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Greenness, Deprivation, and Fatal Police Shootings: A Five-Year Nationwide Study in the United States

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Abstract

Police shootings are a serious form of violence that have profound impacts on social well-being. Although the impacts of socioeconomic, demographic, and regulatory factors on fatal police shootings were well established, the relationship between greenness levels and police shootings remains unclear, especially across varying levels of social deprivation. To address this knowledge gap, we conducted a three-step analysis. First, an analysis of 3,108 counties in the contiguous United States revealed a significant negative association between the level of greenness and incidence of fatal police shootings. Second, a focused analysis of 805 metropolitan counties revealed an even stronger association. Third, we found the negative association

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remains significant across five levels of social deprivation, with a stronger association observed in counties with higher levels of social deprivation. This study is the first to examine relationships between greenness levels and fatal police shootings. These findings may provide initial evidence and a novel perspective for policymakers, researchers, and professionals, suggesting that greenspaces may serve as a promising environmental intervention to reduce fatal police shooting and other types of social violence or conflict.

Keywords
police violence, firearms, green spaces, social deprivation, environmental interventions

Lethal police actions, especially police shootings, are at the center of an intense society-wide debate in the United States (DeGue et al., 2016; Naghavi, 2021; Peeples, 2019). Police shootings can cause immediate fatal consequences and, in some cases, lead to chronic health problems that increase the risk of premature mortality (DeVylder et al., 2018, 2022). Police shootings can also exacerbate social disparities and affect communities of color, teenagers, young adults, and other marginalized groups more than others.

Scholars have worked to understand fatal police shootings through two primary frameworks (Cesario et al., 2019; Goldkamp, 1976; Holmes et al., 2019; D. Jacobs & Britt, 1979; Klinger et al., 2016; Robin, 1963). The socio-economic deprivation framework suggests that police shooting is influenced by factors such as racial composition (Schwartz & Jahn, 2020), population density (Sheppard & Tucker, 2022), educational level (Sheppard & Tucker, 2022; Terrill & Reisig, 2003), and economic disadvantage of a community (Sherman & Langworthy, 1979; Thomas & Drawve, 2018). The crime threat framework examines links among the prevalence of guns in a neighborhood, the perception that a neighborhood is a dangerous place, and fatal police shootings (J. J. Fyfe, 1980; Klinger et al., 2016; Liska & Yu, 1992; Terrill & Reisig, 2003).

Other environmental determinants of fatal police shootings, such as healthy green vegetation cover or "greenness," has been overlooked. The cost of this oversight is borne by individuals, families, communities, and governments who grapple with police shootings that are perceived by residents and others as unwarranted. Police shootings are linked to higher neighborhood mortality rates (Cooper et al., 2004; Duarte et al., 2020; Haskins, 2018) and increased risk of chronic health conditions such as high blood pressure, diabetes, poor self-rated health, and asthma (Cooper & Fullilove, 2016). In contrast, studies on the impact of greener communities repeatedly demonstrate

their health-inducing effects. These impacts range from lower levels of aggression and violence (Kuo & Sullivan, 2001a), reduced crime (Bogar & Beyer, 2016), lower levels of impulsivity (Sullivan & Li, 2021), less stress among residents (Jiang et al., 2014), and greater levels of neighborhood social support and cohesion (Kweon et al., 1998). Such findings suggest the possibility that greener areas might mitigate the number of police shootings. The study presented here is designed to assess this possibility.

As our literature review below will show, the factors that lead a police officer to shoot a person are a multi-layered mix of psychological, structural, and environmental conditions. We acknowledge that even if the greenness level in a community is related to fatal police shootings, a great deal more needs to be done to understand the case. We also acknowledge that addressing police shootings requires considerably more than planting trees and other forms of vegetation in neighborhoods.

Existing Mechanisms: Socio-Economic Deprivation and Crime Threat

Research on police shootings has been guided by two primary theoretical frameworks: the socio-economic deprivation perspective and the crime threat perspective (Keller et al., 2023; Nix & Shjarback, 2021; Sheppard & Tucker, 2022). Both have a strong theoretical basis and are supported by substantial empirical evidence.

Fatal police shootings have long been analyzed with the socio-economic disparity framework (Blalock, 1967) and decades of empirical evidence. Police officers are known to have different levels of trigger sensitivity when engaging with people from social deprivation classes (Takagi, 1974). Socio-economic deprivation factors include racial composition (Cesario et al., 2019; Goldkamp, 1976; Holmes et al., 2019; D. Jacobs & Britt, 1979; Klinger et al., 2016; Robin, 1963), population density (Sheppard & Tucker, 2022), divorced households, and mean educational attainment of community members (Sheppard & Tucker, 2022; Terrill & Reisig, 2003). Economic disadvantage factors include unemployment rate (Sherman & Langworthy, 1979; Thomas & Drawve, 2018), income inequality (D. Jacobs & O'Brien, 1998; Sorensen et al., 1993; Thomas & Drawve, 2018), and poverty rate (Sheppard & Tucker, 2022). Recent studies include public health inequality factors, such as suicide rate, mental illness, and mental fatigue rates (DeGue et al., 2016; S. Smith et al., 2022) to provide a more comprehensive picture of a disadvantaged community.

Violent crime rate is closely linked to the physical environment and is the most well-established ecologic factor associated with police shootings (J. J.

Fyfe, 1980; Klinger et al., 2016; Liska & Yu, 1992; Terrill & Reisig, 2003). Areas with higher levels of violent crime tend to experience more fatal police shootings (J. J. Fyfe, 1980; Klinger et al., 2016). Several classic theories and empirical evidence support the crime perspective. The threat hypothesis by Liska and Yu demonstrates the positive association between violent crime rates and police shootings (Liska & Yu, 1992). More crimes tie to higher threat to the public safety and officers, and more police-citizen encounters, which provides higher chances for officers to deploy the lethal forces (Hemenway et al., 2019; Langworthy, 1986; Miethe & Meier, 1994). The danger-perception theory (MacDonald et al., 1999, 2001) emphasizes the direct link between exposure to dangerous places, gun ownership, and fatal police shootings (Fryer, 2019; Hemenway et al., 2019; Nix & Shjarback, 2021).

It is interesting to note that both the socio-economic deprivation perspective and the crime threat perspective can be directly and indirectly linked to green landscapes. We turn our attention to these links now.

Environmental Determinants of Police Shootings

Built Environments. Considerable theory and empirical evidence link characteristics of the built environment to fatal police shootings (Holmes et al., 2019; Keller et al., 2023). The most prominent built environment factor predicting police shootings is residential segregation; the more racially segregated and non-white a neighborhood is, the more likely it is to be the site of a police shooting (Drawve et al., 2016; Thomas et al., 2022). Urbanicity level is also shown to strongly correlated with police shootings (Leslie et al., 2022). Other built-environment factors include risky locations like bars, schools, parks, and bus stops (Drawve et al., 2016; Keller et al., 2023; Thomas & Drawve, 2018); A variety of visual landscape features have also been associated with police shootings. Disordered settings, ones with graffiti, considerable litter, dilapidated housing, and broken windows may send cues to police officers that a place is uncared for and thus is likely dangerous (Caplan & Kennedy, 2016; Drawve et al., 2016; Kelling & Wilson, 1982; Leslie et al., 2022; Thomas & Drawve, 2018).

Green Environments. Although the relationship between a variety of built environment features and fatal police shootings is well established, the relationship between greenness and police shootings remains unclear. Recent studies have highlighted the role of the urban landscape in reducing police shootings, but the greenness of the setting in which the shooting occurred has not been systematically assessed (Holmes et al., 2019; Keller et al., 2023; Thomas et al., 2022).

More general research on greenness has found both negative and positive relationship to violence, crime, and fear of crime. On the negative side, studies have found that greener areas can become gang territory (Branas et al., 2011) and in some cases sites of contention as gangs compete for terrain they might control (Bogar & Beyer, 2016). Many people fear for their safety when vegetation reduces visibility or limits their capacity to easily escape a setting (Jorgensen et al., 2002; Kaplan, 1984; Nasar & Fisher, 1993). Reasonable people can also fear that greener areas provide hiding places for individuals who might engage in illicit behavior (Michael et al., 2001). Indeed, fear of crime is higher where vegetation blocks views (Fisher & Nasar, 1992; Kuo, Bacaicoa, et al., 1998). Recent studies also found the impacts of green spaces are not fair and may contribute to green gentrification, especially for the social or racial disadvantaged communities (Xu, Jiang, Sullivan, et al., 2024). The less privileged residents in gentrified neighborhood may suffer more from the negative impact brought by green spaces (Cole et al., 2019; Triguero-Mas et al., 2022).

On the positive side, a variety of studies have shown that greener areas are associated with lower levels of violence and crime (Lu et al., 2024). One study conducted in a Chicago public housing neighborhood found that the greener the surroundings, the fewer property and violent crimes (Kuo, Sullivan, & Coley, 1998). A study of Philadelphia, Pennsylvania found that vegetation abundance was significantly associated with lower rates of assaults, robbery, burglary, but not theft (Wolfe & Mennis, 2012). A study in Portland, Oregon, found that trees in the public right of way were associated with lower crime rates but that not all vegetation influences crime in the same way (Donovan & Prestemon, 2012).

Also on the positive side, higher densities of trees in urban landscapes have been shown to reduce fear of crime. In a simulation study that systematically varied a number of landscape features in a large public housing neighborhood courtyard, the density of vegetation and the maintenance of the grass were the strongest positive predictors of sense of safety (Kuo, Bacaicoa, & Sullivan, 1998). In a different public housing neighborhood, residents living in building with more nearby vegetation gave higher ratings to the item "I feel safe living here" than residents living in more barren buildings (Kuo, Sullivan, & Coley, 1998). These general findings have been replicated in different landscape contexts with different populations (Jiang et al., 2017, 2018). Finally, greener areas can reduce some of the psychological precursors to aggression and violence by alleviating mental fatigue and the irritability and impulsiveness that results from mental fatigue (Kaplan, 1987), mental stress (Kondo, Jacoby, & South, 2018; Ulrich et al., 1991), anxiety (Xu, Wang, Sullivan et al., 2024) and depression (Sullivan & Li, 2021). Such psychological precursors are directly linked with danger-perception, place cognition,

and decision making (Bowleg et al., 2022; N. R. Fyfe, 1992; Kaplan, 1987). Higher levels of mental fatigue, stress and depression trigger more officers' self-defensiveness behaviors and provoke more resistance and conflicts of the residents which can stimulate the fatal police shootings (Fryer, 2019; Geller & Karales, 1981).

Taken together, these findings raise the question of the extent to which levels of vegetation in a community are associated with fatal police shootings. On the one hand, if vegetation blocks views, provides opportunities for individuals with ill intent places to hide, and invites conflicts among gangs, we expect to see more police shootings in areas that have higher levels of vegetation. On the other hand, if the overall impact of green landscapes is to reduce aggression, violence, and stress, while sending a signal that a place is cared for, then we would expect to see a lower incidence of police shootings in areas that have higher levels of vegetation.

Critical Knowledge Gaps and Research Questions

Based on our previous analysis, we have identified two critical gaps in our knowledge regarding the relationship between greenness levels and the incidence of fatal police shootings. First, we do not know whether and to what extent exposure to greenspaces, indicated by county-level greenness has a significant association with fatal police shooting incidence, especially in highly urbanized metropolitan areas. Second, we do not know how this relationship varies with levels of social deprivation, despite social deprivation being an important moderator of environmental health. We seek to fill the gaps by pursuing the following research questions:

1. What is the relationship between level of greenness and incidence of fatal police shootings across all contiguous United States counties controlling for potential covariates?
2. What is the relationship between level of greenness and incidence of fatal police shootings across metropolitan counties in the contiguous United States controlling for potential covariates?
3. How does the relationship vary across five levels of social deprivation for all contiguous United States counties controlling for potential covariates?

Methods

We analyzed the relationships between the level of greenness and the incidence of fatal police shootings in the contiguous United States over a 5-year

period (2016–2021). The study design consisted of three steps to address the three research questions. First, we applied the Besag-York-Mollié (BYM) model to all 3,108 counties in the contiguous United States to answer RQ1. Second, we conducted the same analysis for the 805 metropolitan counties over 250,000 populations to answer RQ2. Third, we used the BYM model and covariates to examine how these relationships vary across five levels of social deprivation to answer RQ3.

Study Area and Scale

We examined county-level relationships between greenness and police shooting cases over 5 years (from January 1, 2016, to December 31, 2020) across all 3,108 counties in the contiguous United States and separately for 805 counties that had a population of greater than 250,000 people in 2020. The contiguous United States encompasses the lower 48 states, including the District of Columbia, that share a common border.

Even though most studies of police shootings analyze limited individual-scale data focusing on a small physical setting, evidence suggested that we should analyzed the issue at county scale for two major reasons (D. Jacobs & O'Brien, 1998). Firstly, unlike smaller census units (i.e., tracts or block groups), counties represent geographic areas encompassing jurisdictional areas for many law-enforcement officers (e.g., sheriff's offices). Leading indicators such as law enforcement policy and social stigma toward different races are on a county-scale phenomenon (Galtung & Höivik, 1971; Gilligan, 1999; Hoivik, 1977). Public health, economic, and social outcomes are also contagious on a larger level (Bloom, 2018; Lee, 2019). Thus, it is important to consider each case's social, economic, and environmental context collectively, rather than treating police shootings as isolated incidents. Secondly, counties also provide large-enough geographies to encompass enough shooting cases. Only 5.9% of census tracts had more than one shooting case during our study period, only one tract[1] (tract 12011110321) had more than four cases in this period. Similarly, 3.0% of census blocks had more than one shooting case in this period, and only one block had more than four shootings (block 120111103211).

Variables

Dependent Variable: Police Shooting Cases. We used the sum of police shooting cases across 5 years (January 1, 2016 to December 31, 2020) for each county as the dependent variable. This study focused on fatal police shootings in which a person dies because of being shot by police officers, whether the

officer was on-duty or off-duty. To avoid duplicates, we use the combination of the victim's name and county, resulting in 5,135 cases over the study period. We retrieved police shooting case data from three major non-governmental open-source databases: the Mapping Police Violence project (MPV; Schwartz & Jahn, 2020), the Fatal Encounter Database (FE), and the Washington Post Fatal Force (FF).

The MPV database, maintained by the research-based platform Campaign Zero (Zero, 2022), includes data from FE and FF and contains longitudinal data since 2013 with an estimated 9% missing cases compared to law enforcement and government reports. A recent study published in the *Lancet* found that government reports such as the USA National Vital Statistics System (NVSS) or an FBI's recent program fail to record more than half (55.5%) of police violence instances (Naghavi, 2021). The FE database is a personal blog that tracks data using Google News Alerts, crowd-sourced public record requests, and media flags (Burghart, 2022). The FF database, maintained by the *Washington Post*, provides data from local news reports, law enforcement websites, social media, and independent databases such as Killed by Police and Fatal Encounters (Jenkins et al., 2022).

Independent Variable: Greenness. We estimated the quantity of greenness (Figure 1) with the measure of Normalized Difference Vegetation Index (NDVI) with Google Earth Engine (Gorelick et al., 2017). The data source was the 30-meter resolution Landsat 8 multispectral remote sense imagery (Roy et al., 2014). We calculated the annual NDVI from the mean value of 4 monthly NDVI measurements (March, June, September, December) to represent the four seasons. The NDVI values are calculated with the following formula, which contrasts the chlorophyll pigment absorptions in the red band ("RED") with the high reflectivity of plant materials in the near-infrared band ("NIR"; Matsushita et al., 2007):

$$\mathrm{NDVI} = \left(\mathrm{NIR} - \mathrm{RED}\right) / \left(\mathrm{NIR} + \mathrm{RED}\right)$$

Moderator: Social Deprivation Index (SDI). Given the significant association between the social-economic deprivation factors and fatal police shootings, we controlled the related factors, and introduced the social deprivation index as the moderator to further develop our research questions. We retrieved Social Deprivation Index (SDI) datasets from Robert Graham Center, which include both SDI score and SDI ranking (Center, 2015). The SDI is used to describe area-level socioeconomic variation in deprivation outcomes and is widely recognized as a reliable measure of socioeconomic disadvantage (Bevan et al., 2022; Cottrell et al., 2020; Griggs et al., 2022). The SDI score

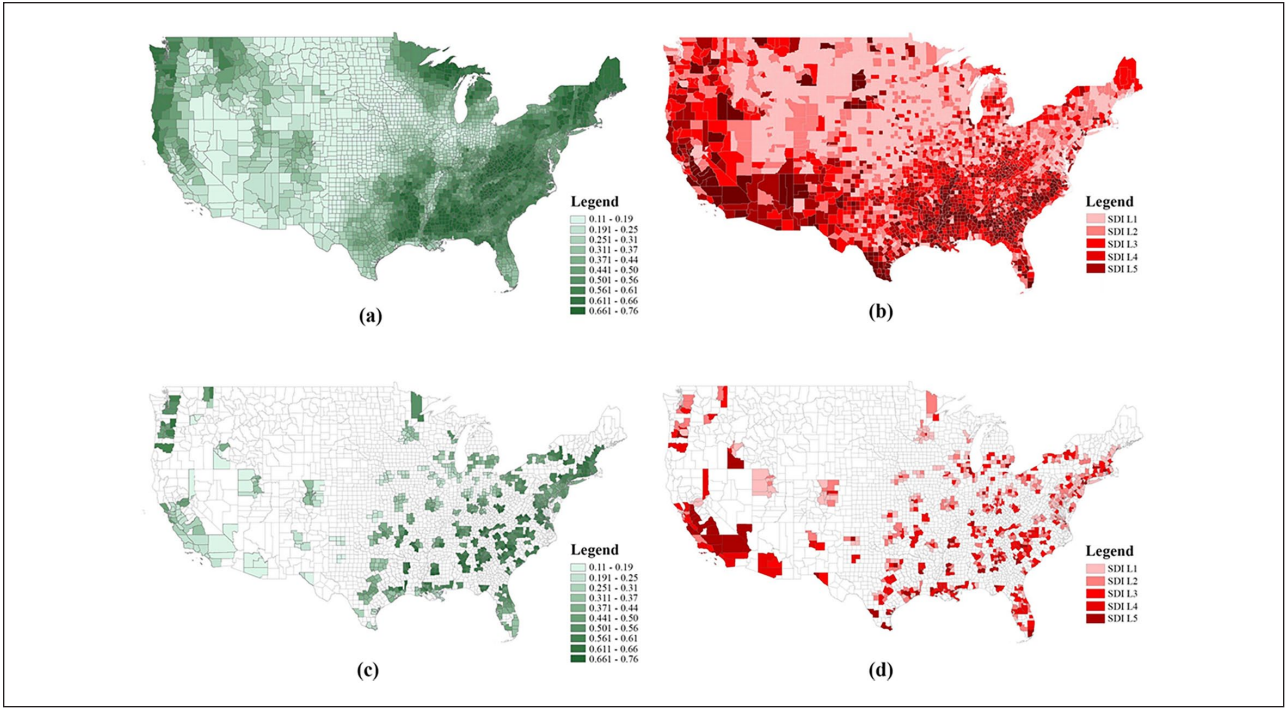

Figure 1. Mapping of key variables. (a) NDVI across all 3,108 counties in the contiguous United States. (b) SDI levels across all 3,108 counties in the contiguous United States. (c) NDVI across the 805 most populated metropolitan counties in the United States. (d) SDI levels across the 805 most populated metropolitan counties in the United States.

ranges from 0 (least deprivation) to 100 (most deprivation). Based on SDI score, geographic areas are classified into five deprivation levels by dividing the 100-point scale into five equal segments. SDI level 1 represents the least deprived areas, while level 5 represents the most deprived areas (Butler et al., 2013; Phillips et al., 2016).

The SDI score is a composite measure calculated with factor analysis method based on seven demographic characteristics from the 2015 to 2019 American Community Survey (ACS) 5-year estimates: the percentage of individuals living in poverty, those with less than 12 years of education, single-parent households, rented housing units, overcrowded housing units, households without a car, and non-employed adults under 65 years of age. Before performing the factor analysis, all seven demographic measures were converted into centiles. The SDI has been used in several studies as a reliable measure of socioeconomic status (Butler et al., 2013).

Potential Covariates. We chose the covariates based on the hypothesized relationships from existing theory frameworks and empirical evidence we covered in the introduction section. We summarized the rationality of covariates selection, and each covariate's corresponding theory bases, empirical study evidence, and descriptions in a flowchart (Appendix 1) in the appendix. We also generated a directed acyclic graph (DAG) of the hypothesized greenness level—police shooting relationship to select and control potential covariates (Appendix 2) for adjustments. The summarized description data sources of the chosen variables are presented in the Appendices 1–3. As a summary, three major categories of covariates used in this study are introduced below:

Social-economic and demographic factors. The social and economic correlates of police shooting cases were selected based on past research on this topic (Bowleg et al., 2022; DeVylder et al., 2018; D. Jacobs & O'Brien, 1998). All the following data are derived from the US Census Bureau's 2020 American Community Survey (ACS) 5-year summary file, which provides estimates of average characteristics from 2016 through 2020. The timeframe is consistent with the shooting cases. Data consists of population density; the proportion of White non-Hispanic, Black or African American non-Hispanic, and Hispanic/Latino (Cesario et al., 2019; Goldkamp, 1976; Holmes et al., 2019; D. Jacobs & Britt, 1979; Klinger et al., 2016; Robin, 1963); the proportion of young male and female (15–24 years old) (Geller & Karales, 1981); the proportion of the divorced households (Sheppard & Tucker, 2022); poverty rate (the proportion of households whose income in the past 12 months are below poverty level) (Sheppard & Tucker, 2022); unemployment rate (Sherman & Langworthy,

1979; Thomas & Drawve, 2018); the Gini index of income inequality; the median house income (D. Jacobs & O'Brien, 1998; Sorensen et al., 1993; Thomas & Drawve, 2018); and the percentage of population with a high school diploma or lower (Sheppard & Tucker, 2022; Terrill & Reisig, 2003).

Crime factors. We selected the crime covariates based on previous published evidence (D. Jacobs & O'Brien, 1998). One of these factors was the violent crimes rate from the FBI Crime Data Explorer Database from 2016 to 2020, including murder and nonnegligent manslaughter, rape, robbery, and aggravated assault (Burghart, 2022). Another factor was the presence of a state firearm restriction law (Alpert & MacDonald, 2001; Jennings & Rubado, 2017; Kivisto et al., 2017; Nowacki, 2015; Sparger & Giacopassi, 1992), and the state-level estimation of household firearm ownership (Hemenway et al., 2019; Nix & Shjarback, 2021). Both of the latter two factors were retrieved from the RAND State Firearm Law Database initiated in January 2016. The restriction law has ten levels range from the loosest to the most restricted. We bring in the mobility index and the POI foot traffic to evaluate the social activity pattern for each county, which is a key triggering factor of the crime rates based on the Risk Terrain Modeling (RTM) and Routine Activity Theory (Caplan & Kennedy, 2016; Liska & Yu, 1992). The mobility index drawn from Descartes Labs calculates the median of maximum moving distances within the threshold of 50 meters each county using the individual cell phone user's GPS locations (Hu et al., 2021; Warren & Skillman, 2020). The place of interest (POI) foot traffic is a GPS-derived count data from the SafeGraph database, it measures the number of times each person on average visits to different risky locations related to crimes, including urban transit systems, grocery stores, parks, gas station, and bars.

Built environment factors. Built environment factors are representative indicators of fatal police violence (Sanciangco et al., 2022; Wolfe & Mennis, 2012). The most convinced built environment covariate associating with police shooting cases is racial residential segregation (Leslie et al., 2022; Siegel et al., 2019). The index measures the concentration and clustering of the different races. The index ranges from 0 to 1, and 1 represents the total segregation (Massey & Denton, 1988; Oka & Wong, 2014). The equation for the racial residential segregation index is listed below:

$$D = \frac{1}{2}\sum_{i=1}^{n}\left|\frac{w_i}{W_T} - \frac{b_i}{B_T}\right|$$

where n is the number of the 3108 counties, w_i is the number of non-Hispanic Whites in county i, W_T is the number of non-Hispanic Whites in the county, b_i is the number of non-Hispanic Blacks in county i, and B_T is the number of non-Hispanic Blacks in the county. In this study, we calculate three groups of indexes between White non-Hispanic and Blacks non-Hispanic, White non-Hispanic and Hispanic, and Blacks non-Hispanic and Hispanic. We also introduce in four variables to measure the urbanization levels. The first is urbanicity level data according to 2013 NCHS (National Center for Health Statistics) Urban-Rural classification scheme.[2] The other three are low, medium, and high intensity levels of the developed areas from the 2019 National Land Cover Database (NLCD). Low intensity developed areas (NLCD code 22) have impervious surfaces 20% to 49% percent of total cover, and include most commonly include single-family housing units. Medium intensity developed areas (NLCD code 23) have 50% to 79% of the impervious surfaces. High intensity developed areas (NLCD code 24) have impervious surfaces over 80% to 100%, and include mostly apartment complexes, row houses and commercial/industrial buildings (Brantingham & Brantingham, 1995). Finally, data for severe housing problems and median home values (Leslie et al., 2022) were retrieved from the 2016 to 2020 American Community Survey (ACS) 5-year estimates. All the statistical analysis in our study were conducted with the software R 4.3.3.

Statistical Analysis

The dependent variable, fatal police shooting case, is count data that fits Poisson distribution, and thus we applied the Besag-York-Mollié (BYM) Poisson regression model. Our study design involved two significant steps (Blangiardo et al., 2015) to understand how the greenness relates to the fatal police shootings. First, we used the BYM model to investigate the association between greenness levels and fatal police shootings. The model has four layers.

1. The first layer examines the associations between county-level police shooting cases and social-economic and demographic factors.
2. The second layer added in the crime factors.
3. The third layer included the built environment factors.
4. The fourth layer incorporated the greenness (NDVI).

Second, we applied the same BYM model and covariates to test how does the relationship between police shooting cases and greenness vary across five levels of social deprivation. The global Moran index of the county-level fatal shooting case was 0.04 (Z-value = 7; p-value < .01), indicating spatial correlation and clustering of shooting cases.[3]

All the covariates were *z*-score standardized, and we tested for multicollinearity using the variance inflation factor (VIF) with a threshold of ≤4.0 and correlation.[4] The multicollinearity results are listed in Appendix 7. We calculated the Deviance Information Criterion (DIC), Watanabe-Akaike Information Criterion (WAIC) and adjusted R^2 to compare the model results. For the significance and performance of different covariates, we calculated and plotted the regression coefficients and 95% CIs were calculated and plotted.

The Besag-York-Mollié (BYM) model is a lognormal Poisson model that includes both an Intrinsic Conditional Autoregressive (ICAR) component for spatial auto-correlation and an ordinary random-effects component for non-spatial heterogeneity. We built the spatial adjacency matrix for 3,108 counties by defining the neighboring counties with the Queen contiguity method.

The equation for the Poisson regression was:

$$Y(i) \sim \text{Poission}(E(i)r(i))$$

Where Y_i was the police shooting cases and $E(i)r(i)$ was the expectation value of the Poisson distribution of police shooting cases. Specifically, $E(i)$ was the expected police shooting cases in county i if the shooting cases were randomly distributed in the research area. $r(i)$ was the relative risk of the police shooting cases in county $i = 1, \ldots, 3108$.

The equation of the BYM model was:

$$\log\left[E(i)r(i)\right] = b_0 + \sum_k \beta_k X_k(i) + U_i + S_i$$

Where b_0 was the intercept. β_k was the fixed effect for the covariables. U_i was the unstructured spatial model with exchangeability among the 3,108 counties that fit the normal distribution. S_i was the structural spatial model using the Intrinsic Conditional Autoregressive (ICAR) specification (Besag et al., 1991; Morris et al., 2019). The spatially independent term is modeled as:

$$S \sim \text{ICAR}(0, \sigma_s^2)$$

In the study, S is specified to follow an intrinsic conditional autoregressive (ICAR) distribution with a variance of σ_s^2, indicating the impact of spatial structure on the risk of shooting incidents. The unstructured spatial term is modeled as:

$$\text{U} \sim \text{N}(0, \sigma_u^2)$$

The unstructured spatial random effect term U_i is specified to follow a normal prior distribution with an expectation of 0 and variance of σ_u^2. This, represents the unstructured distributional changes of the risk of shooting incidents in the study area, indicating that these distributional changes are not influenced by spatial structure.

Results

Our findings reveal three layers of systematically significant negative correlation between greenness within a county and police shootings. First, an analysis of 3,108 counties in the contiguous United States revealed a significant negative association between greenness levels and the incidence of fatal police shootings. Second, a focused analysis of 805 metropolitan counties demonstrated an even stronger association. Third, we found that this negative association remained significant across five levels of social deprivation, with a stronger association observed in counties with higher levels of social deprivation.

Descriptive Statistics

During the 5-year study period, the average number of fatal police shooting cases was 1.65 per county across all 3,108 counties, and 4.66 per county for the 805 metropolitan counties. Fatal police shootings primarily concentrate in eastern and western counties (Figure 2). The descriptive statistics of the covariates across all the 3,108 counties as well as the metropolitan counties over 250,000 populations are listed in Appendices 4–5.

Associations Between Greenness and Fatal Police Shootings Across All Counties and Metropolitan Counties

To what extent does greenness of a county predict police shooting cases for all counties and metropolitan counties with populations over 250,000 in the contiguous United States? We found that adding covariates to the model increased its explanatory power, with a stronger association observed for metropolitan counties (Table 1). At the nationwide scale, the model's explanatory power increases by 212% after adding crime factors and increases an additional 82.8% after adding built environment factors. After controlling all the other factors, we found that the greenness factor increases the adjusted R^2 to 0.61, indicating that 17% of the variation in police shooting cases was independently explained by NDVI. Furthermore, the greenness factor improved the model's explanatory power by 39% for the 805 metropolitan counties.

The results reveal that a higher green space ratio significantly correlates with fewer police shooting cases across all counties (Figure 3), with the relationship stronger and more robust in the metropolitan counties. A unit growth in greenness ratio was significantly associated with 9% decrease in incidence of fatal police shootings for all 3,108 counties. For the metropolitan counties with populations over 250,000, a unit growth in greenness ratio was significantly associated with 15% decrease in fatal police shooting incidence.

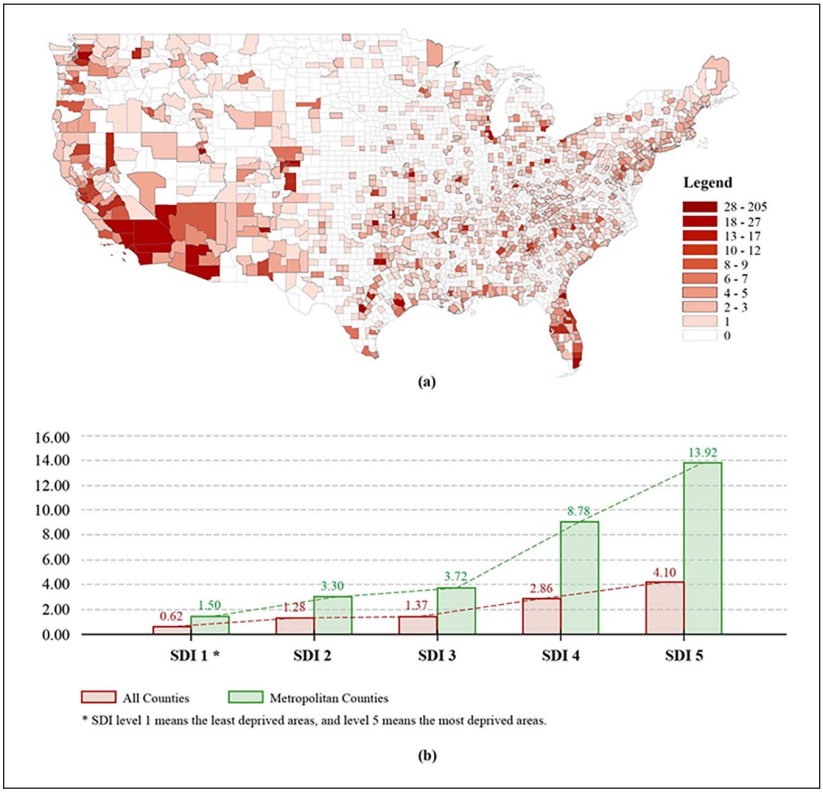

Figure 2. Descriptive figures of the fatal police shooting cases. (a) Mapping of the police shooting cases over 5 years (from January 1, 2016, to May 26, 2021) across all 3,108 counties in the contiguous United States. (b) shows the relationship between SDI levels and fatal police shooting cases per 100,000 people in the contiguous United States ($N = 3,108$) and fatal police shooting cases per 100,000 people in the most populated metropolitan counties ($N = 805$).

Associations Between Greenness and Fatal Police Shootings Across Five Social Deprivation levels

How does the statistical association vary across five levels of social deprivation for all counties in the contiguous United States when controlling for potential covariates? During the 5-year study period, we found that the mean values of police shooting cases increased from 0.62 cases at SDI level 1 to 4.10 cases at level 5 across all counties. In metropolitan counties, the mean values rose from 1.50 cases at level 1 to 13.92 cases at level 5 (Table 2).

Table 1. Increasing Levels of Adjustment and Percentage of Variance Explained for Police Shooting Counts in Nationwide U.S. Counties ($N = 3,108$) and Metropolitan Counties ($N = 805$).

	M1		M2		M3		M4	
Adj R^2 and Factors	Nation	Metro	Nation	Metro	Nation	Metro	Nation	Metro
Adj R^2	0.09	0.20	0.28	0.38	0.52	0.41	0.61	0.57
Adj R^2 increase	NA	NA	213%	90%	83%	8%	17%	39%
SES and demographic factors	Population density		Population density		Population density		Population density	
	White non-Hispanic		White non-Hispanic		White non-Hispanic		White non-Hispanic	
	Black non-Hispanic		Black non-Hispanic		Black non-Hispanic		Black non-Hispanic	
	Young females (18–24)		Young females (18–24)		Young females (18–24)		Young females (18–24)	
	Divorced		Divorced		Divorced		Divorced	
	Gini index		Gini index		Gini index		Gini index	
	Median house income		Median house income		Median house income		Median house income	
	Unemployment rate		Unemployment rate		Unemployment rate		Unemployment rate	
Crime factors			Mobility		Mobility		Mobility	
			Places of interest (POI)		Places of interest (POI)		Places of interest (POI)	
			Violent crimes rate		Violent crimes rate		Violent crimes rate	
			Firearm restriction law		Firearm restriction law		Firearm restriction law	
			Firearm ownership		Firearm ownership		Firearm ownership	
Built environment factors					Urbanicity		Urbanicity	
					Low intensity development areas		Low intensity development areas	
					Residential segregation: Black/ White		Residential segregation: Black/ White	
					Residential segregation: Hispanic/ White		Residential segregation: Hispanic/ White	
					Residential segregation: Black/ Hispanic		Residential segregation: Black/ Hispanic	
					Severe housing problem		Severe housing problem	
Greenness level							NDVI	

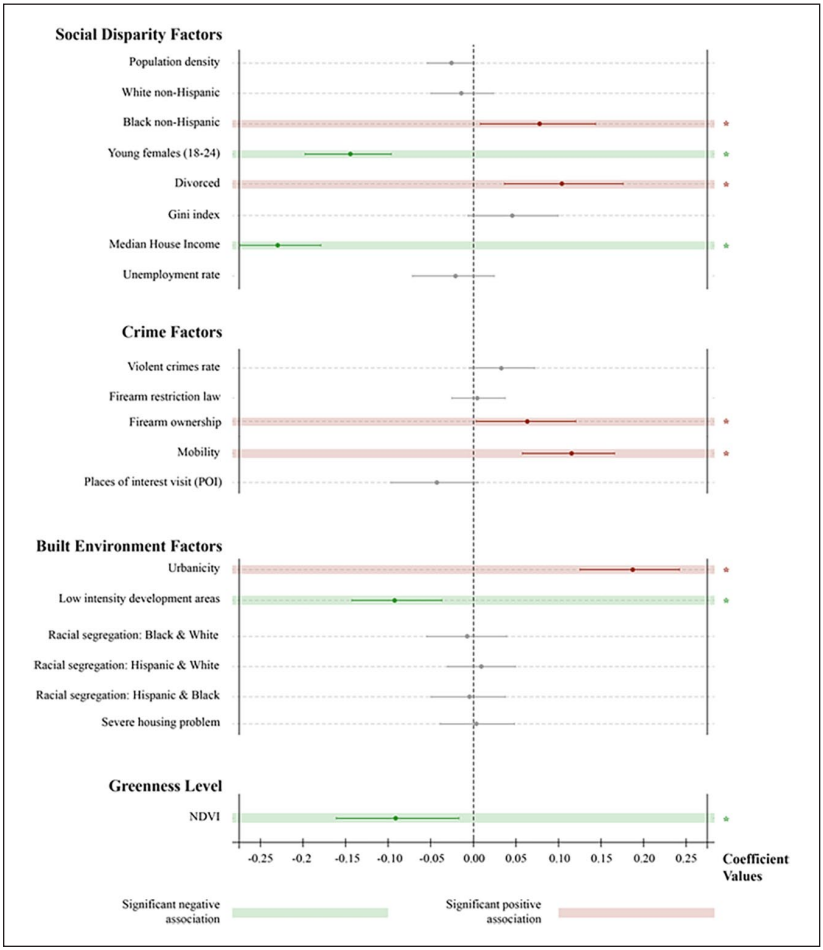

Figure 3. The numerical effects of factors on the police shooting cases in the U.S contiguous model ($N = 3,108$). Coefficient values represent effect sizes for the correlation between covariates and the police shootings. Coefficient values are represented as dots, 95% CIs are represented as bars, and significance are shown in two colors and marked with *: green represents significant negative correlation; red represents significant positive correlation. The insignificant correlations are shown in grey.

These results reveal that the negative association between greenness ratio and fatal police shootings is statistically significant across all social deprivation levels. Furthermore, the greater the social deprivation, the stronger the

Table 2. Police Shooting Cases and Greenness Levels Within Five Levels of the Social Deprivation Index (SDI) in U.S. Nationwide Counties ($N = 3,108$) and Metropolitan Counties ($N = 805$).

		Shooting cases mean (*SD*)		NDVI score mean (*SD*)		County Number	
SDI level	Score range	Nation	Metro	Nation	Metro	Nation	Metro
SDI 1	1–19	0.62 (1.49)	1.50 (2.33)	0.44 (0.11)	0.39 (0.10)	865	254
SDI 2	19.1–38	1.28 (3.29)	3.30 (5.49)	0.50 (0.12)	0.55 (0.10)	681	189
SDI 3	38.1–58	1.37 (3.44)	3.72 (6.45)	0.54 (0.13)	0.57 (0.10)	748	162
SDI 4	58.1–78	2.86 (9.10)	8.78 (16.89)	0.56 (0.14)	0.54 (0.13)	509	124
SDI 5	78.1–100	4.10 (14.67)	13.92 (27.10)	0.53 (0.14)	0.57 (0.11)	305	76

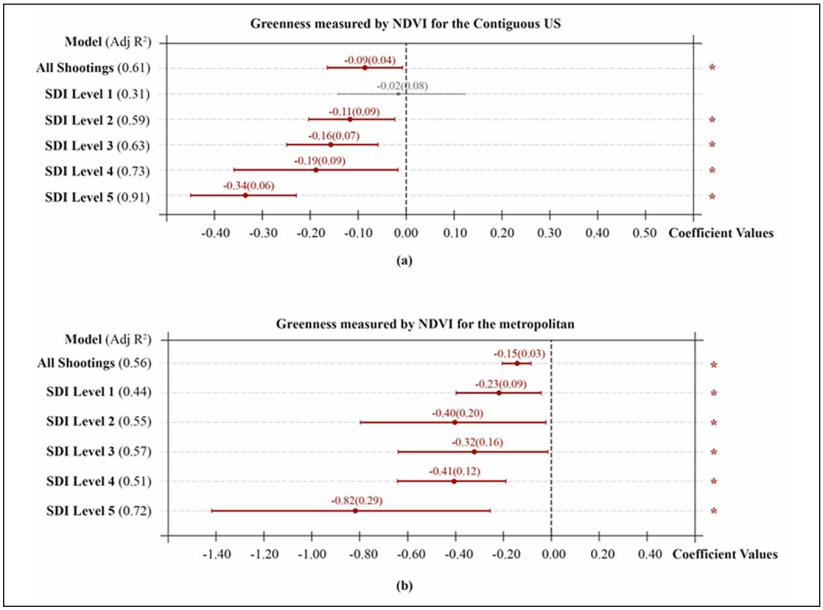

Figure 4. A systematically significant negative correlation between greenness levels and fatal police shooting across all levels of social deprivation, with the strongest associations in areas of higher social deprivation (SDI level 5). These relationships held true in analyses conducted with a subsample of the most populated counties. (a) shows the results for the contiguous U.S. counties ($N = 3{,}108$); (b) shows the results for the most populated metropolitan counties ($N = 805$). Coefficient values represent effect sizes for the associations between greenness levels and fatal police shootings, and are represented as dots. 95% CIs are represented as bars. The significant correlations are shown in red and marked with *, the insignificant correlations are shown in grey.

significance of the greenness factor (Figure 4). From the SDI level 1 to level 5, the coefficient size grew from −0.02 ($SD = 0.08$, 95% CI: [−0.16, 0.13]) to −0.34 ($SD = 0.06$, 95% CI: [−0.45, −0.23]). Such results stand true for the metropolitan counties with a population over 250,000 ($N = 805$). From the SDI level 1 to level 5, the coefficient size grew from −0.23 ($SD = 0.09$, 95% CI: [−0.41, −0.04]) to −0.82 ($SD = 0.29$, 95% CI: [−1.41, −0.26]; Figure 5).

Discussion

Findings of this study can be summarized as three parts, corresponding to our three research questions. After controlling for covariates, our investigation of

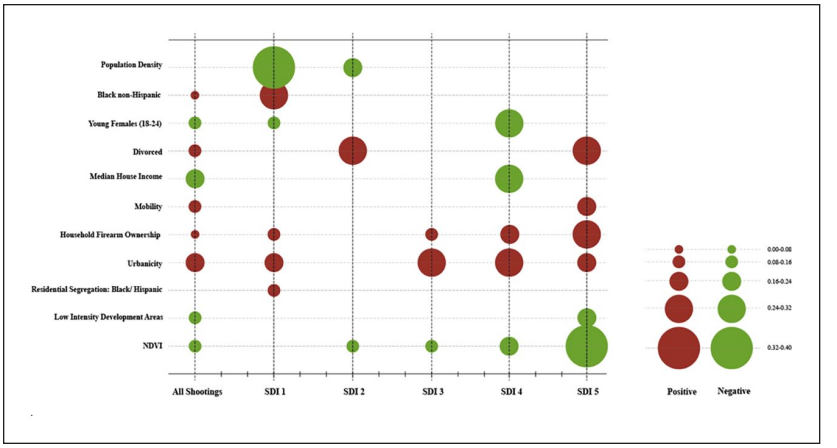

Figure 5. The effect size matrix of all the significant covariates in the U.S contiguous model ($N = 3,108$). Different sizes of circles represent different ranges of effect sizes for the associations between covariates and fatal police shooting cases, and are represented in the legend. The significant negative correlations are shown with green color, and the significant positive correlations are shown with red color.

all 3,108 counties in the contiguous U.S., revealed a significant negative association between the level of greenness and incidence of fatal police shootings. This association remained significant but much stronger (twice as strong) for the 805 metropolitan counties. Finally, we found that the association remained significant for each of five levels of social deprivation with a clear trend: the negative association became stronger when the level of social deprivation increased.

Interpretation

How Might Greenness Mitigate Fatal Police Shootings?. That greenness has a negative association with police shooting cases might be explained through some combination of four mechanisms. Green spaces are associated with reduced crime, improved short-term and long-term mental health, send a signal that a place is well-cared for, and increase the use of outdoor spaces by nearby neighbors. We examine each possibility in turn below.

Crime reduction. Higher levels of greenness have been linked to lower levels of crime in a variety of studies (Bogar & Beyer, 2016; Burley, 2018;

Du & Law, 2016; Irvin-Erickson, 2014). These studies examined places with varying population densities, in multiple countries, using a range of crime statistics. The association between a neighborhood's crime rate and police shootings was described 3 decades ago in the threat hypothesis (Liska & Yu, 1992). In the intervening years, several studies have found empirical evidence to support this theory (Fryer, 2019; Hemenway et al., 2019; Nix & Shjarback, 2021). If police officers have sensitive trigger fingers when they are in areas with higher crime rates and greener places tend to have fewer crimes, then we expect that greener places would also have fewer fatal police shootings. It is also possible that simply through reducing crime, and thus the frequency of encounters with police, greener counties may lower the changes of fatal police shootings.

Improved short-term and long-term mental health. Higher levels of greenness have been shown to help people across the life-span recover from the short-term effects of stress and mental fatigue faster than less green places (Bratman et al., 2012; Jiang et al., 2014; Kaplan, 1987; Ulrich et al., 1991). Access to green spaces has also been linked to improved mental health outcomes, including reduced symptoms of depression (Beyer et al., 2014; Kondo, Fluehr, et al., 2018; Reklaitiene et al., 2014) and anxiety (Gascon et al., 2018; Lan et al., 2022; Nutsford et al., 2013). These findings suggest a pathway through which the negative relationship between greenness and fatal police shootings might occur. When people are less stressed and mentally fatigued, they are also significantly less likely to be irritable, impulsive, and being prone to errors (Jiang et al., 2017, 2018). When they are less depressed and less anxious, they are likely to experience mental health crises, which can sometimes result in fatal police encounters (DeVylder et al., 2018; Frankham, 2018; Lamb et al., 2002).

Indicator of neighborhood care. Higher levels of greenness have been shown to send a message that a setting is better cared for and is therefore less dangerous (Kuo, Bacaicoa, & Sullivan, 1998; Kuo & Sullivan, 2001a, 2001b; Nassauer, 1988). Pervious research has shown that places that appear uncared for and dangerous have more fatal police shootings (Caplan & Kennedy, 2016; Downey et al., 2010; Holmes et al., 2019; Thomas & Drawve, 2018; Thomas et al., 2022). If police officer sense that less green settings are more dangerous, then we expect that greener places would have fewer fatal police shootings.

Enhanced social cohesion. Finally, higher levels of greenness have been shown to attract more nearby neighbors to use and occupy outdoor spaces (Kuo, Sullivan, & Coley, 1998; Kweon et al., 1998). Thus, green spaces increase the face-to-face encounters neighbors have with one another which in turn, can increase social cohesion and neighborhood vitality

(Sullivan et al., 2004). More neighbors outdoors also increases informal surveillance (J. Jacobs, 1964; Jeffery, 1971) and "perceived routine activities" (Jiang et al., 2018). We do not argue that more eyes and more daily living activities on the street would definitely have a direct impact to alter police actions but could have an impact by reducing violent activities that might lead to police aggressive interventions in a place, and thus reduce opportunities for fatal police shootings.

How Might Deprivation Moderate Greenness and Fatal Police Shooting?. The relatively stronger negative association between county-level green space and fatal police shootings in counties with higher social deprivation could be attributed to several interrelated factors. First, green spaces in more socially deprived settings might offer amplified stress relief. In areas with high social deprivation, residents often face increased stressors, such as poverty, unemployment, and crime (Fone & Dunstan, 2006; Mabughi & Selim, 2006). Green spaces may provide disproportionately greater stress relief in these settings, helping to alleviate residents' psychological burdens (Keilow et al., 2020; Roe et al., 2016; Thompson et al., 2012). This could potentially result in reduced aggression and fewer situations escalating to police shootings.

Second, green spaces in socially deprived settings might foster enhanced social cohesion. Green spaces within higher social deprivation areas may have a more significant impact on social cohesion and trust-building among residents by providing opportunities for positive social interactions in otherwise resource-poor neighborhoods (Goyder et al., 2017; Kaźmierczak, 2013; Wickham et al., 2014). As community members bond and develop a shared responsibility sense, they may be more inclined to resolve conflicts non-violently, thereby reducing the need for police intervention.

Third, green spaces might displace crime. The presence of green spaces in socially deprived areas may discourage criminal activity and create a perception of a safer environment (He & Li, 2022; Lockwood, 2007; Wikström & Treiber, 2016). This could lead to crime displacement to areas with less green space, ultimately resulting in a stronger negative association between greenness and fatal police shootings in socially deprived counties.

Finally, green spaces may have greater impact on community engagement in areas of higher social deprivation. Green spaces can symbolize a community's commitment to enhancing the local environment and fostering positive change in socially deprived areas (Coley et al., 1997; Mazumdar et al., 2018). This may result in increased civic engagement, empowering residents to collaborate in addressing local issues and advocating for community-based policing strategies. Such strategies can lead to more effective policing and fewer fatal encounters.

It is crucial to acknowledge that these factors might interact in intricate ways, and their relative importance may vary depending on each county's specific context. Further research is required to unravel the underlying mechanisms and better comprehend the factors influencing the observed relationship between green spaces and fatal police shootings in socially deprived areas.

Implications

The findings presented above suggest that current perspectives on fatal police shootings are missing a crucial factor: the proportion of the landscape that has vegetative cover. We propose that greenness influences the incidence of fatal police shooting by reducing crime, improving individuals'mental states, promoting neighborhood care, and enhancing neighborhood social cohesion. We recommend expanding the socio-economic deprivation framework and the crime threat framework to explicitly include assessments of greenness at the county level.

The findings also suggest several actions that might reduce fatal police shootings. The significant negative correlation between greenness levels within counties and fatal police shootings suggests municipalities and counties can increase the safety of their residents by increasing the proportion of the community that has vegetative cover.

Adding green cover may be one of the least expensive interventions available to a community seeking to reduce violence. This could involve converting vacant lots into mini-parks or community gardens or implementing urban forestry programs. To design effective interventions, it is crucial to involve different stakeholders and experts from various disciplines, such as urban planning, public health, and law enforcement. Collaborative efforts can help ensure that interventions are well-informed, community-driven, and consider the diverse needs of affected populations.

The stronger associations between greenness levels and reduced police shootings in areas of higher social deprivation suggest that improving green spaces in these areas could be particularly beneficial. However, the increase of greenness should consider the potential unequal benefits and social consequences, such as gentrification (Cole et al., 2019). The policies and practical implications should ensure that design and planning cater to the needs and socio-cultural identities of various residents, especially underprivileged groups to promote equal benefits from urban green spaces (Triguero-Mas et al., 2022). This finding underscores the importance of addressing socio-economic inequalities to enhance public safety.

Although enhancing green spaces could be a valuable strategy, it is essential to address the issue of police shootings from a comprehensive perspective. This includes examining and addressing systemic issues within the criminal justice system (Herbert, 2006; Langworthy, 1986), implementing community-oriented policing practices (Brogden & Nijhar, 2013; Trojanowicz & Bucqueroux, 1990), and providing ongoing training and support for police officers in areas such as de-escalation techniques and implicit bias awareness (B. W. Smith, 2004).

By considering the results of this study and implementing a combination of targeted interventions, cross-disciplinary collaboration, and a comprehensive approach, it may be possible to reduce the occurrence of police shootings and improve public safety in communities across the nation.

Limitations and Future Research

This study has several limitations which can be addressed in future research. First, police shooting data has some fundamental, unavoidable limitations. Even though we have applied the most comprehensive data sources for fatal police shootings available, there are undercounts of fatal shootings due to privacy, data restriction and data errors. Many local governments and police departments do not consistently preserve and maintain data regarding lethal police shootings (Krieger, 2015). There is evidence, moreover, that some fatal police shootings are not recorded (Naghavi, 2021). We did not include in our analyses non-fatal shootings either. Future research should include all lethal and non-lethal police shooting cases.

The second limitation concerns the possibility of an ecological fallacy. Our analysis employed aggregate, county-level data, and thus individual-level conclusions cannot be drawn from this work. Future research should use multilevel models or hierarchical models that include both individual-level and group-level variables. Such an approach will help distinguish between variations that occur at the group level from those at the individual level.

Third, we chose to conduct county scale analysis due to the availability of data regarding structural violence and crime policy. The county scale is commonly employed when examining macro-scale police shooting research. Future studies can explore finer geographic scales if data are available at these finer grained levels. Future studies should also cross-validate the aggregate-level findings with individual-level data.

Fourth, we applied two-dimensional remote sensing Normalized Difference Vegetation Index (NDVI) as the greenness factor. Future studies might explore more detailed types of green landscapes and eye-level perception of green spaces to examine the influence of green factors on fatal police shootings in a more complete fashion (Jiang et al., 2017; Yang et al., 2025). Future studies

could also focus on greenspace quality by examining levels of maintenance, cleanliness, access to facilities, and safety. Moreover, it is important that, future studies should use the latest NDVI data.

Lastly, more research is needed to understand the causal mechanisms behind the negative correlations between green spaces and police shootings. Investigating other factors that may contribute to this relationship, such as community engagement, mental health, and policing practices might help refine intervention strategies and better target limited resources.

Conclusions

This study is an initial investigation into the associations between greenness and fatal police shootings. Our findings demonstrate that greater levels of greenness at the county level are tied to fewer police shooting cases after controlling social, economic, crime, behavioral, and built environment factors. Notably, the association between greenness and fatal shooting cases is stronger in counties with higher levels of social deprivation. Environmental interventions, such as urban greening, may decrease the risk of fatal police violence while promoting community health and well-being, particularly in underserved communities. This research provides evidence that encourages future researchers to explore the mitigating effects of greenness on racial, social, and economic disparities. By providing evidence of the negative relationship between greenness and fatal police shootings, this study is part of a body of work demonstrates that access to green spaces is a critical part of a healthy human habitat.

Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

Notes

1. The only one tract (12011110321) and block (120111103211) that has more than four shooting cases are all in the Broward County, Florida, and follow the same GEOID. Broward County has 27 fatal police shooting cases within the study period and ranked top twenty counties with most police shootings.
2. The scheme has six levels: large central metro (68 counties), large fringe metro (368 counties), medium metro (373 counties), small metro (358 counties), micropolitan (641 counties), and noncore (1335 counties).
3. The value range of Moran's I is between −1 to 1. Moran's $I > 0$ indicates positive spatial correlation, and the larger the value, the more obvious spatial correlation. Moran's $I < 0$ indicates negative spatial correlation, the smaller the value, the greater the spatial difference. Moran's $I = 0$ means a lack of spatial autocorrelation.
4. $|r| > 0.95$ means the covariates are significantly associated, and $|r| \geq 0.8$ indicates that the covariates are highly associated, $0.5 \leq |r| < 0.8$ implies that the covariates are associated.

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