

Does neighborhood context change the association between tree canopy and allostatic load? Findings from a large, nationally representative sample

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Abstract

Background: Many studies find associations between neighborhood greenery and lower stress. However, few studies have explicitly examined biomarkers of stress or the specific neighborhood contexts in which this is true.

Methods: The objective was to examine the cross-sectional relationship between residential tree canopy and allostatic load among US adults (n=40,307) in the National Health and Nutrition Examination Survey (NHANES), to determine whether relationships differ by neighborhood context and after adjustment for individual demographics.

Results: We found that greater tree canopy was associated with lower allostatic load. We did not observe a difference in this benefit by rural/urban neighborhood status. We consistently found that those residing in more vulnerable neighborhoods, regardless of indicator, were associated with significant and larger benefits for allostatic load. The largest effect was detected for those living in high vulnerability minority status and language neighborhoods such that for every 20% increase in tree canopy in such neighborhoods, we would expect allostatic load scores for residents to drop by 0.08.

Conclusion: In vulnerable neighborhoods and in both urban and rural areas where the association between higher tree canopy and lower allostatic load was detected, there may be opportunities for tree planting to lower stress. These findings offer new insights beyond individual-level moderation of the effect of nature on health.

INTRODUCTION

Reductions in everyday neighborhood stressors may serve as an important strategy to improve mental health at scale. Mental health challenges represent a substantial and growing public health concern in the United States. Recent World Health Organization estimates suggest that over one billion people are living with mental health conditions globally (WHO, 2025), with anxiety and depressive disorders among the most prevalent (Fan et al., 2025). These burdens are not distributed evenly; communities facing socioeconomic disadvantage and environmental hazards often experience disproportionately high levels of stress and poorer mental health outcomes (Holt, 2025; Morello-Frosch et al., 2011).

Reducing everyday neighborhood stressors is therefore a critical, yet often underemphasized, strategy for improving population mental health. Daily exposures such as noise pollution (Ma et al., 2020), crime (Lorenc et al., 2012), and environmental degradation (Riediker and Koren, 2004) can cumulatively erode psychological well-being. Unlike acute traumatic events, these stressors are persistent and embedded within neighborhood environments. Interventions that address these neighborhood-level conditions—such as improving safety, enhancing environmental quality, and increasing access to calming and restorative spaces—have the potential to benefit entire communities rather than individuals.

The connection between chronic stress and health is often conceptualized through the framework of allostatic load. Allostasis refers to the body's process of adapting to stressors through physiological change, including activation of the hypothalamic-pituitary-adrenal (HPA) axis and the release of stress hormones like cortisol (McEwen, 1998). While these responses are adaptive in the short term, repeated or prolonged activation can lead to cumulative biological wear and tear—known as allostatic load (Geronimus et al., 2006). Elevated allostatic load has been linked to a range of adverse outcomes, including lower cognitive function (Juster et al., 2010), cardiovascular disease mortality (Parker et al., 2022), and depression and anxiety (Gou et al., 2025). Understanding contextual features that may lower stress and thus allostatic load in disadvantaged communities is particularly salient given that living in disadvantaged neighborhoods is associated with higher allostatic load (Tan et al., 2017; Whitley et al., 2022). Thus, reducing everyday neighborhood stressors is not only a matter of improving mental health, but also of mitigating broader patterns of physiological dysregulation and long-term health risk.

Residential greenery, as a salutogenic neighborhood feature, has been consistently linked to improved mental health outcomes, including lower levels of stress, anxiety, and depression, even after accounting for both individual- and area-level socioeconomic status (Beyer et al., 2014; Klein et al., 2022; Reimer et al., 2024). These findings suggest that the benefits of greenspace are not solely a function of wealth or access to resources, but may reflect more fundamental psychosocial and physiological processes, such as stress reduction, attention restoration, and increased opportunities for social interaction. However, relatively little research has examined how these associations may vary across different contexts, including urbanicity and various forms of neighborhood vulnerability. Understanding these contextual differences is critical for identifying where and for whom residential greenery may have the greatest stress-reduction potential.

Existing studies of differential effects of context on the greenspace-mental health association are limited. Most studies focus explicitly on urban greenspace. But, a few studies have evaluated differences across rural and urban settings. For example, one study found that higher residential greenspace was associated with better mental health outcomes across both urban to rural settings (Beyer et al., 2014). Similarly, another study found that higher neighborhood greenspace was associated with significantly lower emergency department visits for anxiety, depression, mental illness, mood, substance abuse, and self-injury for patients in both rural and urban communities (Ryan et al., 2023). Others have descriptively noted that some rural areas experience the paradox of high levels of greenery and poor health outcomes, including the U.S. Appalachian region (Dong et al., 2024).

We are aware of only two large studies to evaluate how greenspace-mental health associations vary across socioeconomic neighborhood contexts. One large ($n = 364,557$) Dutch study found that neighborhood socio-economic status modified the association between green space and self-reported mental issues, with stronger associations in high SES areas (Bijnens et al., 2025). In a large ($n = 54,666$) longitudinal UK study, they found a positive effect of increasing residential green space on mental health, which was positively modified and intensified by area deprivation even after confounder adjustment

(Belcher et al., 2024; Ribeiro et al., 2018). The two studies, both from outside the United States, came to conflicting conclusions, representing an area where further research is warranted.

Targeting residential greenery is particularly compelling because it represents an inherently community-based intervention that can reach individuals in their daily living environments, rather than requiring travel to destination parks or recreational areas. Among various greening strategies, increasing tree canopy stands out as one of the most scalable and feasible approaches. Unlike the creation of new parks or green infrastructure projects that often require land acquisition and substantial redevelopment costs, tree planting and preservation can be integrated into existing streetscapes, yards, and public rights-of-way and tree canopy offers other health-promoting benefits (e.g., lowering urban heat, providing shade) in addition to mental health.

The objectives of this study were to test the hypothesis that higher levels of residential greenery are associated with lower allostatic load in a large, nationally representative U.S. sample and examine whether any detected association is modified by neighborhood context.

METHODS

Study sample

We relied on data from the National Health and Nutrition Examination Survey (NHANES) continuous surveys for 2001–2010 and 2015–2018 (7 cohorts). These cohorts were selected based on the recency of data and the availability of essential variables to measure allostatic load. NHANES is a nationally representative, cross-sectional survey and includes participants from the non-institutionalized US population. We analyzed data from the NHANES demographic, questionnaire, examination and laboratory datasets. NHANES involves a multiple cluster sampling design where counties are selected, followed by block groups, and then households. All participants were primary residents in selected households and we only analyzed participants 19 and older ($n = 40,307$). This study was approved by the Medical College of Wisconsin Institutional Review Board (#PRO00021838). We utilized the STROBE checklist for reporting cross-sectional studies (von Elm et al., 2014).

Allostatic load

Most definitions of allostatic load involve a summative index of indicators of cardiovascular, metabolic, neuroendocrine and immune function, where higher scores indicate poorer health.(Duong et al., 2017) While many studies have proposed and used working definitions of allostatic load,(Schulz et al., 2012) there still remains widespread variation in operational definitions. Here, we estimated allostatic load using laboratory variables and the following cut-offs, similar to previous NHANES studies:(Parente et al., 2013) systolic blood pressure ≥ 140 mmHg; diastolic blood pressure ≥ 90 mmHg; heart rate ≥ 90 beats per minute; total cholesterol level ≥ 240 mg/dL; high-density lipoprotein cholesterol < 50 mg/dL; body mass index ≥ 30 kg²/m; glycosylated hemoglobin $\geq 6.4\%$; C-reactive protein > 3 mg/L; and albumin < 4

g/dL. Cut-offs were used to define nine dichotomous variables, which were then summed to create an allostatic load score. Next, following guidance, (Geronimus et al., 2006) we added a point to each participant's preliminary score when they reported taking medication for diabetes, hypertension, or high cholesterol, assuming that individuals who are taking medication have already deleterious effects.

Predictor

We generated a measure of residential greenery using the National Land Cover Database 2016 Tree Canopy data and a resolution cell size of 90 meters (with sensitivity analyses for tree canopy data at 150 meters and 210 meters, aerial greenness or NDVI, and distance to nearest park, results not shown). To account for varying sizes of census blocks (the smallest unit of aggregation in the US census), we calculated the mean value for the relevant cells at each resolution when the area of a block was equal to or less than the area of those cells (e.g., 90m², ~20% of total blocks) centered at the raster cell containing the block centroid. For larger blocks (~ 80% of total blocks), we calculated the mean of all cells within block boundaries.

Residential geocodes used to assign residential greenery are restricted and only accessible via an application process and secure vetting and access procedures. Centers for Disease Control and Prevention (CDC) analysts must merge the public use data files and geographic variables in house. Because CDC analysts cannot conduct GIS-based analyses using participants' home coordinates, we carried out a computationally intensive process to calculate the tree canopy within the three cell sizes (90, 150, and 210 meters) of the centroid of each US 2010 Census block for the entirety of the United States. Then, CDC analysts linked the census block of the respondent's address with the corresponding tree canopy (and other neighborhood variables). We evaluated tree canopy as both a continuous measure, and using a cut-off of 30%, to align with the 3-30-300 rule which states that individuals should be able to see three trees from their dwelling, have 30% tree canopy in their neighborhood and live within 300 meters of a high-quality greenspace (Browning et al., 2024).

Neighborhood-level control and effect modifier variables

A number of neighborhood-level control and effect modifier variables were specified, based on the US 2010 Census tract. The urban/rural designation of each tract was incorporated via RUCA codes, where 1 was assigned to metropolitan, 2 was assigned to micropolitan, 3 was assigned to small town, and 4 was assigned to rural tracts. For stratified analyses, we compared participants residing in metropolitan tracts to those in all other types. We also included a regional identifier from the census as a control variable to account for regional differences in landcover. The regions were Southwest (1), Midwest (2), Northeast (3), and West (4). We also included the CDC 2016 social vulnerability index's socioeconomic status component as a control variable (using the raw values range 0–4). Finally, we stratified by the social vulnerability index (range = 0–1), and three of its components (socioeconomic status, minority status

and language, and housing type and transportation, raw values range 0–4) as potential effect modifiers (using median values as the thresholds). Higher values indicate more vulnerable settings.

Individual-level control variables

We controlled for age and biological sex (male = 1, female = 2) in all models. Race and ethnicity were defined using US Census categories (non-Hispanic White = 1, Mexican American = 2, other Hispanic = 3, non-Hispanic Black = 4, and other race/ethnicity including multiracial = 5). Race and ethnicity data are self-reported by participants. Education was defined in five categories (less than 9th grade = 1, 9-11th grade without diploma = 2, high school graduate or equivalent = 3, some college or Associate's degree = 4, and college degree or more = 5). A binary measure of the poverty to income ratio (values ≥ 2 scored as 1, values < 2 scored as 0) was used, whereby those with a value of 1 had higher income. We also included health insurance (yes, no), occupational status (working at a job or business = 1, with a job or business but not at work = 2, looking for work = 3, not working at a job or business = 4), and marital/partnered status (married = 1, widowed = 2, divorced = 3, separated = 4, never married = 5, living with partner = 6). We included a measure of employment (working at a job or business = 1, with a job or business, but not at work = 2, looking for work = 3, and not working at a job or business = 4).

Statistical analyses

Exam weights were used for all analyses, and adjusted to the seven-cohort sample, as instructed by NHANES. Specifically, we utilized the complex sampling design designations in the `svy` commands in Stata. We calculated descriptive statistics for the sample, stratified by high ($\geq 30\%$) versus low tree canopy (unweighted results in TableS1 in Supplementary Materials). To address our first research objective, we fitted a structural equation model to examine relationships between percent residential tree canopy and allostatic load, adjusted for both individual-level and area-level controls, as well as wave of data collection. Finally, we fitted stratified models based on neighborhood context for the following designations: 1) those residing in metropolitan tracts versus all others; and 2) those residing in tracts with high vulnerability versus others (for each component and the overall social vulnerability index). As sensitivity analyses, we also examined other cell sizes of tree canopy, and greenspace as aerial greenness or distance to park and examined predictors as both continuous and binary measures. However, results were largely consistent and are not shown. For each of these measures, we examined the predictor as a binary and as a continuous measure and findings were consistent for all measures (not shown). We previously assessed the potential need to impute missing data and determined it was unnecessary (Pearson et al., 2026). Thus, only complete data were analyzed using Stata v17 (Statacorp, College Station, TX).

RESULTS

Descriptive statistics of the sample, stratified by high/low residential tree canopy are shown in Table 1. We observed significant differences by race/ethnicity, education, marital/partnered status, and region.

Those residing in a census block with at least 30% tree canopy were significantly older, have higher income, and were also likely to be insured, and physically active. A total of 83% of participants resided in metropolitan areas and only 3% resided in rural areas. Most participants were from the Southwest region of the United States, followed by the Midwest and West regions, with only 17% of participants from the Northeast region. The average allostatic load score in the sample was 2.6 (95%CI: 2.5–2.6).

Table 1
Sample characteristics by proportion tree canopy (90-meter resolution)

	Tree canopy < 30%			Tree canopy ≥ 30%			Total			p-value
	<i>unweighted n = 30736</i>			<i>unweighted n = 7592</i>			<i>Unweighted n = 40,307</i>			
	% or mean	95% CI		% or mean	95% CI		% or mean	95% CI		
Age	46.1	45.6	46.7	48.9	47.7	50.1	46.8	46.3	47.4	< 0.0001
Sex										0.921
Male	48.2	47.5	48.8	48.2	47.2	49.3	48.2	47.7	48.7	
Female	51.8	51.2	52.5	51.8	50.7	52.8	51.8	51.3	52.3	
<i>Race and ethnicity</i>										< 0.0001
Non-Hispanic White	64.0	61.3	66.5	78.3	75.1	81.2	67.3	64.9	69.6	
Mexican American	10.2	8.8	11.8	2.3	1.8	3.0	8.4	7.2	9.6	
Other Hispanic	6.2	5.3	7.3	2.7	2.1	3.6	5.4	4.6	6.3	
Non-Hispanic Black	11.7	10.3	13.1	12.0	9.6	15.0	11.7	10.5	13.2	
Other race - including Multi-Racial	8.0	7.1	9.0	4.6	3.9	5.4	7.2	6.4	8.0	
<i>Education</i>										< 0.0001
Less than 9th grade	6.6	6.1	7.2	3.8	3.0	4.7	6.0	5.5	6.5	
9-11th grade, no diploma	11.2	10.6	12.0	9.8	8.5	11.4	10.9	10.3	11.6	
High School graduate or equivalent	24.2	23.2	25.1	25.4	23.7	27.3	24.5	23.6	25.4	
Some college or AA degree	31.1	30.1	32.1	28.9	27.6	30.3	30.6	29.7	31.5	
College graduate or above	26.9	25.2	28.6	32.1	29.0	35.4	28.1	26.5	29.8	

	Tree canopy < 30%			Tree canopy ≥ 30%			Total			p-value
	unweighted n = 30736			unweighted n = 7592			Unweighted n = 40,307			
Poverty income ratio										< 0.0001
PIR < 2	35.8	34.2	37.5	26.5	23.8	29.4	33.6	32.3	35.0	
PIR ≥ 2	64.2	62.5	65.8	73.5	70.6	76.2	66.4	65.0	67.7	
Marital/partnered status										< 0.0001
Married	53.6	52.3	55	61.6	59	64.1	55.5	54.3	56.7	
Widowed	6.1	5.8	6.5	6.1	5.4	6.9	6.1	5.8	6.5	
Divorced	10.1	9.6	10.7	8.8	8.0	9.6	9.8	9.3	10.3	
Separated	2.5	2.3	2.8	2.0	1.7	2.5	2.4	2.2	2.6	
Never married	19.4	18.4	20.5	14.9	13.1	16.8	18.4	17.5	19.3	
Living with partner	8.2	7.6	8.9	6.6	5.7	7.7	7.8	7.3	8.4	
Employment status										0.696
Working at a job or business	62.0	60.9	63.1	61.2	59.2	63.1	61.8	60.9	62.8	
With a job/business, but not at work	2.8	2.5	3.2	2.7	2.1	3.3	2.8	2.5	3.1	
Looking for work	2.7	2.4	2.9	2.5	2.0	3.1	2.6	2.4	2.9	
Not working at a job or business	32.5	31.4	33.6	33.6	31.6	35.7	32.7	31.8	33.7	
Insured										< 0.0001
Yes	82.0	80.8	83.1	86.0	84.3	87.6	82.9	81.9	83.9	
No	18.0	16.9	19.2	14.0	12.4	15.7	17.1	16.1	18.1	
Physically active										0.002
No	50.7	49.3	52.2	46.8	44.5	49.2	49.8	48.4	51.2	
Yes	49.3	47.8	50.7	53.2	50.8	55.5	50.2	48.8	51.6	

	Tree canopy < 30%			Tree canopy ≥ 30%			Total			p-value
	unweighted n = 30736			unweighted n = 7592			Unweighted n = 40,307			
Rural/urban residence										0.075
Metropolitan	85.2	81.7	88.2	76.5	67	83.9	83.2	79.2	86.6	
Micropolitan	8.4	6.2	11.3	14.1	9.1	21.3	9.7	7.3	12.8	
Small town	3.6	2.0	6.6	5.5	2.5	11.8	4.1	2.4	6.9	
Rural	2.7	1.4	5.3	3.8	1.9	7.5	3.0	1.7	5.3	
Region										< 0.0001
Southwest	29.2	25.5	33.3	58.4	51.2	65.1	36.1	32.5	39.8	
Midwest	27.6	23.1	32.5	12.3	8.5	17.7	24	20.2	28.3	
Northeast	13.6	11.4	16.3	27.4	21.5	34.3	16.9	14.4	19.6	
West	29.6	25.4	34.1	1.9	0.8	4.1	23.1	19.7	26.8	
Allostatic load	2.6	2.5	2.6	2.6	2.5	2.6	2.6	2.5	2.6	0.871
Vulnerability: household composition	2.0	1.9	2.0	2.0	1.9	2.0	2.0	2.0	2.0	0.953

In regression modeling (Table 2), we found a significant negative association between percent tree canopy and allostatic load, whereby greater tree canopy was associated with lower allostatic load, after full adjustment. Stratified analyses revealed a significant negative association between percent tree canopy and allostatic load and identical effect sizes for participants residing in both rural and urban areas (Fig. 1, Table S1). We also observed a significant and larger effect (double the size) for those residing in neighborhoods considered more vulnerable in terms of socioeconomic status, minority status and language, housing type and transportation, and overall social vulnerability index scores (Tables S2-S5). The largest effect was detected for those living in high vulnerability minority status and language neighborhoods such that for every 20% increase in tree canopy in such neighborhoods, we would expect allostatic load scores for residents to drop by 0.08.

Table 2
Structural equation models for percent tree canopy predicting allostatic load

Percent tree canopy	coef	p-value	95%ci
	-0.002	0.013	-0.003–0
Non-Hispanic White	<i>ref</i>		
Mexican American	-0.008	0.793	-0.065–0.049
Other Hispanic	-0.010	0.799	-0.089–0.069
Non-Hispanic Black	0.140	< 0.0001	0.091–0.189
Other race - including Multi-Racial	-0.021	0.574	-0.097–0.054
Male sex	<i>ref</i>		
Female sex	0.095	< 0.0001	0.062–0.129
Age	0.026	< 0.0001	0.025–0.028
Married	<i>ref</i>		
Widowed	-0.109	0.003	-0.18 - -0.039
Divorced	0.022	0.489	-0.041–0.086
Separated	0.029	0.536	-0.064–0.122
Never married	-0.027	0.292	-0.079–0.024
Living with partner	-0.034	0.369	-0.108–0.04
Less than 9th grade	<i>ref</i>		
9-11th grade, no diploma	0.039	0.350	-0.043–0.12
High School graduate or equivalent	0.065	0.085	-0.009–0.139
Some college or AA degree	0.061	0.069	-0.005–0.126
College graduate or above	-0.127	0.001	-0.202 - -0.051
PIR < 2	<i>ref</i>		
PIR ≥ 2	-0.003	0.897	-0.05–0.044
Insured	<i>ref</i>		
Uninsured	-0.138	< 0.0001	-0.188 - -0.087
Working at a job or business	<i>ref</i>		
With a job or business, but not at work	0.066	0.203	-0.036–0.169
Looking for work	0.034	0.523	-0.072–0.140

Percent tree canopy	coef	p-value	95%ci
	-0.002	0.013	-0.003–0
Not working at a job or business	0.071	0.002	0.026–0.117
Metropolitan	<i>ref</i>		
Micropolitan	0.099	0.017	0.018–0.180
Small town	0.019	0.756	-0.104–0.143
Rural	0.149	0.001	0.060–0.238
Social vulnerability: SES	0.295	< 0.0001	0.212–0.378
Wave 2001–2002	<i>ref</i>		
Wave 2002–2003	0.041	0.245	-0.029–0.112
Wave 2004–2005	0.076	0.094	-0.013–0.166
Wave 2006–2007	0.044	0.239	-0.03–0.118
Wave 2008–2009	0.105	0.005	0.033–0.176
Wave 2015–2016	0.446	< 0.0001	0.355–0.537
Wave 2017–2018	0.507	< 0.0001	0.403–0.612
Southwest	<i>ref</i>		
Midwest	-0.041	0.171	-0.101–0.018
Northeast	-0.088	0.006	-0.15 - -0.025
West	-0.105	0.002	-0.172 - -0.038

DISCUSSION

Neighborhood context is a critical determinant of health, shaping daily exposures to stressors but also to restorative environments like green space. Understanding how these contextual factors may differentially affect the greenspace-mental health relationships may be critical in determining where best to conduct community-based greening interventions to support emotional well-being at the population level. By targeting neighborhood conditions, interventions can move beyond individual-level approaches to more effectively prevent mental health disorders and promote equitable improvements in population mental health.

In this study of neighborhood context, tree canopy, and allostatic load, our lack of rural/urban differences in the benefits of greenery for allostatic load echo the few previous studies (Beyer et al., 2014; Ryan et al., 2023). Tree canopy was also greater in all non-metropolitan neighborhoods in this study. Another study

showed respondents reported greater connectedness to nature and restoration following visits to rural greenspaces compared with urban greenspaces (Wyles et al., 2019). Perhaps living near such spaces is equally as beneficial. A recent systematic review (Batterham et al., 2022) of greenspace studies conducted only in rural contexts concluded that most studies ($n = 3$, 75%) found that greater percentages of forests or natural areas were associated with better mental health outcomes, suggesting that the current neglect of rural areas in greenspace-mental health research is a yawning omission.

Our findings related to differential benefits based on forms of contextual vulnerability provide some additional insights into the current small but mixed state of the evidence. We consistently found that those residing in more vulnerable neighborhoods, regardless of indicator, were associated with significant and larger benefits for allostatic load. While most research focuses on effect modification by individual-levels of socioeconomic status (Rigolon et al., 2021), there are two large studies of effect modification by neighborhood-level socioeconomic status. Each of these European studies found different associations; one found greater benefits in high SES areas (Bijmens et al., 2025) while the other found a larger, positive effect in low SES areas (Belcher et al., 2024). Therefore, this US-based large, national study bolsters the evidence base for an equigenesis effect of tree canopy on allostatic load, particularly for more socioeconomically vulnerable neighborhoods.

Still, what remains the more perplexing comparison is our results showing that those in more disadvantaged neighborhoods benefit more from greenery, whereas a previous study using the same sample, outcome, and predictor consistently found that more disadvantaged *individuals* did not benefit (Pearson et al., 2026). This mismatch may, in part, be explained by neighborhood vulnerability masking vulnerabilities faced by individuals. For example, those living in more vulnerable neighborhoods may share strong personal connections and sense of cohesion by sharing collective experiences which allow them to also benefit more from surrounding greenery. In contrast, those experiencing individual-level vulnerability but living in advantaged neighborhoods may inadvertently have unfavorable experiences such as financial strain, exposure to discrimination, or limited leisure time. These encounters can influence how such individuals engage with or benefit from greenery. Further, tree canopy is a neighborhood-level intervention that contests adverse neighborhood contexts. However, it may not be sufficient to overcome individual-level vulnerabilities that are arguably more proximal to health measures. When we control for individual vulnerabilities, then neighborhood vulnerability-tree canopy associations are more apparent. But, if individual-level vulnerabilities are pronounced, neighborhood trees cannot overcome them.

Strengths and limitations

This study was conducted in a large, nationally representative sample and leveraged relatively fine-scale measurement of tree canopy to show that both urban and rural contexts show the benefits of tree canopy on allostatic load. Further, regardless of measure of neighborhood vulnerability, consistently, those places ranked as more vulnerable showed larger and significant effects of tree canopy on allostatic load. The sample included large numbers of individuals by race/ethnicity, income, education,

marital status, and other demographics, which were all controls in analyses. Limitations include our inability to account for greenery exposure from the exact home location of each participant, due to the restrictions of CDC staff conducting data linkage. It is worth noting that residential greenness is but one indicator of nature exposure and does not include other areas where people often spend time (e.g., work, school) nor account for actual usage of greenspaces.

Future research and policy implications

The temporal dimension of tree canopy expansion must be acknowledged. Mature canopy, which provides the greatest ecological and mental health benefits—such as shade, cooling, and aesthetic value—can take years or even decades to fully develop. This lag underscores the importance of long-term planning, sustained investment, preservation, and complementary short-term strategies to ensure that communities begin to experience benefits early in the implementation process.

CONCLUSION

We found that greater tree canopy was associated with lower allostatic load, with indications that benefits are more pronounced in vulnerable neighborhoods but are consistent across rural and urban settings. Our findings indicate that tree planting and conservation programs may benefit the mental health and chronic disease risk of individuals living in vulnerable neighborhood contexts.

DECLARATIONS

Authors and contributors

KB and AP conceived of the study and received approval to conduct the research by the US Census Bureau. BC and YZ created spatial measures. All authors compiled spatial data and NHANES data for analysis. AP and KB conducted analyses and drafted the original manuscript. All authors provided edits and approved the final manuscript.

Declaration of interests statement

AP has received honoraria from NIH, NSF, and Duke University within the last three years. KB has received honoraria from NIH, NSF and the University of California San Francisco in the last three years.

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Figures

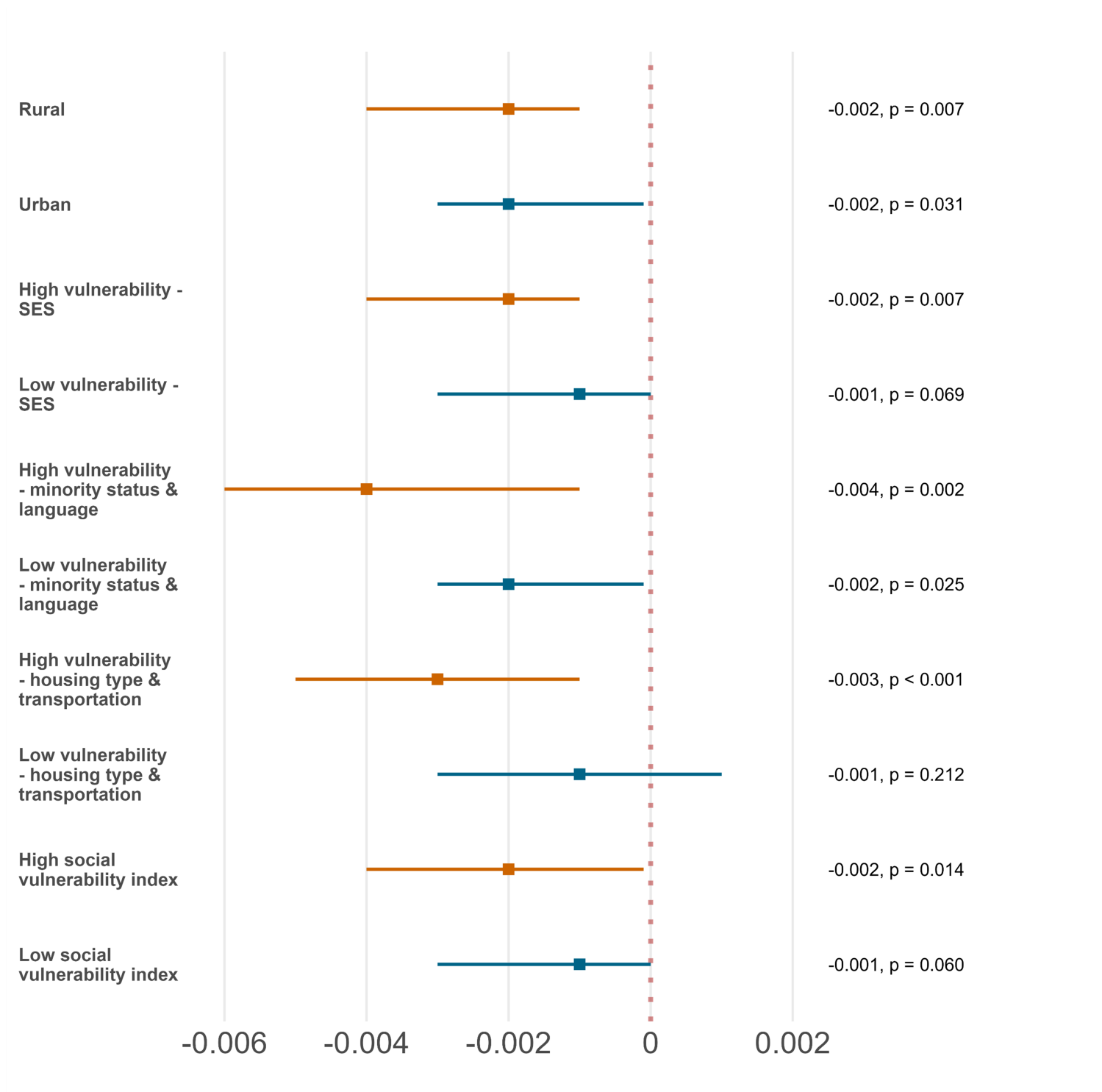


Figure 1

Results of stratified analyses of the effect of tree canopy on allostatic load, where rural and vulnerable contexts shown in orange, urban and more advantaged settings shown in blue

Supplementary Files

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- [PearsonAllostaticTreesNeighborhoodSM8April2026.docx](#)