Title: The Relationship Between Green Space Exposure in Early Adulthood and Neuropsychiatric Risk in Later Life: A Socioeconomically Stratified National Analysis Based on the "All of Us" Research Program

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Conflicts of Interest: None

Short title: Green Space and Neuropsychiatric Risk

Abstract

Background: Exposure to green space has been associated with improved mental and cognitive health, but few studies have investigated how early-life greenness affects neuropsychiatric risk later in life. This study examines the relationship between green space exposure during early adulthood and the likelihood of depression or dementia in later life, and whether these associations differ by socioeconomic status (SES).

Methods: Data from 120,840 participants aged ≥60 in the All of Us Research Program was analyzed. Green space exposure was estimated using the Normalized Difference Vegetation Index (NDVI) averaged across ages 18–25 and linked to ZIP3 geographic units. Outcomes included clinical diagnoses of depression or dementia, identified through curated SNOMED codes. Logistic regression and generalized additive models (GAMs) were used to assess associations and test for SES effect modification using ZIP3-level deprivation indices.

Results: Higher early-life NDVI was strongly associated with lower odds of neuropsychiatric disease (OR = 0.17; 95% CI: 0.14–0.22, $p < 0.0001$). GAMs revealed a non-linear, inverted-U shaped relationship, with risk peaking near NDVI ≈ 0.3. SES modified this association significantly (interaction $p < 2 \times 10^{-16}$), with individuals in low-deprivation areas deriving greater benefit from greenness across multiple NDVI intervals.

Discussion: These findings suggest that green space exposure during early adulthood may confer long-term protection against depression and dementia, potentially through mechanisms involving stress-buffering and reduced neuroinflammation. Socioeconomic disadvantage may attenuate

these benefits, underscoring the need for equitable access to high-quality green spaces to promote brain health across the lifespan.

Keywords: Green space, Mental disorders, Socioeconomic factors, Environmental exposure, Cohort studies

Introduction

1.1. Background.

Dementia and depression are among the most prevalent neuropsychiatric conditions affecting older adults, contributing significantly to global disability and healthcare burden (1, 2) As the global population ages, the incidence of both disorders is projected to rise sharply, making it critical to understand modifiable risk factors beyond the well-known influences of age, genetics, and cardiovascular health (1, 2). While traditionally studied in isolation, there is growing recognition of the link between depression and dementia, with research indicating that depression in midlife can act both as a prodromal symptom and as an independent risk factor for later cognitive decline (3-5). These intertwined trajectories underscore the need to investigate shared environmental determinants that may shape long-term mental and cognitive health outcomes.

One such environmental factor gaining attention is green space exposure. A common way to quantify greenness is the Normalized Difference Vegetation Index (NDVI)**,** a satellite-derived measure that captures vegetation density by comparing near-infrared and red-light reflectance. NDVI is widely used in environmental epidemiology for its objectivity and spatial resolution, and has been linked to reduced risk of depression, anxiety, and cognitive decline in diverse populations (6, 7). However, most studies using NDVI focus on current or childhood exposure, leaving a gap in understanding how greenness in young adulthood, a time of neurodevelopmental sensitivity and geographic mobility that might influence long-term neuropsychiatric outcomes. Natural environments are thought to influence mental health through multiple mechanisms,

including stress reduction, promotion of physical activity, and decreased exposure to environmental pollutants (6, 8). Empirical evidence supports an association between access to green space and reduced psychological distress, with some studies suggesting lower incidence rates of major depression among individuals residing in greener neighborhoods (9, 10). Although research on green space and cognitive health is more nascent, emerging findings suggest potential protective effects against dementia, particularly when exposure occurs during sensitive periods of development.

Most studies have focused on childhood exposure, yet early adulthood may also represent a critical window during which green space may impact long-term brain health. This period is characterized by heightened neural plasticity, increased autonomy, and, for many, a transition to urban environments with varying levels of green exposure (11). Despite its developmental importance, green space exposure during early adulthood remains understudied in relation to late-life neuropsychiatric outcomes.

Moreover, socioeconomic status (SES) may significantly modify the health benefits associated with greenness. Individuals living in socioeconomically deprived areas often have reduced access to both quantity and quality of green spaces and may experience environmental stressors, such as noise and air pollution, that attenuate the mental health benefits of vegetation (12-15). These SES-based disparities not only shape exposure patterns but also likely influence the extent to which green space confers long-term neuropsychiatric resilience. Understanding the interplay between early-life greenness and SES is therefore essential to inform equitable urban planning and public health interventions aimed at reducing depression and dementia risk later in life.

1.2. Objective.

The objective of this study is to investigate whether exposure to green space during early adulthood (ages 18–25), as measured by the Normalized Difference Vegetation Index (NDVI), is associated with reduced risk of later-life neuropsychiatric conditions, specifically depression and dementia, in a large, nationally representative U.S. cohort aged 60 and above. Additionally, the study aims to determine whether these associations vary by socioeconomic status (SES).

Methods

2.1. Cohort Construction.

Two primary cohorts were constructed using the *All of Us Researcher Workbench*: one for participants aged ≥60 with depression diagnoses (n = 39,503) and one with dementia-related conditions (n = 4,311). Participants were included if they had a recorded age 60 and over at the time of their Condition Data Record (CDR) and carried at least one relevant SNOMED diagnosis code from our curated concept sets. The depression cohort included codes such as Depressive disorder, Major depressive disorder, and Dysthymia (Supplementary Table 1). The dementia cohort included [note: fix capitalization here] Alzheimer's disease, Vascular dementia, Frontotemporal dementia, and related behavioral variants (Supplementary Table 2).

Exclusion criteria were applied using a third concept set to remove individuals with diagnoses potentially confounding cognitive outcomes, including bipolar disorder, schizophrenia, schizoaffective disorder, intellectual disability, multiple sclerosis, and Parkinson’s disease (Supplementary Table 3) Only individuals with complete ZIP3 socioeconomic metadata and no missing demographic linkage were retained.

2.2. Socioeconomic and Demographic Variables.

Demographic data (age, gender, race, ethnicity) and ZIP3-level socioeconomic indicators were extracted using linked tables in the All of Us Workbench. ZIP3-based socioeconomic

indicators included median income, fraction of population in poverty, and a composite deprivation index, provided through a structured join on person-level zip3_as_string. All continuous variables were standardized prior to modeling.

2.3. Environmental Exposure Data (NDVI).

To assess green space exposure, participants' ZIP3 codes were linked to Normalized Difference Vegetation Index (NDVI) estimates from NOAA's AVHRR-Land archive. Historical NDVI data from 1981 to 1990 were aggregated annually and matched to participants' ZIP3 during ages 18–25, corresponding to the years when the oldest eligible cohort (those aged 60+ at data collection) would have been in early adulthood. This linkage was implemented using custom Python scripts that processed NOAA.nc raster files via xarray, rioxarray, and geopandas. Mean NDVI per ZIP3 was extracted for each relevant year and averaged over the 7-year exposure window.

2.4. Data Integration and Cleaning.

Demographic data, including sex, race, ethnicity, and birth year, were extracted from the person table and joined with concept lookups for race/ethnicity harmonization. Socioeconomic status was represented by the ZIP3-level deprivation index, poverty fraction, and median household income. Individuals with incomplete demographic or NDVI exposure data were excluded from downstream modeling.

2.5 Statistical Analysis.

Analyses were performed in Python using pandas, statsmodels, patsy, and pygam libraries. All packages were force-installed at fixed versions to avoid dependency conflicts.

2.6 Descriptive Statistics.

Descriptive summaries were stratified by quartiles of NDVI exposure using groupwise means, standard deviations, and counts for age and ZIP3-level SES metrics.

2.7 Logistic Regression and Spline Modeling.

To assess the relationship between early-life NDVI exposure and later-life risk of disease, logistic regression models were used, incorporating restricted cubic splines (cr() with 3 degrees of freedom). The primary binary outcome was presence of either dementia or depression. It was adjusted for age, NDVI, sex (collapsed into Male/Female/Other), race (White/Black/Other), and deprivation index. Multivariable regression outputs included log-odds estimates, 95% confidence intervals, and odds ratios.

2.8 Generalized Additive Models.

A Generalized Additive Model (GAM) with tensor product smooths using pygam was additionally utilized, specifying interaction terms for NDVI and SES groups. The final model included spline-by-factor interactions (s(NDVI, by=SES_Group)) and categorical main effects. Predicted probabilities and their 95% confidence intervals were visualized.

2.9 Spatial Analysis.

To visualize spatial heterogeneity in NDVI exposure, cohort ZIP3 values were merged with shapefiles from the U.S. Census-derived ZIP3 boundaries using geopandas. Maps were rendered using matplotlib with continuous NDVI color gradients and standardized limits across plots.

2.10 Effect Modification by Socioeconomic Status.

To assess effect modification, the cohort was stratified by median ZIP3-level deprivation index into “High Deprivation” and “Low Deprivation” groups. Separate spline models (df=4) were fit within each stratum. Predicted probabilities and marginal risk differences were plotted across the NDVI gradient. Spline derivatives were numerically approximated using a finite difference method ($\varepsilon = 1e{-}4$) to estimate exposure sensitivity.

Results

3.1. Cohort Characteristics.

The relationship between early adulthood exposure to greenness was examined, measured via average Normalized Difference Vegetation Index (NDVI) from ages 18–25, and later-life diagnosis of dementia or depression. Our analysis included 120,840 individuals aged ≥60, drawn from the All of Us Research Program, stratified into NDVI quartiles for cohort-level comparisons.

Cohort characteristics (Table 1) varied slightly across NDVI quartiles, with higher quartiles showing modestly older mean age (Q1: 63.3 years; Q4: 65.8 years) and marginal differences in income and deprivation index (mean deprivation ranged from 0.31 to 0.34). Despite these socioeconomic differences being relatively small, they were adjusted for in multivariable models.

3.2. The Relationship Between NDVI and Disease.

A logistic regression model (GLM) adjusting for age, gender identity, race, and deprivation index revealed a strong, inverse association between NDVI exposure and the likelihood of disease (Table 2). Specifically, higher NDVI was significantly protective (OR = 0.17; 95% CI: 0.13–0.21, $P < 0.0001$). Deprivation index was also independently protective in the model (OR = 0.58; 95% CI: 0.41–0.84), whereas older age was associated with increased risk (OR = 1.31; 95% CI: 1.30–1.32).

To evaluate the non-linear relationship between green space exposure in early adulthood and later-life neuropsychiatric outcomes, we fit a generalized additive model (GAM) using NDVI values averaged from ages 18 to 25 as the predictor of predicted disease risk. The fitted GAM spline revealed a significant inverted-U shaped association, with risk increasing at lower NDVI values, peaking near NDVI ≈ 0.3, and declining at higher exposures (Figure 1). The 95% confidence interval (shaded region) demonstrated tight uncertainty bands around the central curve, confirming robustness of the non-linear association. This suggests a threshold effect whereby both low and excessively high levels of greenness may confer lower risk, possibly reflecting a balance between environmental enrichment and urbanicity-related factors.

3.3. Spatial Analysis.

Spatial analysis (Figure 2) demonstrated considerable variation in early-life NDVI exposure across the U.S., with the lowest exposure in dense urban ZIP3s (e.g., New York City, ZIP3 100) and highest in rural western and northern regions.

3.4. The Effects of Socioeconomic Status.

To examine whether the association between greenness and predicted health risk differs by socioeconomic status (SES), we fit a generalized additive model (GAM) with SES-specific smooth terms for the Normalized Difference Vegetation Index (NDVI). The model included separate smooth functions for NDVI in high and low deprivation SES groups, allowing us to assess effect modification by SES (Figure 3).

The model explained nearly all variance in predicted risk (adjusted $R^2 = 1.00$, deviance explained = 100%), with both the parametric SES term and the smooth NDVI terms achieving statistical significance (all $p < 2 \times 10^{-16}$). Notably, the smooth terms for NDVI differed significantly between SES groups, with effective degrees of freedom (edf) of 8.88 for high deprivation and 9.00 for low deprivation, suggesting non-linear and group-specific associations.

Estimated derivatives (i.e., slopes) of the smooth terms revealed that increases in NDVI were associated with reductions in predicted health risk across most of the NDVI range, but the magnitude and statistical significance of these reductions varied by SES group. For both groups, statistically significant negative slopes were observed across large portions of the NDVI continuum (95% confidence intervals for the first derivatives excluded zero), indicating beneficial effects of greenness on risk.

Comparison of the smooth functions between SES groups further identified three distinct NDVI intervals with statistically significant differences in risk reduction: [−0.046, 0.123], [0.138, 0.396], and [0.411, 0.683]. Within these windows, the association between NDVI and predicted risk was consistently stronger for individuals in the low deprivation group, underscoring a potential SES-based modification of environmental health benefits.

These findings indicate that although greenness is generally associated with reduced predicted health risk, the magnitude of this protective effect is modified by socioeconomic status, with individuals in less deprived groups experiencing greater benefit per unit increase in NDVI.

Discussion

4.1. Key Findings.

This study found a strong and statistically significant inverse association between green space exposure during early adulthood and later-life risk of depression or dementia. Participants with higher average NDVI exposure from ages 18 to 25 were substantially less likely to develop neuropsychiatric conditions after age 60. Socioeconomic status (SES) significantly modified these associations. The protective effect of early-life greenness was consistently stronger for individuals from lower deprivation (higher SES) ZIP3 regions. GAM-based analysis revealed statistically significant differences in the NDVI-risk relationship across three key exposure

intervals, with the low-deprivation group benefiting more from green space exposure than those in high-deprivation areas. These findings highlight that while green space exposure is generally beneficial for neuropsychiatric health, its protective effects are not equitably distributed across socioeconomic strata.

4.2. Possible Environmental Mechanisms on Brain Health.

Several plausible environmental and neurobiological mechanisms may explain the observed protective association between early adulthood green space exposure and reduced neuropsychiatric risk in later life. While causality cannot be definitively established, three key pathways have garnered empirical support: stress-buffering via HPA axis regulation, reduction of neuroinflammation through decreased pollution exposure, and cognitive and affective enrichment via restorative environmental experiences.

A. Stress-Buffering and HPA Axis Regulation.

Exposure to natural environments has been shown to buffer stress by modulating the hypothalamic-pituitary-adrenal (HPA) axis, a key regulator of cortisol and other stress hormones. Chronic stress and HPA axis dysregulation are implicated in both depression and cognitive decline, particularly when initiated early in life or sustained across time. Studies demonstrate that individuals exposed to green space show lower salivary cortisol levels, lower perceived stress, and enhanced parasympathetic nervous system activity (16, 17). In adolescence and early adulthood, which are critical periods for stress sensitivity, sustained exposure to vegetation may reduce allostatic load, thereby conferring long-term neuroprotective effects. Importantly, flatter diurnal cortisol slopes, a marker of chronic stress, have been linked to accelerated cognitive decline and mood disorders in later life, suggesting that sustained green exposure during early adulthood may help stabilize stress response systems long-term (18, 19).

B. Reduced Neuroinflammation via Pollution Mitigation.

Green spaces are associated with lower levels of air pollutants such as PM2.5, nitrogen dioxide (NO_2), and ozone, all of which are known to cross the blood–brain barrier and contribute to neuroinflammation, microglial activation, and oxidative stress (20). Neuroinflammation is increasingly recognized as a common pathological substrate in both dementia and depression. Longitudinal studies have linked chronic exposure to air pollution with increased risk of Alzheimer's disease and major depressive disorder (21, 22). Vegetation can improve local air quality through deposition and filtration mechanisms, suggesting that green space may exert indirect protective effects on brain health by reducing cumulative pollutant exposure during early adulthood. Green space may exert neuroprotective effects by limiting such exposure and reducing downstream inflammatory cytokines, including IL-6 and TNF-α, which are elevated in both major depressive disorder and Alzheimer's pathology (23, 24). Preliminary evidence also suggests that early environmental exposures may induce epigenetic modifications in genes regulating immune and stress responses, potentially programming brain vulnerability or resilience across the life course (25).

C. Cognitive and Affective Enrichment Through Restorative Experience.

Natural environments also promote mental restoration by offering opportunities for cognitive respite, aesthetic engagement, and positive affect. The Attention Restoration Theory (ART) posits that green spaces enable recovery from directed attention fatigue, while the Stress Reduction Theory (SRT) suggests that natural settings facilitate emotion regulation and psychological recovery (26, 27). These restorative processes may support affective resilience and cognitive reserve, psychological constructs that are inversely associated with neuropsychiatric disease risk (28). Importantly, early adulthood often involves academic, occupational, and

emotional stressors, and individuals with consistent access to green space may derive long-term benefit through repeated cognitive restoration and enhanced emotional regulation. In addition, neuroimaging studies have shown associations between residential greenness and increased hippocampal volume, supporting the idea that environmental enrichment may influence structural brain development (29, 30).

Together, these mechanisms suggest that green space exposure during early adulthood may shape neurodevelopmental trajectories, modulate lifelong stress and inflammation pathways, and support emotional resilience and cognitive function—factors that are critical in delaying or mitigating the onset of dementia and depression in later life.

4.3. Future Research.

This study contributes to a growing body of evidence linking natural environmental exposures with long-term neuropsychiatric health. However, important avenues for future investigation remain. First, while our findings suggest that green space during early adulthood is protective, the precise timing and duration of exposure that yields optimal benefit is not well established. Longitudinal studies that compare exposures across multiple developmental windows, including childhood, adolescence, and midlife, could help clarify critical periods for intervention and cumulative dose-response effects.

Additional mechanistic studies are needed to validate and expand upon the pathways proposed here. Integration of biomarker data, including inflammatory cytokines, cortisol rhythms, and neuroimaging markers of brain structure and function, would provide more direct evidence of causal links between early-life greenness and later brain health. The inclusion of objective measures (e.g., wearable sensors, GPS tracking) may also improve precision in estimating actual exposure to green environments beyond satellite-derived NDVI.

Additionally, future work should explore green space quality, type, and accessibility, which were not accounted for in our ZIP3-level NDVI estimates. Not all vegetation confers the same health benefits; tree canopy, park infrastructure, biodiversity, and safety perceptions may all shape the psychological and physiological impact of green space. Incorporating more granular, locally informed green metrics could help distinguish between mere presence and effective use.

Moreover, there is a need for more international and low- and middle-income country studies**.** Our U.S.-based cohort limits generalizability to urban forms, cultural contexts, and environmental exposures that differ globally. Given the rapid pace of urbanization in these countries, often with high levels of deprivation and poor green space access, future research should assess whether early-life greenness offers similar neuropsychiatric protection across diverse global settings.

And lastly, it will be important to test interventions and policy reforms aimed at expanding equitable green infrastructure. Experimental or quasi-experimental designs (e.g., natural experiments, urban greening initiatives) can provide more robust evidence of causal impacts and inform strategies for scaling up environmental health interventions. Future work should prioritize evaluating whether increasing green access in underserved communities yields meaningful reductions in population-level psychiatric and cognitive morbidity over time.

Together, these lines of inquiry can help deepen our understanding of the role of urban nature in shaping lifelong mental and cognitive health, while guiding actionable steps to build healthier, more equitable environments.

4.4. The Strengths and Limitations.

This study offers several notable strengths. First, it is among the few investigations to examine green space exposure during early adulthood**,** a developmentally sensitive but understudied life stage in relation to long-term brain health. By focusing on ages 18–25, a transitional period marked by increased autonomy and environmental change, a window is captured that may be critical for shaping lifelong neuropsychiatric trajectories.

Secondly, the use of a large, nationally representative cohort from the All of Us Research Program (n = 120,840) enhances the statistical power and generalizability of these findings across diverse U.S. populations. The integration of structured electronic health records, ZIP3-level deprivation indices, and satellite-derived NDVI provides a robust multimodal dataset that enables both individual- and community-level inference.

However, several limitations must be acknowledged. First, our exposure estimates are ecological**,** based on ZIP3-level NDVI data, which may not reflect individual-level access or interaction with green space. Although ZIP3 provides better spatial resolution than county-level data, it may still introduce exposure misclassification, particularly in heterogeneous urban regions. Also, the NDVI metric captures quantity but not quality of green space. Biodiversity, usability, maintenance, or perceived safety were not assessed, which are all factors that may mediate the psychological benefits of greenery. This limitation may explain some of the observed SES differences in effect size. Moreover, the study is observational, and although temporally ordered, it cannot establish causality. Residual confounding by unmeasured variables (e.g., physical activity, comorbid health conditions, life course stressors) may influence both green space exposure and neuropsychiatric outcomes. And finally, while the cohort is diverse, the findings may not be generalizable to non-U.S. or rural contexts**,** where environmental

exposures, healthcare access, and mental health burdens differ substantially. Further cross-cultural validation is needed to confirm these patterns globally.

Despite these limitations, this study adds important evidence to the growing literature on the role of urban environmental factors in shaping brain health across the life course and underscores the potential of early-life interventions aimed at expanding access to nature.

4.5. Clinical Translation & Intervention Implications.

Although this study is observational, its findings suggest several concrete opportunities for integrating environmental context into clinical and preventive mental health care. Green space exposure during early adulthood appears to confer long-term protective effects against depression and dementia. These results highlight the relevance of considering early-life environmental exposures in psychiatric and cognitive risk assessments, especially for patients presenting with chronic mood disorders or early signs of cognitive decline.

Clinicians may not directly control the environments their patients inhabit, but they can play a key role in promoting nature-based behavioral interventions**.** Emerging research supports the use of “green prescriptions," which are structured recommendations to spend time in natural environments, as an adjunct to standard treatments for depression and anxiety. Such prescriptions, already adopted in several countries, are associated with improved mood, reduced stress, and enhanced cognitive functioning (31, 32). For example, time spent in parks or green corridors has been shown to buffer stress responses, particularly in younger and urban populations (33). Incorporating nature engagement into behavioral activation strategies, mindfulness therapy, or social prescribing programs may provide a scalable, low-cost approach to mental health promotion (34).

Importantly, this study's stratified findings suggest that individuals from high-deprivation backgrounds may experience diminished benefits from ambient green exposure. This aligns with recent randomized trials showing that green interventions have the greatest mental health benefits when targeted to underserved neighborhoods**,** where green infrastructure is often sparse or poorly maintained (35). Clinicians serving marginalized populations can help address this gap by advocating for safe and equitable green access through community partnerships, referring patients to structured outdoor programs, and working with social workers to overcome barriers such as transportation or safety concerns (15). These steps are especially critical during early adulthood, when neurodevelopment and psychosocial habits are still in flux.

There is also growing interest in using green environments to enhance the effectiveness of existing therapies**.** For example, mindfulness-based interventions conducted in natural settings may lead to stronger reductions in stress and emotional dysregulation than those delivered in clinical environments alone (36). Similarly, exposure to green space may bolster resilience and cognitive reserve, key protective factors against both depression and neurodegeneration in later life (37, 38). Given these benefits, clinicians might begin incorporating questions about environmental context into patient histories, especially when working with high-risk or early-intervention populations.

In sum, although the structural inequities that shape green space access require systemic solutions, clinicians can still act within their sphere to help patients leverage nature as a mental health resource. Encouraging safe, routine contact with natural environments, and advocating for broader environmental justice, may help reduce the burden of neuropsychiatric disease over the life course, particularly among those least likely to access these benefits passively.

4.6. The Public Health Policy Implications.

The observed association between green space exposure in early adulthood and reduced risk of neuropsychiatric conditions in later life has direct implications for public health planning, urban development, and health equity policy. These findings suggest that access to green environments during formative life stages may serve as a low-cost, community-level intervention capable of enhancing long-term brain health across populations.

Importantly, the modifying effect of socioeconomic status (SES) on this relationship underscores a pressing need to address spatial inequalities in green space availability and quality. Individuals residing in deprived areas consistently benefit less from greenness, likely due to environmental factors such as lower vegetation quality, reduced safety, or higher co-exposures to pollution and stressors. As such, targeted investment in green infrastructure in low-resource neighborhoods is not merely an urban design issue but a public health imperative. Programs that enhance the distribution, safety, and usability of green space can potentially yield long-term reductions in the burden of depression and dementia, both of which are growing contributors to disability-adjusted life years (DALYs) globally.

These findings align with the principles of upstream prevention and the broader shift toward place-based health equity strategies. Municipal and regional governments should consider integrating historical and cumulative environmental exposure data, such as early adulthood greenness, into health risk assessments, environmental justice mapping, and long-term planning for mental health services. By embedding nature-based health promotion into zoning regulations, transportation planning, and school campus design, public policy can proactively shape environments that foster psychological resilience and cognitive reserve from a young age.

Additionally, cross-sector collaboration between public health agencies, urban planners, environmental scientists, and healthcare providers is critical to translating these insights into

effective policy. The adoption of “green prescriptions,” incentives for green housing developments, and strategic use of urban land parcels for restorative natural spaces may all serve as viable tools in addressing both mental illness and cognitive aging at scale. As cities worldwide continue to densify, ensuring equitable access to green environments should be recognized as a central strategy in preventing neuropsychiatric disease and advancing population brain health.

CONCLUSION

This study demonstrates that green space exposure during early adulthood is associated with a reduced risk of depression and dementia in later life. The findings highlight early adulthood as a critical window for environmental influence on brain health and reveal that socioeconomic status modifies access to these benefits. These results point to green space as a modifiable, yet inequitable, determinant of neuropsychiatric resilience. Promoting equitable access to natural environments may offer a scalable strategy to support mental and cognitive health across the lifespan.

Tables

Table 1 Demographic and Socioeconomic Characteristics by NDVI Quartile

NDVI Quartile	Age (Mean)	Age (SD)	Age (Count)	Income (Mean, USD)	Income (SD)	Income (Count)	Poverty % (Mean)	Poverty % (SD)	Poverty % (Count)	Deprivation Index (Mean)	Deprivation Index (SD)	Deprivation Index (Count)
Q1	63.32	2.78	30295	$65,921.32	$16,986.98	30295	15.12	5.71	30295	0.31	0.06	30295
Q2	64.39	2.57	30157	$65,041.81	$17,271.63	30157	14.87	5.29	30157	0.32	0.07	30157
Q3	64.58	2.89	30187	$60,343.89	$13,882.33	30187	16.74	5.35	30187	0.34	0.06	30187
Q4	65.77	2.68	30201	$67,417.32	$17,050.08	30201	15.67	5.3	30201	0.32	0.06	30201

Caption:

Characteristics of participants aged ≥60 years stratified by quartile of average NDVI exposure between ages 18 and 25. Means and standard deviations are shown for age, annual household income, poverty percentage, and deprivation index. Sample sizes are provided for each measure. NDVI: Normalized Difference Vegetation Index; SD: standard deviation.

Table 2 Multivariable Logistic Regression Predicting Dementia or Depression Diagnosis

Covariate	Estimate (log-odds)	Standard error	P-value *(4 sig. figs.)*	P-value *(formatted)*	Odds ratio	95% CI (lower)	95% CI (upper)
Intercept (Male, White, NDVI=0, age=0, deprivation=0)	-19.728	0.295	0.0000	<0.0001	0.00	0.00	0.00
Female vs Male (gender)	0.391	0.023	5.049×10^{-63}	<0.0001	1.48	1.41	1.55
Other vs Male (gender)	0.255	0.095	7.078×10^{-3}	0.007078	1.29	1.07	1.55
Gender missing vs Male (gender)	0.000	0.000	2.404×10^{-6}	<0.0001	1.00	1.00	1.00
Black or African American vs White (race)	0.035	0.029	2.302×10^{-1}	0.2302	1.04	0.98	1.10
Other racial identity vs White (race)	0.070	0.029	1.594×10^{-2}	0.01594	1.07	1.01	1.14
Race missing vs White (race)	0.000	0.000	3.928×10^{-3}	0.003928	1.00	1.00	1.00
NDVI (ages 18–25)	-1.794	0.128	1.591×10^{-44}	<0.0001	0.17	0.13	0.21
Age	0.267	0.004	0.0000	<0.0001	1.31	1.30	1.32
Deprivation Index	-0.539	0.184	3.427×10^{-3}	0.003427	0.58	0.41	0.84

Caption:
Results from a fully adjusted logistic regression model estimating odds of later-life dementia or depression diagnosis as a function of early adulthood NDVI exposure, age, gender identity, race, and deprivation index. Values shown include log-odds estimates, 95% confidence intervals, and odds ratios (OR). NDVI (Normalized Difference Vegetation Index) was strongly protective (OR = 0.17; 95% CI: 0.13–0.21; $P < 0.0001$), independent of age and socioeconomic factors. Age and

most race categories were significant predictors, while gender associations varied in magnitude and precision. CI: confidence interval; OR: odds ratio.

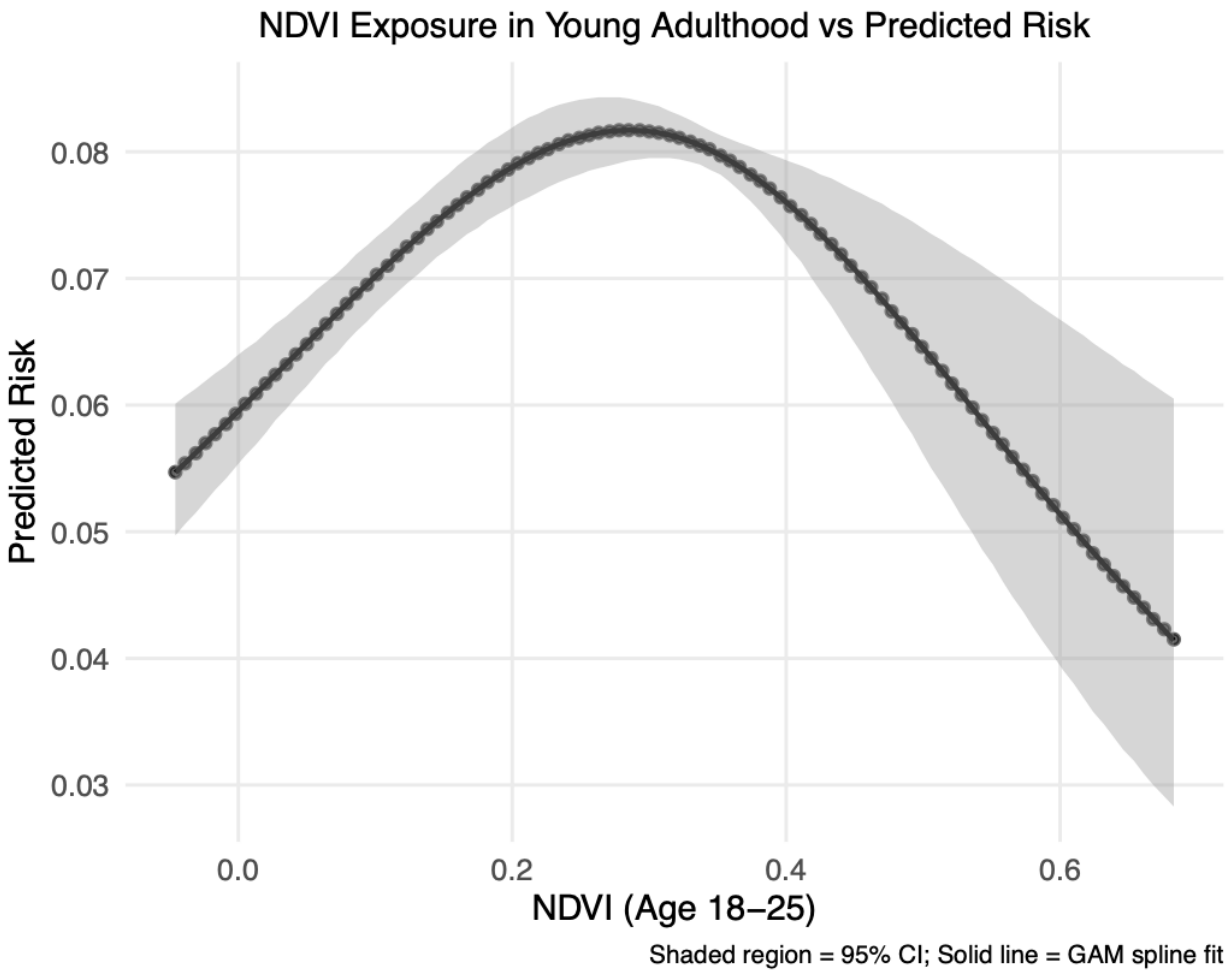
Additional Information

All code used for data analysis and figure generation is publicly available at:

https://github.com/danrosen3/green-exposure-mental-health.git

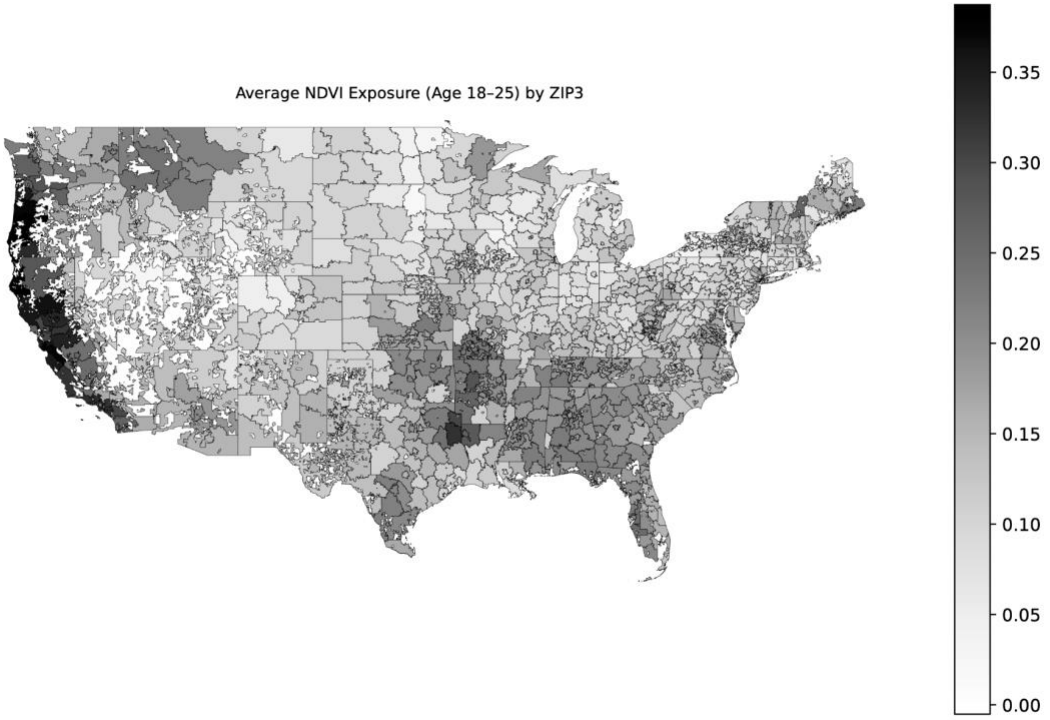
Figures

Figure 1. Dose–Response Relationship Between NDVI Exposure and Predicted Risk of Dementia or Depression



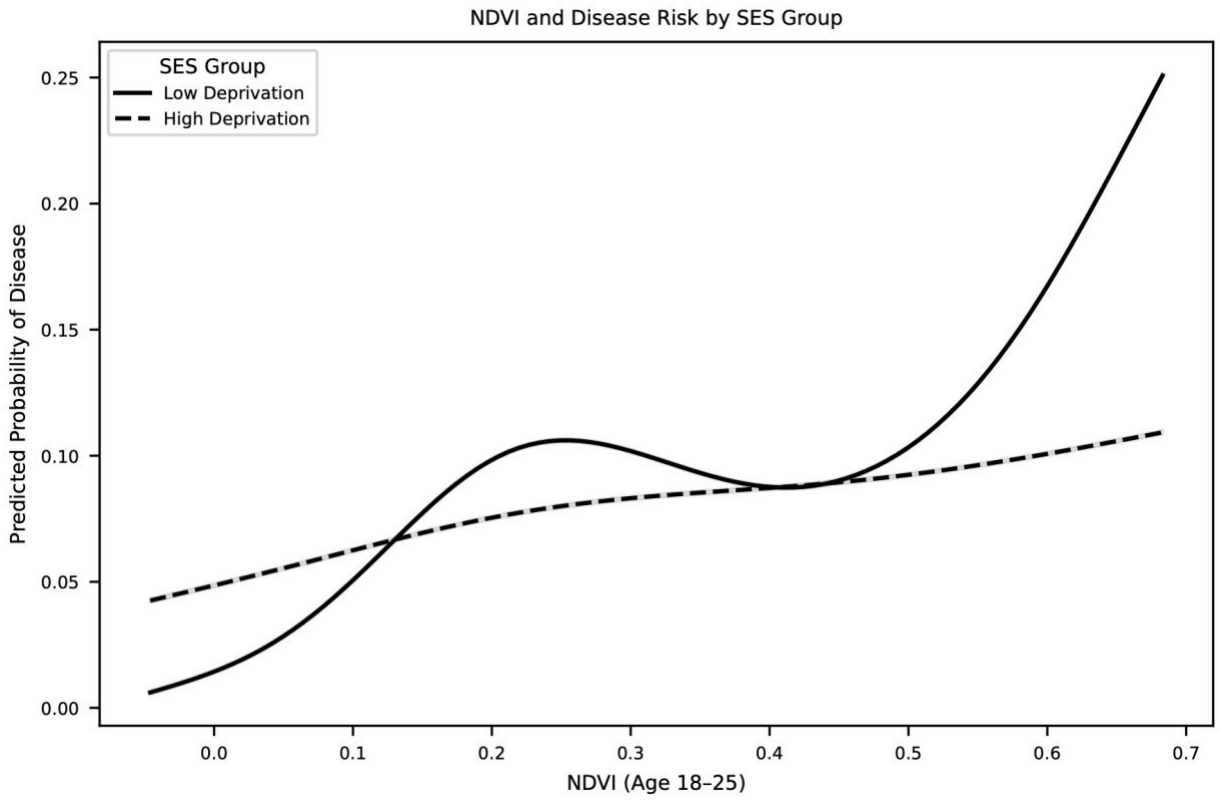
Caption**:**
A generalized additive model (GAM) spline fit demonstrates an inverted-U shaped relationship between mean NDVI (Normalized Difference Vegetation Index) exposure during ages 18–25 and predicted risk of later-life neuropsychiatric conditions. Risk increases at lower NDVI levels, peaks near NDVI ≈ 0.3, and declines thereafter. The shaded region denotes the 95% confidence interval. This pattern suggests a threshold-dependent association, potentially reflecting competing influences of green space and urbanicity.

Figure 2. Geographic Distribution of Average NDVI Exposure During Early Adulthood (Age 18–25) by ZIP3



Caption:
Spatial map of average Normalized Difference Vegetation Index (NDVI) values across U.S. ZIP3 regions, representing participant exposure between ages 18 and 25. Darker regions indicate higher greenness exposure. NDVI was derived from NOAA AVHRR satellite data and aggregated to ZIP3-level means. Substantial regional variation is visible, with lower greenness in urban and industrialized areas and higher exposure in rural and forested ZIP codes, providing ecological context for later-life mental health outcomes. NDVI: Normalized Difference Vegetation Index.

Figure 3. Socioeconomic modification of the association between greenness and predicted health risk.



Caption:
Generalized additive model–derived smooth functions illustrating the relationship between Normalized Difference Vegetation Index (NDVI) and predicted health risk, stratified by socioeconomic status (SES) group. Curves represent estimated risk across the range of NDVI for individuals in high (dashed line) and low (solid line) deprivation groups, with shaded areas denoting 95% confidence intervals. The association between NDVI and predicted risk is non-

linear and significantly different across SES strata (interaction $p < 2 \times 10^{-16}$), with greater reductions in risk observed for the low deprivation group across several NDVI intervals.

Supplementary Information

Supplementary Table 1

Concept set used to identify depression-related conditions.						
Diagnosis	**Concept ID**	**Concept Type**	**Vocab**	**SNOMED Code**	**Mapped Count**	**Direct Matches**
Atypical depressive disorder	438727	Standard	SNOMED	191659001	0	193
Brief depressive adjustment reaction	440698	Standard	SNOMED	192046006	0	8
Chronic recurrent major depressive disorder	4094358	Standard	SNOMED	2618002	0	14
Depressive disorder	440383	Standard	SNOMED	35489007	112427	71156
Depressive disorder in remission	44782943	Standard	SNOMED	698957003	16349	5
Depressive episode	3656234	Standard	SNOMED	871840004	0	1290
Dysthymia	433440	Standard	SNOMED	78667006	18259	18257
Major depression, single episode	4282096	Standard	SNOMED	36923009	71027	64554
Major depressive disorder	4152280	Standard	SNOMED	370143000	86617	890
Minor depressive disorder	4174987	Standard	SNOMED	48589009	710	3
Mixed anxiety and depressive disorder	4338031	Standard	SNOMED	231504006	0	2705
Persistent depressive disorder	607543	Standard	SNOMED	1153575004	0	73
Prolonged depressive adjustment reaction	433751	Standard	SNOMED	192049004	0	16
Recurrent major depression	4282316	Standard	SNOMED	66344007	42822	15542
Recurrent major depressive disorder co-occurrent with anxiety in full remission	35615154	Standard	SNOMED	16265061000119105	0	1
Recurrent major depressive disorder in partial remission co-occurrent with anxiety	35615155	Standard	SNOMED	16265301000119106	0	5
Recurrent major depressive episodes	432285	Standard	SNOMED	268621008	12561	446
Recurrent major depressive episodes, mild	438998	Standard	SNOMED	191610000	0	3550
Recurrent major depressive episodes, moderate	432883	Standard	SNOMED	191611001	0	8860
Recurrent major depressive episodes, severe, with psychosis	434911	Standard	SNOMED	191613003	0	2515
Severe major depression, single episode, with psychotic features	438406	Standard	SNOMED	430852001	0	1154
Symptoms of depression	4191716	Standard	SNOMED	394924000	0	23

Supplementary Table 2

Concept set used to identify dementia-related conditions.						
Diagnosis	Concept ID	Concept Type	Vocab	SNOMED Code	Mapped Count	Direct Matches
Agitation due to dementia	37312035	Standard	SNOMED	788862002	0	1
Altered behavior in Alzheimer's disease	44784643	Standard	SNOMED	97751000119108	0	2
Alzheimer's disease	378419	Standard	SNOMED	26929004	1284	1115
Behavioral and psychological symptoms of dementia	35608576	Standard	SNOMED	10171000132106	0	190
Behavioral disturbance co-occurrent and due to late onset Alzheimer dementia	37117145	Standard	SNOMED	16219201000119101	0	1
Cerebral degeneration presenting primarily with dementia	4092747	Standard	SNOMED	279982005	1413	0
Dementia	4182210	Standard	SNOMED	52448006	8142	3146
Dementia associated with AIDS	4228133	Standard	SNOMED	421529006	0	1
Dementia associated with alcoholism	378726	Standard	SNOMED	281004	0	63
Dementia associated with another disease	374888	Standard	SNOMED	191519005	5601	1738
Dementia due to Huntington chorea	40483103	Standard	SNOMED	442344002	0	1
Dementia of frontal lobe type	441002	Standard	SNOMED	278857002	0	4
Dementia of the Alzheimer type with behavioral disturbance	43530664	Standard	SNOMED	1581000119101	0	11
Dementia with behavioral disturbance	43530666	Standard	SNOMED	1591000119103	785	687
Diffuse Lewy body disease	380701	Standard	SNOMED	80098002	170	89
Drug-induced dementia	376095	Standard	SNOMED	191493005	71	5
Early onset Alzheimer's disease with behavioral disturbance	44782432	Standard	SNOMED	105421000119105	0	2
Frontotemporal dementia	4043378	Standard	SNOMED	230270009	0	178
General paresis - neurosyphilis	377788	Standard	SNOMED	51928006	0	12
Hallucinations co-occurrent and due to late onset dementia	37109222	Standard	SNOMED	2421000119107	0	1
Inhalant-induced persisting dementia	4139421	Standard	SNOMED	32875003	0	1
Lewy body dementia with behavioral disturbance	44782763	Standard	SNOMED	135811000119107	0	4
Mild dementia	762497	Standard	SNOMED	428051000124108	0	195
Mixed cortical and subcortical vascular dementia	4046090	Standard	SNOMED	230287006	0	2
Mixed dementia	43021816	Standard	SNOMED	79341000119107	0	9
Moderate dementia	762704	Standard	SNOMED	430771000124100	0	77
Multi-infarct dementia	379778	Standard	SNOMED	56267009	138	3
Multi-infarct dementia with delirium	444091	Standard	SNOMED	10349009	0	10
Multi-infarct dementia with delusions	443790	Standard	SNOMED	25772007	0	5
Multi-infarct dementia with depression	443864	Standard	SNOMED	14070001	0	13
Multi-infarct dementia, uncomplicated	377254	Standard	SNOMED	70936005	0	114
Post-traumatic dementia with behavioral change	44784521	Standard	SNOMED	698687007	0	3
Presenile dementia	378125	Standard	SNOMED	12348006	301	4
Presenile dementia with delirium	381832	Standard	SNOMED	191452002	0	4
Presenile dementia with delusions	44782771	Standard	SNOMED	31081000119101	0	4
Presenile dementia with depression	377527	Standard	SNOMED	191455000	0	33
Primary degenerative dementia of the Alzheimer type, presenile onset	4218017	Standard	SNOMED	416780008	168	168
Primary degenerative dementia of the Alzheimer type, presenile onset, uncomplicated	4277444	Standard	SNOMED	6475002	0	4
Primary degenerative dementia of the Alzheimer type, senile onset	4220313	Standard	SNOMED	416975007	306	305
Primary degenerative dementia of the Alzheimer type, senile onset, uncomplicated	4278830	Standard	SNOMED	66108005	0	16
Progressive aphasia in Alzheimer's disease	4043379	Standard	SNOMED	230280008	0	1
Progressive supranuclear ophthalmoplegia	4103534	Standard	SNOMED	28978003	0	40
Psychoactive substance-induced organic dementia	4009647	Standard	SNOMED	111480006	0	3
Senile degeneration of brain	373179	Standard	SNOMED	45864009	0	49
Senile dementia	4048875	Standard	SNOMED	15662003	580	3
Senile dementia of the Lewy body type	4196433	Standard	SNOMED	312991009	0	111
Senile dementia with delirium	376946	Standard	SNOMED	191461002	0	10
Senile dementia with delusion	380986	Standard	SNOMED	371024007	0	8
Senile dementia with depression	379784	Standard	SNOMED	191459006	0	16
Senile dementia with depressive or paranoid features	4101137	Standard	SNOMED	191457008	16	0
Severe dementia	765653	Standard	SNOMED	428351000124105	0	32
Subcortical vascular dementia	4047747	Standard	SNOMED	230286002	0	0
Uncomplicated presenile dementia	376085	Standard	SNOMED	191451009	0	95
Uncomplicated senile dementia	375791	Standard	SNOMED	191449005	846	151
Vascular dementia	443605	Standard	SNOMED	429998004	0	51
Vascular dementia with behavioral disturbance	37018688	Standard	SNOMED	288631000119104	0	147
Vascular dementia without behavioral disturbance	37109056	Standard	SNOMED	16276361000119109	0	713

Supplementary Table 3

Concept set used to identify excluded conditions.

Diagnosis	Concept ID	Concept Type	Vocab	SNOMED Code	Mapped Count	Direct Matches
Active infantile autism	439703	Standard	SNOMED	191689008	0	283
Acute exacerbation of chronic catatonic schizophrenia	436071	Standard	SNOMED	191548004	0	1
Acute exacerbation of chronic latent schizophrenia	433734	Standard	SNOMED	191564007	0	7
Acute exacerbation of chronic paranoid schizophrenia	437243	Standard	SNOMED	191555002	0	106
Acute exacerbation of chronic schizoaffective schizophrenia	435236	Standard	SNOMED	191572009	0	93
Acute exacerbation of chronic schizophrenia	4100366	Standard	SNOMED	191531007	145	50
Acute exacerbation of subchronic catatonic schizophrenia	439275	Standard	SNOMED	191547009	0	2
Acute exacerbation of subchronic latent schizophrenia	439274	Standard	SNOMED	191563001	0	2
Acute exacerbation of subchronic paranoid schizophrenia	434901	Standard	SNOMED	191554003	0	14
Acute exacerbation of subchronic schizoaffective schizophrenia	432865	Standard	SNOMED	191571002	0	10
Acute relapsing multiple sclerosis	4046108	Standard	SNOMED	230372003	0	10
Acute schizophrenia-like psychotic disorder	4133495	Standard	SNOMED	278853003	140	0
Adult-onset dystonia parkinsonism	36715010	Standard	SNOMED	720466001	0	1
Atypical Parkinsonism	36716783	Standard	SNOMED	722964001	0	3
Autism spectrum disorder	439776	Standard	SNOMED	35919005	1,049	363
Autistic disorder	439780	Standard	SNOMED	408856003	768	672
Benign multiple sclerosis	4231948	Standard	SNOMED	438511000	0	1
Bipolar affective disorder, current episode depression	439254	Standard	SNOMED	191627008	5,243	3,866
Bipolar affective disorder, current episode manic	440078	Standard	SNOMED	191618007	2,236	1,313
Bipolar affective disorder, current episode mixed	435226	Standard	SNOMED	192362008	1,890	843
Bipolar affective disorder, currently depressed, in full remission	439251	Standard	SNOMED	191634005	0	204
Bipolar affective disorder, currently depressed, mild	439253	Standard	SNOMED	191629006	0	961
Bipolar affective disorder, currently depressed, moderate	437528	Standard	SNOMED	191630001	0	1,548
Bipolar affective disorder, currently manic, in full remission	439255	Standard	SNOMED	191625000	0	147
Bipolar affective disorder, currently manic, mild	441834	Standard	SNOMED	191620005	0	385
Bipolar affective disorder, currently manic, moderate	433992	Standard	SNOMED	191621009	0	555
Bipolar affective disorder, currently manic, severe, with psychosis	439256	Standard	SNOMED	191623007	0	582
Bipolar affective disorder, most recent episode mixed	35624745	Standard	SNOMED	767633005	1,895	6
Bipolar disorder	436665	Standard	SNOMED	13746004	20,540	16,456
Bipolar disorder in full remission	4220618	Standard	SNOMED	41836007	891	123
Bipolar disorder in partial remission	436072	Standard	SNOMED	5703000	1,098	181
Bipolar disorder in remission	4310821	Standard	SNOMED	85248005	2,453	1,215
Bipolar disorder, most recent episode depression	35624743	Standard	SNOMED	767631007	5,275	42
Bipolar disorder, most recent episode manic	35624744	Standard	SNOMED	767632000	2,240	10
Bipolar I disorder	432876	Standard	SNOMED	371596008	5,970	3,043
Bipolar I disorder, most recent episode depressed with catatonic features	4071442	Standard	SNOMED	21900002	0	2
Bipolar I disorder, most recent episode depression	35624748	Standard	SNOMED	767636002	27	24
Bipolar I disorder, most recent episode hypomanic	4150985	Standard	SNOMED	31446002	0	606
Bipolar I disorder, most recent episode manic	35624747	Standard	SNOMED	767635003	0	17
Bipolar I disorder, single manic episode	432866	Standard	SNOMED	76400000	961	914
Bipolar I disorder, single manic episode, in full remission	4148842	Standard	SNOMED	3530005	0	25
Bipolar I disorder, single manic episode, in remission	4327669	Standard	SNOMED	75360000	35	13
Bipolar II disorder	4307956	Standard	SNOMED	83225003	2,837	2,836
Bipolar II disorder, most recent episode hypomanic	4172156	Standard	SNOMED	48937005	0	11
Bipolar II disorder, most recent episode major depressive	4037669	Standard	SNOMED	16295005	43	35
Bipolar II disorder, most recent episode major depressive with atypical features	4185096	Standard	SNOMED	43568002	0	3
Bipolar II disorder, most recent episode major depressive with melancholic features	4144519	Standard	SNOMED	34315001	0	2
Bipolar II disorder, most recent episode major depressive with postpartum onset	4148934	Standard	SNOMED	30687003	0	1
Bipolar type I disorder currently in full remission	37109940	Standard	SNOMED	723903001	675	1
Bipolar type II disorder currently in full remission	37117177	Standard	SNOMED	723905008	9	8
Borderline intellectual disability	4299505	Standard	SNOMED	77287004	0	132
Borderline schizophrenia	4168389	Standard	SNOMED	274952002	14	0
Catatonic schizophrenia	433996	Standard	SNOMED	191542003	131	124
Catatonic schizophrenia in remission	434332	Standard	SNOMED	111483008	0	2
Cerebral degeneration due to Parkinson's disease	4231949	Standard	SNOMED	438513002	1	0
Chronic bipolar I disorder, most recent episode depressed	4197669	Standard	SNOMED	51637008	0	1
Chronic bipolar II disorder, most recent episode major depressive	4001733	Standard	SNOMED	1196001	0	2
Chronic catatonic schizophrenia	441538	Standard	SNOMED	68995007	3	2
Chronic disorganized schizophrenia	440368	Standard	SNOMED	12939007	16	14
Chronic disorganized schizophrenia with acute exacerbation	436385	Standard	SNOMED	35218008	0	3
Chronic latent schizophrenia	435235	Standard	SNOMED	191562006	0	8
Chronic paranoid schizophrenia	436944	Standard	SNOMED	31658008	333	278
Chronic residual schizophrenia	436673	Standard	SNOMED	71103003	108	105
Chronic residual schizophrenia with acute exacerbations	435218	Standard	SNOMED	30336007	0	7
Chronic schizoaffective schizophrenia	441835	Standard	SNOMED	191570001	0	239
Chronic schizophrenia	435782	Standard	SNOMED	83746006	555	63
Chronic undifferentiated schizophrenia	4105330	Standard	SNOMED	29599000	0	149
Cognitive impairment due to multiple sclerosis	761978	Standard	SNOMED	2.547E+16	0	5
Dementia due to Huntington chorea	40483103	Standard	SNOMED	442344002	0	1
Depressed bipolar I disorder	441836	Standard	SNOMED	49468007	1,504	117
Depressed bipolar I disorder in full remission	435225	Standard	SNOMED	22121000	0	405
Depressed bipolar I disorder in partial remission	4177651	Standard	SNOMED	49512000	0	632
Depressed bipolar I disorder in remission	4201739	Standard	SNOMED	53607008	905	12
Disorganized schizophrenia	441828	Standard	SNOMED	35252006	230	221
Exacerbation of multiple sclerosis	4102337	Standard	SNOMED	192929006	0	11
High-functioning autism	45765723	Standard	SNOMED	702732007	0	4
Huntington's chorea	374341	Standard	SNOMED	58756001	0	53
Hypokinetic parkinsonian dysphonia	4177039	Standard	SNOMED	51100001	0	3
Infantile autism	4254211	Standard	SNOMED	408857007	286	0
Intellectual disability	40277917	Standard	SNOMED	110359009	1,149	781
Intellectual functioning disability	4041136	Standard	SNOMED	228156007	0	38
Latent schizophrenia	433742	Standard	SNOMED	191559008	29	28
Latent schizophrenia in remission	432300	Standard	SNOMED	191565008	0	1
Manic bipolar I disorder	4287544	Standard	SNOMED	66569003	594	22
Manic bipolar I disorder in full remission	436086	Standard	SNOMED	30935000	0	159
Manic bipolar I disorder in partial remission	442600	Standard	SNOMED	63249007	0	184
Manic bipolar I disorder in remission	4166701	Standard	SNOMED	45479006	312	1
Mild bipolar disorder	4028027	Standard	SNOMED	13313007	65	8
Mild bipolar I disorder, single manic episode	432290	Standard	SNOMED	41552001	0	18
Mild bipolar II disorder, most recent episode major depressive	4324945	Standard	SNOMED	71294008	0	6

Diagnosis	Concept ID	Concept Type	Vocab	SNOMED Code	Mapped Count	Direct Matches
Mild depressed bipolar I disorder	437250	Standard	SNOMED	74686005	0	24
Mild intellectual disability	432612	Standard	SNOMED	90765009	0	405
Mild manic bipolar I disorder	4215917	Standard	SNOMED	71984005	34	16
Mild mixed bipolar I disorder	440079	Standard	SNOMED	43769008	0	6
Mixed bipolar affective disorder	439250	Standard	SNOMED	191636007	2,847	13
Mixed bipolar affective disorder, in full remission	439245	Standard	SNOMED	191643001	218	95
Mixed bipolar affective disorder, mild	439249	Standard	SNOMED	191638008	0	388
Mixed bipolar affective disorder, moderate	439248	Standard	SNOMED	191639000	0	741
Mixed bipolar affective disorder, severe, with psychosis	439246	Standard	SNOMED	191641004	0	307
Mixed bipolar I disorder	443906	Standard	SNOMED	16506000	1,512	668
Mixed bipolar I disorder in full remission	4009648	Standard	SNOMED	111485001	0	173
Mixed bipolar I disorder in partial remission	437529	Standard	SNOMED	36583000	0	336
Mixed bipolar I disorder in remission	433743	Standard	SNOMED	35481005	479	5
Moderate bipolar disorder	4194222	Standard	SNOMED	79584002	90	0
Moderate bipolar I disorder, single manic episode	440067	Standard	SNOMED	28844001	0	19
Moderate bipolar II disorder, most recent episode major depressive	4262111	Standard	SNOMED	35846004	0	5
Moderate depressed bipolar I disorder	4280361	Standard	SNOMED	66631006	0	37
Moderate intellectual disability	436682	Standard	SNOMED	61152003	0	69
Moderate manic bipolar I disorder	4307804	Standard	SNOMED	82998009	46	28
Moderate mixed bipolar I disorder	439785	Standard	SNOMED	40926005	0	14
Multiple sclerosis	374919	Standard	SNOMED	24700007	3,780	3,770
Neuroleptic-induced parkinsonism	4248716	Standard	SNOMED	72820004	0	73
Orthostatic hypotension co-occurrent and due to Parkinson's disease	36713737	Standard	SNOMED	718685006	0	1
Paranoid schizophrenia	433450	Standard	SNOMED	64905009	1,709	1,606
Paranoid schizophrenia in remission	435217	Standard	SNOMED	63181006	0	33
Parkinson's disease	381270	Standard	SNOMED	49049000	2,565	2,565
Parkinsonian features	4126631	Standard	SNOMED	304535004	0	7
Parkinsonian tremor	4204820	Standard	SNOMED	308090003	0	3
Parkinsonism	4140090	Standard	SNOMED	32798002	2,792	52
Parkinsonism due to drug	4171569	Standard	SNOMED	4223005	213	167
Postencephalitic parkinsonism	4064308	Standard	SNOMED	19972008	0	2
Primary progressive multiple sclerosis	4178929	Standard	SNOMED	428700003	0	10
Profound intellectual disability	438733	Standard	SNOMED	31216003	0	5
Progressive multiple sclerosis	37311816	Standard	SNOMED	816984002	14	4
Progressive relapsing multiple sclerosis	37110514	Standard	SNOMED	724778008	0	3
Psychosis and severe depression co-occurrent and due to bipolar affective disorder	35622934	Standard	SNOMED	765176007	0	432
Rapid cycling bipolar II disorder	37312578	Standard	SNOMED	789061003	0	2
Relapsing remitting multiple sclerosis	4145049	Standard	SNOMED	426373005	0	42
Residual infantile autism	439702	Standard	SNOMED	191690004	0	10
Residual schizophrenia	439004	Standard	SNOMED	26025008	293	200
Residual schizophrenia in remission	440686	Standard	SNOMED	51133006	0	3
Schizoaffective disorder	4286201	Standard	SNOMED	68890003	4,359	3,712
Schizoaffective disorder, bipolar type	4244078	Standard	SNOMED	38368003	0	1,659
Schizoaffective disorder, depressive type	4224940	Standard	SNOMED	84760002	0	896
Schizoaffective disorder, mixed type	4152971	Standard	SNOMED	270901009	0	2
Schizoaffective schizophrenia	432597	Standard	SNOMED	191567000	343	17
Schizoaffective schizophrenia in remission	434321	Standard	SNOMED	191574005	0	31
Schizophrenia	435783	Standard	SNOMED	58214004	5,800	4,985
Schizophrenia in remission	435219	Standard	SNOMED	4926007	90	27
Schizophrenic prodrome	4085662	Standard	SNOMED	247804008	0	1
Secondary parkinsonism	374013	Standard	SNOMED	230292008	486	299
Secondary progressive multiple sclerosis	4137855	Standard	SNOMED	425500002	0	1
Severe bipolar disorder	4155798	Standard	SNOMED	371600003	1,059	4
Severe bipolar disorder with psychotic features	4195158	Standard	SNOMED	4441000	277	0
Severe bipolar disorder with psychotic features, mood-incongruent	4131027	Standard	SNOMED	26530004	1	0
Severe bipolar disorder without psychotic features	4200385	Standard	SNOMED	53049002	852	0
Severe bipolar I disorder	4154283	Standard	SNOMED	371599001	1,055	1
Severe bipolar I disorder, single manic episode with psychotic features	4220817	Standard	SNOMED	41832009	0	28
Severe bipolar I disorder, single manic episode without psychotic features	4030856	Standard	SNOMED	14496005	0	18
Severe bipolar II disorder	4161200	Standard	SNOMED	371604007	4	2
Severe bipolar II disorder, most recent episode major depressive without psychotic features	4217940	Standard	SNOMED	81319007	0	1
Severe bipolar II disorder, most recent episode major depressive, in full remission	4045263	Standard	SNOMED	12969000	0	1
Severe bipolar II disorder, most recent episode major depressive, in remission	4262272	Standard	SNOMED	35722002	1	0
Severe depressed bipolar I disorder	42872413	Standard	SNOMED	2.81E+11	580	17
Severe depressed bipolar I disorder with psychotic features	436386	Standard	SNOMED	59617007	0	246
Severe depressed bipolar I disorder without psychotic features	442570	Standard	SNOMED	61403008	0	386
Severe intellectual disability	432898	Standard	SNOMED	40700009	0	18
Severe manic bipolar I disorder	43020451	Standard	SNOMED	2.3741E+13	257	2
Severe manic bipolar I disorder with psychotic features	4102603	Standard	SNOMED	28663008	6	5
Severe manic bipolar I disorder with psychotic features, mood-incongruent	4141603	Standard	SNOMED	33380008	0	1
Severe manic bipolar I disorder without psychotic features	443797	Standard	SNOMED	162004	0	253
Severe mixed bipolar I disorder	42872412	Standard	SNOMED	2.71E+11	302	0
Severe mixed bipolar I disorder with psychotic features	439001	Standard	SNOMED	10981006	0	4
Severe mixed bipolar I disorder without psychotic features	372599	Standard	SNOMED	46229002	0	299
Simple schizophrenia	436067	Standard	SNOMED	191527001	377	179
Subchronic catatonic schizophrenia	433990	Standard	SNOMED	42868002	2	0
Subchronic disorganized schizophrenia	436724	Standard	SNOMED	27387000	3	1
Subchronic disorganized schizophrenia with acute exacerbations	436384	Standard	SNOMED	14291003	0	2
Subchronic latent schizophrenia	440077	Standard	SNOMED	191561004	2	0
Subchronic paranoid schizophrenia	432299	Standard	SNOMED	78666005	30	18
Subchronic residual schizophrenia	433442	Standard	SNOMED	76566000	14	1
Subchronic residual schizophrenia with acute exacerbations	444396	Standard	SNOMED	70814008	0	13
Subchronic schizoaffective schizophrenia	433443	Standard	SNOMED	191569002	0	18
Subchronic schizophrenia	440073	Standard	SNOMED	16990005	95	42
Subchronic schizophrenia with acute exacerbations	432598	Standard	SNOMED	111482003	38	9
Subchronic undifferentiated schizophrenia	4310121	Standard	SNOMED	85861002	0	1
Symptomatic parkinsonism	4140881	Standard	SNOMED	265377002	0	1
Undifferentiated schizophrenia	4008566	Standard	SNOMED	111484002	448	317
Vascular parkinsonism	4046093	Standard	SNOMED	230296006	0	49
Young onset Parkinson disease	37395785	Standard	SNOMED	715345007	0	1

REFERENCES

1. Tetsuka S. Depression and Dementia in Older Adults: A Neuropsychological Review. Aging Dis. 2021;12(8):1920-34.

2. Reynolds CF, 3rd, Jeste DV, Sachdev PS, Blazer DG. Mental health care for older adults: recent advances and new directions in clinical practice and research. World Psychiatry. 2022;21(3):336-63.

3. Ownby RL, Crocco E, Acevedo A, John V, Loewenstein D. Depression and risk for Alzheimer disease: systematic review, meta-analysis, and metaregression analysis. Arch Gen Psychiatry. 2006;63(5):530-8.

4. Byers AL, Yaffe K. Depression and risk of developing dementia. Nat Rev Neurol. 2011;7(6):323-31.

5. Aunsmo RH, Strand BH, Anstey KJ, Bergh S, Kivimäki M, Köhler S, et al. Associations between depression and anxiety in midlife and dementia more than 30 years later: The HUNT Study. Alzheimers Dement (Amst). 2024;16(4):e70036.

6. Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Rojas-Rueda D, Plasència A, et al. Residential green spaces and mortality: A systematic review. Environ Int. 2016;86:60-7.

7. Beyer KM, Kaltenbach A, Szabo A, Bogar S, Nieto FJ, Malecki KM. Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. Int J Environ Res Public Health. 2014;11(3):3453-72.

8. Hartig T, Mitchell R, de Vries S, Frumkin H. Nature and health. Annu Rev Public Health. 2014;35:207-28.

9. Engemann K, Pedersen CB, Arge L, Tsirogiannis C, Mortensen PB, Svenning JC. Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. Proc Natl Acad Sci U S A. 2019;116(11):5188-93.

10. Xian Z, Nakaya T, Liu K, Zhao B, Zhang J, Zhang J, et al. The effects of neighbourhood green spaces on mental health of disadvantaged groups: a systematic review. Humanities and Social Sciences Communications. 2024;11(1):488.

11. Baker AE, Galván A, Fuligni AJ. The connecting brain in context: How adolescent plasticity supports learning and development. Developmental Cognitive Neuroscience. 2025;71:101486.

12. Mitchell R, Popham F. Effect of exposure to natural environment on health inequalities: an observational population study. Lancet. 2008;372(9650):1655-60.

13. Barton J, Rogerson M. The importance of greenspace for mental health. BJPsych Int. 2017;14(4):79-81.

14. Bloemsma LD, Wijga AH, Klompmaker JO, Hoek G, Janssen NAH, Lebret E, et al. Green space, air pollution, traffic noise and mental wellbeing throughout adolescence: Findings from the PIAMA study. Environment International. 2022;163:107197.

15. Rigolon A, Browning M, McAnirlin O, Yoon HV. Green Space and Health Equity: A Systematic Review on the Potential of Green Space to Reduce Health Disparities. Int J Environ Res Public Health. 2021;18(5).

16. Ward Thompson C, Roe J, Aspinall P, Mitchell R, Clow A, Miller D. More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and Urban Planning. 2012;105(3):221-9.

17. Roe JJ, Thompson CW, Aspinall PA, Brewer MJ, Duff EI, Miller D, et al. Green space and stress: evidence from cortisol measures in deprived urban communities. Int J Environ Res Public Health. 2013;10(9):4086-103.

18. Steptoe A, Kunz-Ebrecht SR, Brydon L, Wardle J. Central adiposity and cortisol responses to waking in middle-aged men and women. Int J Obes Relat Metab Disord. 2004;28(9):1168-73.

19. Miller GE, Chen E, Parker KJ. Psychological stress in childhood and susceptibility to the chronic diseases of aging: moving toward a model of behavioral and biological mechanisms. Psychol Bull. 2011;137(6):959-97.

20. Block ML, Calderón-Garcidueñas L. Air pollution: mechanisms of neuroinflammation and CNS disease. Trends Neurosci. 2009;32(9):506-16.

21. Power MC, Adar SD, Yanosky JD, Weuve J. Exposure to air pollution as a potential contributor to cognitive function, cognitive decline, brain imaging, and dementia: A systematic review of epidemiologic research. Neurotoxicology. 2016;56:235-53.

22. Chen H, Kwong JC, Copes R, Tu K, Villeneuve PJ, van Donkelaar A, et al. Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. Lancet. 2017;389(10070):718-26.

23. Dowlati Y, Herrmann N, Swardfager W, Liu H, Sham L, Reim EK, et al. A meta-analysis of cytokines in major depression. Biol Psychiatry. 2010;67(5):446-57.

24. Holmes C, Cunningham C, Zotova E, Woolford J, Dean C, Kerr S, et al. Systemic inflammation and disease progression in Alzheimer disease. Neurology. 2009;73(10):768-74.

25. Houtepen LC, Vinkers CH, Carrillo-Roa T, Hiemstra M, van Lier PA, Meeus W, et al. Genome-wide DNA methylation levels and altered cortisol stress reactivity following childhood trauma in humans. Nat Commun. 2016;7:10967.

26. Kaplan S. The restorative benefits of nature: Toward an integrative framework. Journal of Environmental Psychology. 1995;15(3):169-82.

27. Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M. Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology. 1991;11(3):201-30.

28. Stern Y. What is cognitive reserve? Theory and research application of the reserve concept. J Int Neuropsychol Soc. 2002;8(3):448-60.

29. Nicole W. Nature and Neurodevelopment: Differences in Brain Volume by Residential Exposure to Greenness. Environmental Health Perspectives. 2018;126(6):064001.

30. Drewelies J, Fiedler A, Brick TR, Kühn S. Investigating associations between the physical living environment and hippocampus in adulthood and older age. Environmental Research. 2025;267:120728.

31. Shanahan DF, Astell–Burt T, Barber EA, Brymer E, Cox DTC, Dean J, et al. Nature–Based Interventions for Improving Health and Wellbeing: The Purpose, the People and the Outcomes. Sports. 2019;7(6):141.

32. Bloomfield D. What makes nature-based interventions for mental health successful? BJPsych Int. 2017;14(4):82-5.

33. Marselle MR, Hartig T, Cox DTC, de Bell S, Knapp S, Lindley S, et al. Pathways linking biodiversity to human health: A conceptual framework. Environ Int. 2021;150:106420.

34. Hunter RF, Cleland C, Cleary A, Droomers M, Wheeler BW, Sinnett D, et al. Environmental, health, wellbeing, social and equity effects of urban green space interventions: A meta-narrative evidence synthesis. Environment International. 2019;130:104923.

35. South EC, Hohl BC, Kondo MC, MacDonald JM, Branas CC. Effect of Greening Vacant Land on Mental Health of Community-Dwelling Adults: A Cluster Randomized Trial. JAMA Network Open. 2018;1(3):e180298-e.

36. Menardo E, Di Marco D, Ramos S, Brondino M, Arenas A, Costa P, et al. Nature and Mindfulness to Cope with Work-Related Stress: A Narrative Review. Int J Environ Res Public Health. 2022;19(10).

37. Bratman GN, Anderson CB, Berman MG, Cochran B, de Vries S, Flanders J, et al. Nature and mental health: An ecosystem service perspective. Sci Adv. 2019;5(7):eaax0903.

38. Twohig-Bennett C, Jones A. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research. 2018;166:628-37.