2.782	(1.916)
Pseudo R^2	0.124		0.121	
Observations	275			

Note: Standard errors in parentheses; *** p < 0.001, ** p < 0.01, * p < 0.05

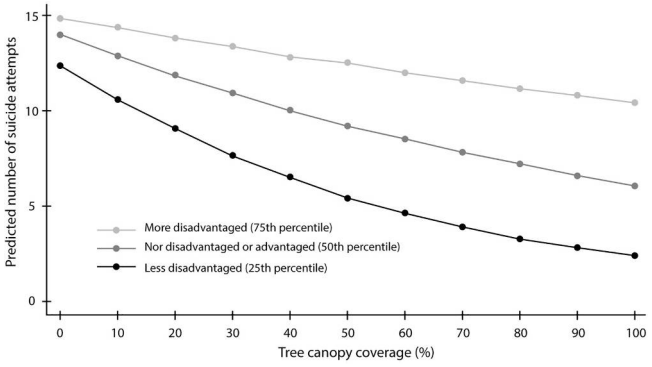

Fig. 2. Local Tree Canopy Cover and Suicide Attempts Contingent upon the Area Deprivation Index (ADI).

therefore be further explored considering other factors than mental illness. Interestingly, the percentage of urban park areas did not significantly predict suicide attempts despite more general findings on the positive impact of green space on mental health. This shows the importance of specifying what elements of green space may be influential.

4.2. From the environmental justice viewpoint: planning for marginalized communities

Marginalized communities have been historically more affected by mental health issues due to limited resources and support to overcome them. Highly disadvantaged areas are particularly at-risk for greater depression (Cohen-Cline et al., 2018) and more suicide attempts than other areas even after adjusting for individual-level socioeconomic status (Ngui et al., 2015). We also found that the Areal Deprivation Index (ADI), an indicator of neighborhood socioeconomic status and inequality, is a significant predictor of neighborhood-level suicide attempts. People in more disadvantaged areas tend to have restricted access to the local amenities (Olsen et al., 2017), live in inadequate housing conditions (Adamkiewicz et al., 2014), have more safety concerns (Cohen et al., 2016), and face greater challenges in recreational walking and use of outdoor recreational facilities during the COVID-19 pandemic (Lee et al., 2022). Supporting this notion, we found that disadvantaged areas tend to have a higher housing vacancy rate, longer foreclosure days, and higher violent crimes. A recent study also using the Areal Deprivation Index also found that higher neighborhood deprivation was associated with suicidal ideation during the COVID-19 pandemic (Okubo et al., 2021). Thus, systematically disadvantaged areas cannot be underestimated as a risk factor for suicide especially if marginalized communities are disproportionally affected by them and when risk factors for suicide are examined and community health is meant to be promoted.

Notably, what makes it challenging to support and implement policies targeting marginalized communities is the complexity of neighborhood dynamics; When the benefits of new policies are not the same across communities, they might not work as expected. Socioeconomic inequalities in health are known to be less pronounced in people with greater exposure to green space than in those with less exposure (Mitchell & Popham, 2008; Thompson et al., 2012). Contrary to previous findings, however, we found that socioeconomic inequalities in suicide attempts were greater as tree canopy cover increased across the neighborhoods with different ADI levels in Model 3. This result is in line with our concerns on the role of a socioeconomic environment that could affect mental health. While tree canopy turned out to mitigate potential suicides, not all areas may similarly profit from the same benefits. It is uncertain what underlies this finding, but it implies that simply examining tree canopy cover might not be enough to improve local mental health especially in highly deprived areas. The mitigating effects of tree canopy on reducing mental health issues could also be weaker in areas with highly disadvantaged neighborhoods. This may be because tree canopies and green spaces within disadvantaged neighborhoods are often of poorer quality and maintenance than in advantaged areas (Crawford et al., 2008), which may potentially offset the role of tree canopy in reducing the suicide attempts in our study.

For environmental justice, therefore, interventions to improve tree canopy coverage seems critical, especially for communities with high deprivation levels. Increasing tree canopy cover still helps especially disadvantaged communities by mitigating mental health issues and suicide, but the benefits may not be as great as in other areas. This leads to a few additional questions to promote environmental justice and maximize the benefit from tree canopy across communities. First, what should be the priority when implementing mental health-related policies in marginalized communities? Future studies need to examine the qualitative and perceptional aspects of tree coverage to better understand what limits the benefits of tree canopy. We also question if there would be certain types of tree species that could especially benefit disadvantaged communities (for example, tree species with lower maintenance cost). Species that require less maintenance and that are visually more organized could potentially mitigate perception of disorder when tree canopy is meant to be increased through changed city-wide policies and landscaping guidelines. Lastly, are there other neighborhood resources that could be implemented in conjunction with

improving tree canopy to maximize the benefits of tree coverage? Utilizing existing vacant properties as additional green spaces could potentially benefit marginalized communities to further enhance the quality of the neighborhood environment and to maximize the benefits of green spaces and tree canopy coverage.

4.3. Limitations

The present study is subject to several limitations. First, this study relied on cross-sectional approach, which might fail to sufficiently reflect on possible causalities of changes in areal deprivation and tree canopy on suicide attempts at the Census block group level. Secondly, the data sets used in our analyses were captured at slightly different time periods due to data availability. For example, tree canopy coverage rate was measured based on 2016 data, while the areal deprivation index relied on 2019 ACS data, and suicide attempts, foreclosure, and crime data were aggregated for 5 years (2015–2019) in this study. Thus, we were unable to assess seasonal or temporal effects. For example, previous studies indicated that suicide rates are higher in the spring due to allergic reactions (Postolache et al., 2010) and acute circadian rhythm shifting from a sudden increase in the duration and amount of sunlight (Cho & Lee, 2018). Future research will have to consider seasonal and weather-specific patterns and effects on suicide attempts in much greater detail than we could. However, using a 5-year aggregated data, this study could help account for annual fluctuations and ensure sufficient counts and variation in the data. At the same time, more studies need to be done and further examine quality aspects around trees and green spaces that could further reduce the gap especially among disadvantaged communities. Moreover, this study is subject to generalizability concerns as our study is an examination of one U.S. city with relatively greater tree canopy coverage. Typically, suicide rates are lower in less densely populated urban areas but higher in rural over urban areas. While green spaces can be a powerful tool to help improving mental health in urban areas, more factors and geographic diversity need to be addressed in future studies (e.g., Barry et al., 2020). Finally, our secondary data relies on the tree canopy data at the 30-meter resolution. Additional data with higher resolution such as one-meter tree canopy data and additional surveys or interviews could add precision to our understanding of the causes of the differential effects of tree canopy cover.

5. Conclusion

This study found that local tree canopy cover could be a useful tool to improve local mental health-related outcomes including suicide attempts. Results showed that the effects of tree canopy cover were stronger in less disadvantaged areas as compared to highly disadvantaged areas, suggesting that interventions to the local living quality and safety in conjunction with the provision of more urban green space might be most effective to reduce local suicide attempts and increase mental well-being of vulnerable residents. For environmental justice, interventions to qualitatively improve green space seem most fruitful for historically marginalized and disadvantaged communities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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