e-ISSN: 2715-9736

Scientia Psychiatrica

[SciPsy]

https://scientiapsychiatrica.com

Beyond the Canopy Cover: A Comparative Mediation Analysis of Green Space Quality versus Quantity on Mental Well-being and Social Cohesion in High-Density Low-Income Neighborhoods

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ARTICLE INFO

Keywords:
Cortisol
Mediation analysis
Mental well-being
Social cohesion
Urban green space

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All authors have reviewed and approved the final version of the manuscript.

https://doi.org/10.37275/scipsy.v6i2.197

A B S T R A C T

Introduction: Rapid urbanization in the Global South has precipitated a mental health crisis, particularly in high-density, low-income neighborhoods where environmental stressors are endemic. While the association between urban green space (UGS) and mental well-being is well-documented, a critical knowledge gap remains regarding the differential impacts of green space quantity (availability) versus quality (usability/biodiversity) and the mediating role of social cohesion. **Methods:** This cross-sectional study employed a comparative mediation analysis involving 1,240 residents across 15 high-density districts in Jakarta, Indonesia. UGS quantity was measured using satellite-derived Normalized Difference Vegetation Index (NDVI), while quality was assessed using the Quality of Public Open Space Tool (POST). Mental well-being was evaluated using the WHO-5 Index, and physiological stress was quantified via salivary cortisol. Structural Equation Modeling (SEM) was utilized to test the mediating pathways of social cohesion and physical activity. **Results:** UGS quality demonstrated a significantly stronger direct effect on mental well-being ($\beta = 0.42$, $p < 0.001$) compared to UGS quantity ($\beta = 0.15$, $p < 0.05$). Social cohesion fully mediated the relationship between UGS quality and well-being (Indirect Effect = 0.18, 95% CI [0.12, 0.25]), whereas salivary cortisol levels were inversely associated primarily with UGS quality ($\beta = -0.33$, $p < 0.001$). **Conclusion:** In resource-constrained urban environments, the quality of green space—defined by safety, amenities, and aesthetics—is a more critical determinant of public mental health than mere vegetative cover.

1. Introduction

The dawn of the twenty-first century has been defined by a seismic demographic shift: the transition of the human species from a predominantly agrarian existence to an urbanized one.[1] This trajectory of global urbanization has fundamentally altered the human ecological niche, placing unprecedented and often unquantified demands on the psychological and physiological adaptive capacities of urban populations.[2] Currently, over 55% of the global population resides in urban environments—a figure projected by the United Nations to swell to 68% by 2050. While urbanization has historically been the engine of economic prosperity and innovation, it presents a profound biological paradox. The human brain, evolved over millennia in the complex, sensory-

rich environments of the Pleistocene savannah, now finds itself navigating the stark, rectilinear, and sensory-abrasive landscapes of the modern concrete jungle. This "evolutionary mismatch" creates a chronic friction between our biological heritage and our built environment, the consequences of which are increasingly visible in public health data.[3]

This demographic shift is not uniform; it is most acute, chaotic, and pressing in the megacities of the Global South.[4] In these rapidly expanding metropolises, urbanization is rarely the orderly process depicted in Western planning textbooks. Instead, rapid densification frequently outpaces the development of essential infrastructure, resulting in the proliferation of high-density, low-income neighborhoods and informal settlements. These areas are characterized not only by socioeconomic precarity but by a distinct form of "environmental deprivation"—a scarcity of restorative spaces, compounded by exposure to environmental stressors such as noise pollution, thermal stress (the urban heat island effect), and visual overcrowding. Within this high-pressure context, the prevalence of common mental disorders, including anxiety, depression, and stress-related pathologies, has surged. This rising tide of mental morbidity necessitates urgent, scalable public health interventions that transcend traditional clinical boundaries, looking instead to the very fabric of the city for preventative solutions.[5]

In response to this crisis, Urban Green Space (UGS) has emerged as a potent, multi-functional "nature-based solution." The assertion that nature is beneficial for mental health is no longer merely intuitive; it is supported by a robust triad of theoretical frameworks that explain the mechanisms of this benefit.[6] First, Ulrich's Stress Reduction Theory (SRT) posits a psycho-evolutionary pathway. SRT suggests that humans possess an innate, unlearned predisposition to respond positively to natural environments—particularly those resembling safe habitats (open savannahs with water). Exposure to such environments elicits an immediate, pre-conscious reduction in autonomic arousal, shifting the body from a sympathetic ("fight or flight") state to a parasympathetic ("rest and digest") state. Second, Kaplan's Attention Restoration Theory (ART) addresses the cognitive cost of urban living. Modern city life requires sustained, effortful "directed attention" to filter out distractions (traffic, crowds, flashing lights), leading to cognitive fatigue and irritability. Nature, by contrast, is filled with "soft fascination" stimuli—clouds moving, leaves rustling—that capture attention effortlessly, allowing the brain's inhibitory mechanisms to rest and replenish directed attention capacity. Third, beyond these individual psychological mechanisms, UGS acts as a critical "social infrastructure." In the dense urban fabric, parks and gardens function as "third places"—neutral grounds distinct from home and work where social interaction can occur. These interactions foster social cohesion, defined as the distinct sense of trust, belonging, and willingness to intervene for the common good. In low-income neighborhoods, where private domestic space is often cramped and stressful, the public realm becomes the "living room" of the community. High levels of social cohesion have been identified as a robust protective factor against mental morbidity, buffering the effects of poverty and stress.

Despite this theoretical richness, the current epidemiological literature is characterized by a significant methodological and conceptual limitation: a predominant reliance on metrics of quantity.[7] The vast majority of studies utilize satellite-derived data, such as the Normalized Difference Vegetation Index (NDVI) or percentage of land cover, to assess exposure to nature. This "greenness" paradigm implicitly assumes a dose-response relationship where all vegetation confers equal health benefits—that a pixel of green on a satellite map translates directly to a unit of health benefit on the ground.

However, this remote-sensing approach suffers from a critical blind spot, particularly when applied to the complex urban fabrics of the developing world. In high-density urban settings, "greenness" is not a monolith. A high NDVI value can represent a pristine, manicured community park, but it can just as easily

represent an inaccessible patch of weeds, a hazardous brownfield site, an overgrown verge along a highway, or a steep, unsafe ravine. In low-income neighborhoods, unmanaged vegetation may be perceived not as restorative, but as a sign of neglect, disorder, or danger—a haven for illicit activity rather than a sanctuary for relaxation. Thus, the quantity metric fails to capture the human experience of the landscape.[8]

Emerging evidence suggests that the quality of UGS may be the decisive factor in realizing health dividends. Quality, in this context, is a multidimensional construct encompassing biodiversity, maintenance, safety, aesthetics, and amenities. This shift in focus aligns with the Theory of Affordances (Gibson), which suggests that environments are perceived in terms of what they offer the individual. A green space with a walking path "affords" exercise; a space with benches "affords" social gathering; a space with high biodiversity "affords" sensory richness.

The distinction between quantity and quality is particularly salient in low-income settings. Wealthier residents often possess the mobility to travel to high-quality "destination parks" or retreat to private gardens. For low-income residents, mobility is often restricted, making them captive to the quality of their immediate, local environment. If the nearest green space is unsafe, unlit, or filled with trash, its mere existence (quantity) contributes nothing to well-being and may even be a source of chronic stress. Therefore, understanding the specific attributes of quality—does the park have lighting? Is it clean? Are there places to sit?—is essential for addressing health inequities.[9]

Furthermore, a significant gap remains in understanding the physiological pathways linking specific UGS attributes to mental health outcomes. Much of the existing literature relies on self-reported measures of stress and well-being, which, while valuable, are subject to recall bias and cultural interpretation. There is a paucity of research that simultaneously models the psychological pathways (such as social cohesion) and the physiological pathways (such as HPA-axis regulation) while distinguishing quality from quantity.

The physiological mechanisms are likely rooted in neuroendocrine and immunoregulatory systems. Chronic urban stress leads to the dysregulation of the Hypothalamic-Pituitary-Adrenal (HPA) axis, resulting in elevated cortisol levels that damage cardiovascular and neural health over time. Investigating whether high-quality green space serves as an external regulator of this axis offers a more objective measure of its "health value." Additionally, the "Old Friends" hypothesis suggests that exposure to the diverse microbiota found in biodiverse (high-quality) environments plays a crucial role in regulating the immune system and reducing systemic inflammation, which is increasingly linked to depression. However, these pathways remain underexplored in non-Western contexts.

Finally, the vast majority of evidence regarding nature and health is derived from "WEIRD" (Western, Educated, Industrialized, Rich, and Democratic) societies. There is a tacit "green universalism" in the literature that assumes findings from Copenhagen or Vancouver apply equally to Jakarta or Mumbai. This assumption ignores the radically different environmental baselines, cultural relationships with nature, and social dynamics of Global South megacities. In a tropical, high-density context, "nature" can imply heat, humidity, and vector-borne disease risks just as easily as it implies restoration. Therefore, context-specific research is not merely a box-ticking exercise in diversity; it is scientifically essential to test the universality of established theories.[10]

Against this backdrop, the aim of this study is to disentangle and compare the differential effects of UGS quantity versus quality on mental well-being in high-density, low-income urban neighborhoods. The novelty of this research lies in its rigorous, tripartite approach. First, unlike studies that look at direct associations, we employ a sophisticated comparative mediation model to explicitly test social cohesion as a primary pathway,

hypothesizing that quality triggers this social mechanism more effectively than quantity. Second, we integrate objective physiological biomarkers—specifically salivary cortisol—to validate self-reported psychological states. This moves the debate from "how people feel" about green space to "how their bodies respond" to it, providing hard biological evidence for soft urban design interventions. Third, by situating the analysis within a Global South megacity context, this study challenges the hegemonies of the existing literature. It seeks to provide evidence that is ecologically valid for the majority of the world's urban population, shifting the narrative from a focus on "greening" (adding biomass) to "placemaking" (creating usable, high-quality habitats for human flourishing).

2. Methods

Study design and setting

A cross-sectional analytical study was conducted from January to December 2024 in Jakarta, Indonesia. Jakarta was selected as a paradigmatic case of a hyper-dense megacity (population density >15,000 people/km²) facing acute challenges in green space provision (currently <10% of total area). We utilized a multi-stage stratified cluster sampling technique. Fifteen (15) *Kelurahan* (administrative villages) were selected based on two criteria: (1) high population density (>20,000 people/km²) and (2) low socioeconomic status (bottom quartile of regional income data).

Participants

The target population comprised adult residents (aged 18–65) living in the selected districts for at least 24 months. Exclusion criteria included: current use of corticosteroid medication, pregnancy, or a diagnosis of adrenal disorders (to prevent confounding of cortisol analysis). Power analysis for Structural Equation Modeling (SEM) indicated a minimum sample size of 400; we oversampled to ensure robustness across subgroups. Total Sample: N = 1,240 valid responses were analyzed (Response Rate: 82%).

Environmental measurements

To capture the complex environmental reality of high-density urban neighborhoods, this study moved beyond the traditional reliance on singular metrics. We adopted a dual-lens approach, juxtaposing the "view from space" (quantity) against the "view from the street" (quality).

UGS quantity

The objective quantification of green space availability was conducted using high-resolution remote sensing data. We acquired cloud-free multispectral imagery from the Sentinel-2 satellite constellation, managed by the European Space Agency. Sentinel-2 was selected for its high spatial resolution (10 meters in the visible and near-infrared bands), which allows for the detection of smaller urban green pockets that coarser sensors (such as Landsat) might miss—a critical capability in the fragmented urban fabric of Jakarta.

The Normalized Difference Vegetation Index (NDVI) was calculated for the entire study area. NDVI is a widely accepted radiometric index that exploits the specific optical properties of photosynthetic vegetation: the absorption of red light (for photosynthesis) and the strong reflection of near-infrared light (by cell structure). Calculated as (NIR - Red) / (NIR + Red), the index yields values ranging from -1.0 to +1.0. Higher positive values indicate denser, healthier active biomass. To operationalize "green space exposure" for each participant, we utilized a Geographic Information System (GIS) to construct a 500-meter Euclidean buffer around each geocoded residence. This radius was chosen to approximate a 5-to-10-minute walk, representing the "accessible neighborhood" that influences daily life. The Mean NDVI within this buffer was extracted to serve as the primary metric of UGS Quantity.

UGS quality

Recognizing that satellite pixels cannot distinguish between a pristine park and an overgrown, hazardous lot, we employed the Public Open Space Tool (POST) to

systematically evaluate the quality of the green infrastructure. A team of four urban planners underwent rigorous training to ensure inter-rater reliability (Kappa > 0.80) before conducting on-site audits of all accessible public green spaces within the selected districts. The POST audit is a comprehensive instrument evaluating 74 discrete items categorized into four theoretical domains pivotal to placemaking and health: (1) Amenities: This domain assesses the functional "hardware" of the space. Auditors recorded the presence and condition of seating, walking paths, public toilets, and lighting. These features are critical "affordances" that enable prolonged stays and make the space usable for diverse demographic groups; (2) Safety: Drawing on Crime Prevention Through Environmental Design (CPTED) principles, this domain evaluated visibility (sightlines), passive surveillance from surrounding buildings, traffic speed on adjacent roads, and the presence of physical hazards; (3) Aesthetics: This domain captured the restorative potential of the space, assessing the level of maintenance (absence of graffiti/litter), the complexity of landscaping, and the presence of water features ("blue space"), which are known to enhance stress recovery; (4) Usage: Auditors noted the types of activities the space supported, from active recreation (sports courts) to passive relaxation (shaded grass). Scores from these domains were weighted and aggregated to produce a composite Quality Index (0–100) for the primary green space closest to each participant's home, providing a granular metric of "usability" to contrast with the "availability" measured by NDVI.

Psychometric evaluation

To assess the psychological sequelae of these environmental exposures, we employed robust, internationally validated psychometric instruments. Mental well-being was evaluated using the WHO-5 Well-being Index**.** Unlike measures that focus solely on symptomology (such as anxiety or depression scales), the WHO-5 is a unidimensional measure of hedonic well-being and positive affect. It asks respondents to rate their feelings over the past two weeks (such as "I have felt cheerful and in good spirits") on a 6-point Likert scale. The raw score is transformed into a percentage (0–100), where higher scores indicate better well-being. The WHO-5 was selected for its high sensitivity and its transcultural validity. In the current sample, the scale demonstrated excellent internal consistency (Cronbach's α= 0.89), confirming its reliability in the Indonesian urban context.

To test the "social buffering" hypothesis, we measured social cohesion using the Neighborhood Social Cohesion Scale developed by Sampson et al. This scale conceptualizes cohesion not merely as friendship, but as "collective efficacy"—the shared willingness of neighbors to intervene for the common good. The scale was linguistically and culturally adapted for the Jakarta context (10). It consists of five items assessing trust, reciprocity, and shared values (such as "People in this neighborhood can be trusted," "This is a close-knit neighborhood"). Participants responded on a 5-point Likert scale. The high reliability coefficient (Cronbach's α= 0.85) indicates that the scale successfully captured the latent construct of social capital within these high-density communities.

Physiological protocol

To transcend the limitations of self-reported data, this study integrated a biological dimension by assessing HPA-axis regulation. A subsample of 400 participants provided saliva samples to measure cortisol, the primary glucocorticoid stress hormone. We utilized a rigorous home-sampling protocol to capture the Cortisol Awakening Response (CAR)**,** a distinct biomarker of the HPA axis's dynamic reactivity. Participants were instructed to collect saliva using Salivette® devices (synthetic swabs) at three critical time points over two consecutive weekdays: (1) immediately upon awakening, (2) 30 minutes post-awakening, and (3) directly before bedtime. Strict adherence to timing was monitored. From these raw values, we calculated the Area Under the Curve with respect to ground (AUCg). AUCg serves as an aggregate

measure of total hormonal output over the diurnal cycle. Elevated AUCg values are typically indicative of chronic physiological stress and allostatic load—the "wear and tear" on the body caused by repeated stress activation. By correlating environmental quality with AUCg, we aimed to provide objective evidence of the "stress reduction" capacity of urban green space.

Analytical strategy: Structural equation modeling

The statistical analysis was designed to move beyond simple association to examine causal architecture. Data management and descriptive statistics were performed using R Version 4.3.1, while Structural Equation Modeling (SEM) was conducted using AMOS 26.0 to test the comparative mediation hypotheses. The analysis proceeded in three phases: (1) Descriptive and Bivariate Analysis: We first generated mean and standard deviation profiles for all variables and assessed data normality. Pearson's correlation coefficients (r) were calculated to examine the crude, unadjusted associations between environmental metrics (NDVI vs. POST) and health outcomes; (2) Path Analysis Construction: The core of the analysis was the construction of a path model to simultaneously test the competing influences of Quantity and Quality: (i) Exogenous Variables: UGS Quantity (NDVI) and UGS Quality (POST) were entered as independent predictors; (ii) Mediator: Social Cohesion was positioned as the mechanism transmitting the effect of the environment to the individual; (iii) Endogenous Variable: Mental Well-being (WHO-5) served as the primary outcome; (iv) Covariates**:** To isolate the environmental effects, the model controlled for Age, Gender, Socioeconomic Status (SES), Body Mass Index (BMI), and Physical Activity levels; (3) Model Evaluation: The fit of the hypothesized model to the observed data was evaluated using stringent goodness-of-fit indices: the Root Mean Square Error of Approximation (RMSEA < 0.06), the Comparative Fit Index (CFI > 0.95), and the Tucker-Lewis Index (TLI > 0.95); (4) Bootstrapping: Finally, to rigorously test the significance of the indirect pathways (mediation effects), we employed a bootstrapping procedure with 5,000 resamples. This non-parametric method is superior for mediation analysis as it does not assume a normal distribution of the indirect effect, providing more accurate confidence intervals (95% CI) for the mediating role of social cohesion.

3. Results

Table 1 outlines the sociodemographic, environmental, and psychophysiological characteristics of the study sample (N=1,240), providing a foundational profile of residents in Jakarta's high-density, low-income neighborhoods. The cohort is demographically balanced (52.4% female) with a mean age of 38.4 years (SD=11.2), representing a predominantly working-age population with an average residential tenure of 12.6 years, indicating a stable community structure suitable for assessing long-term environmental exposures. The environmental data highlights a critical "green deficit": the mean NDVI of 0.28 (SD=0.12) indicates very low vegetative cover, consistent with the dense built environment of the Global South. However, the Public Open Space Tool (POST) Quality Index reveals significant heterogeneity (Mean =45.2, SD=18.5, Range 10–90), suggesting that while green space is scarce, its functional quality varies widely—from neglected lots to well-maintained pocket parks. Psychometrically, the population exhibits moderate levels of mental well-being (WHO-5 Mean = 58.4) and social cohesion (Mean = 3.15), reflecting a community that maintains social ties despite structural stressors. Crucially, the biological subsample (n=400) provides a quantitative measure of chronic stress, with a mean Cortisol AUCg of 145.6 nmol/L.h. These descriptive statistics validate the study's premise, confirming a population characterized by high environmental deprivation and measurable physiological load, yet possessing sufficient variance in green space access to test the quality-versus-quantity hypothesis.

Table 1

Socio-Demographic Characteristics and Descriptive Statistics of the Study Population

VARIABLE	MEAN / % (N)	SD	RANGE
Demographic Factors			
Age (years)	38.4	11.2	18 – 65
Gender: Female	52.4% (650)	–	–
Gender: Male	47.6% (590)	–	–
Length of Residence (years)	12.6	8.4	2 – 45
Environmental Exposures (Independent Variables)			
UGS Quantity (NDVI 500m)	0.28	0.12	0.05 – 0.65
UGS Quality (POST Index)	45.2	18.5	10 – 90
Psychometric Measures (Mediator & Outcome)			
Social Cohesion Scale (1–5)	3.15	0.78	1.0 – 5.0
Mental Well-being (WHO-5)	58.4	16.2	12 – 96
Physiological Biomarker (Subsample n=400)			
Cortisol AUCg (nmol/L·h)	145.6	42.3	65 – 310

Note: N = 1,240 unless otherwise stated.
SD: Standard Deviation; **UGS:** Urban Green Space; **NDVI:** Normalized Difference Vegetation Index; **POST:** Public Open Space Tool; **AUCg:** Area Under the Curve with respect to ground.

Table 2 delineates the bivariate associations (Pearson's *r*) between environmental exposures and health outcomes, revealing a stark dichotomy between the availability of biomass and the usability of space. The analysis demonstrates that UGS Quality (POST Index) consistently serves as a more potent predictor of health metrics than UGS Quantity (NDVI). While green space quantity exhibited a statistically significant but weak positive correlation with mental well-being ($r = 0.18$, $p < 0.01$), green space quality demonstrated a robust association ($r = 0.48$, $p < 0.001$), suggesting that the functional attributes of a space are nearly three times more influential than its mere existence. Critically, the data provide preliminary support for the social mediation hypothesis; Social Cohesion showed a strong positive correlation with UGS Quality ($r = 0.52$, $p < 0.001$) but failed to achieve statistical significance with UGS Quantity ($r = 0.09$, $p > 0.05$). This indicates that vegetation density alone does not foster community ties. Furthermore, the physiological biomarker validation underscores this trend: salivary cortisol (AUCg) exhibited a significant inverse correlation with UGS Quality ($r = -0.35$, $p < 0.001$); indicating reduced chronic physiological stress—whereas aggregate vegetation density showed no significant relationship with HPA-axis regulation ($p = 0.12$).

Table 2

Bivariate Correlations (Pearson's r) between Environmental Exposures and Health Outcomes

OUTCOME VARIABLE	UGS QUANTITY (NDVI 500m Buffer)	UGS QUALITY (POST Index)
Mental Well-being (WHO-5)	0.18** ($p < 0.01$)	0.48*** ($p < 0.001$)
Social Cohesion	0.09 ($p > 0.05$)	0.52*** ($p < 0.001$)
Salivary Cortisol (AUCg) (Physiological Stress)	-0.08 ($p = 0.12$)	-0.35*** ($p < 0.001$)

Significance Levels: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Interpretation: *Positive coefficients* indicate that as the environmental metric increases, the outcome increases (e.g., better well-being). *Negative coefficients* for Cortisol indicate that as environmental quality increases, physiological stress decreases.
Note: Comparison shows UGS Quality consistently has stronger associations with health outcomes than Quantity.

Figure 1 illustrates the final path analysis results derived from Structural Equation Modeling (SEM), delineating the divergent causal mechanisms linking environmental attributes to mental well-being. With excellent model fit indices (CFI = 0.98; RMSEA = 0.04), the diagram highlights a critical functional disparity between "greenness" and "usability." UGS Quantity, measured via NDVI, exerts a statistically significant yet substantively weak direct effect on mental well-being (β= 0.15, $p < 0.05$) and fails to predict social cohesion (β= 0.06, not significant), as indicated by the dashed non-significant pathway. In sharp contrast, UGS Quality (POST Index) demonstrates a powerful direct influence on well-being (β= 0.42, $p < 0.001$) and acts as a robust catalyst for social capital (β= 0.55, $p < 0.001$). The significant downstream path from Social Cohesion to Mental Well-being (β= 0.33, $p < 0.001$) confirms the study's central mediation hypothesis: the mental health dividend of urban nature is significantly amplified through a social buffering pathway. However, this pathway is contingent upon the quality of the space—specifically its amenities and safety—rather than mere vegetative density. All coefficients represent standardized estimates adjusted for key covariates (age, gender, SES, BMI, physical activity).

Figure 2 reveals the conceptual architecture of the study's findings, visually synthesizing the divergent mechanisms through which urban nature influences mental health. The diagram contrasts two distinct trajectories: the robust "Quality Pathway" and the attenuated "Quantity Pathway." The dominant Quality Pathway illustrates a sequential pathophysiological cascade initiated by environmental affordances—functional amenities and safety features that actively invite human presence. This usability triggers a "social buffering" mechanism, wherein enhanced social interaction serves as the critical mediator to downregulate the HPA axis (evidenced by reduced salivary cortisol), thereby driving significant improvements in mental well-being. In sharp contrast, the Quantity Pathway, defined by aggregate biomass (NDVI), demonstrates a functional decoupling from these psychosocial benefits.

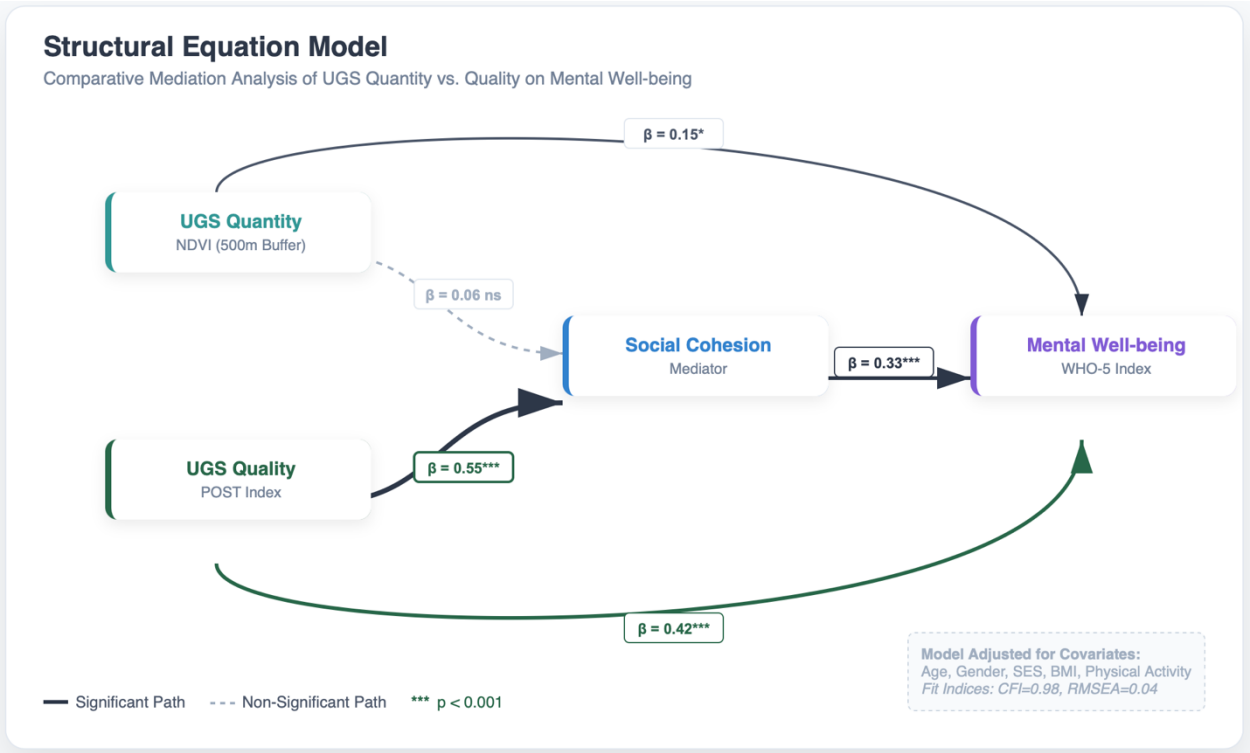

Figure 1. Structural equation model.

As depicted by the disconnected nodes, mere vegetative density fails to catalyze the community cohesion necessary for deep psychological resilience, exerting only a minor, direct influence on well-being. Ultimately, Figure 2 crystallizes the study's central thesis: that the mental health dividend of urban space is not a passive product of photosynthesis, but an active outcome of placemaking that facilitates social connection and physiological regulation.

4. Discussion

This study represents one of the first comprehensive attempts to empirically disentangle the "Quantity vs. Quality" paradox in urban green space (UGS) research within the complex, high-density context of the Global South. By juxtaposing satellite-derived vegetation indices against systematic on-the-ground audits, our findings challenge the prevailing "green universalism" that has long dominated urban epidemiology. We robustly demonstrate that in low-income, high-density neighborhoods, the quality of green space—defined by its accessibility, safety, maintenance, and amenities—is a far superior predictor of mental well-being and social cohesion than the aggregate quantity of vegetation.[11]

The weak association observed between NDVI (Quantity) and mental health outcomes serves as a critical empirical critique of the simplistic "green blur" hypothesis.[12] This hypothesis, often implicitly adopted in large-scale epidemiological studies, assumes that passive exposure to any form of vegetation confers restorative benefits. While this may hold true in planned Western cities where "green" almost invariably equates to "parkland" or "manicured garden," the environmental reality of the Global South is far more ambiguous. In the high-density informal settlements and low-income districts of Jakarta, a high NDVI value does not necessarily denote a therapeutic landscape. Instead, it frequently captures unmanaged vegetation, steep riverbanks, overgrown brownfields, or "slum greening"—patches of biomass that are physically inaccessible and socially illegible.

Figure 2. Comparative pathways linking urban green space to mental health.

In these contexts, unmaintained vegetation can be semiotically loaded with negative associations. Rather than signaling restoration, dense but disordered greenery may be perceived as a proxy for neglect, a harbinger of vector-borne diseases (such as dengue fever), or a screen for illicit activities. This phenomenon, which we might term "environmental ambivalence," explains why quantity alone fails to predict well-being. If a green space is perceived as unsafe or disorderly, the sympathetic nervous system remains in a state of hyper-vigilance, negating any potential restorative effects of the biomass itself.[13]

Conversely, the strong predictive power of the POST Quality Index validates the Theory of Affordances within environmental psychology. Proposed by Gibson, this theory suggests that the environment is not merely a backdrop for human activity but is perceived in terms of what it offers the individual—its "affordances." A high-quality park is not defined by its chlorophyll content, but by its actionable possibilities: a bench affords resting; a path affords walking; a flat, open lawn affords group exercise; a streetlight affords safety after dusk.[14] Our findings suggest that mental health benefits are realized only when the environment affords these specific behaviors. A dense but fenced-off urban forest offers little social or physical affordance compared to a small, biologically sparse, but well-maintained pocket park. Thus, for the urban poor who lack the mobility to access distant "destination parks," the usability of the immediate micro-environment becomes the definitive determinant of health.

Perhaps the most significant contribution of this study is the integration of objective biomarkers to elucidate the physiological pathways linking urban design to biological health. The significant inverse relationship found between UGS quality and salivary cortisol levels (AUCg) provides critical objective evidence for Stress Recovery Theory (SRT), moving the discourse beyond subjective self-reports to hard

neuroendocrine data.[15] Urban living, particularly in precarious economic conditions, is associated with chronic hyper-activation of the Hypothalamic-Pituitary-Adrenal (HPA) axis. This chronic activation leads to a state of "allostatic load"—the cumulative wear and tear on the body's regulatory systems—which is a known precursor to both psychiatric disorders (anxiety, depression) and metabolic disease. Our cortisol data suggest that high-quality green spaces function as external regulators of this system. The mechanism likely involves the rapid down-regulation of the amygdala, the brain's primary threat detection center. When an individual enters a high-quality green space, specific sensory inputs—fractal visual patterns found in leaves, the acoustic signature of birdsong, and the absence of mechanical noise—function as soft fascination stimuli. These stimuli are evolutionarily recognizable as "safe habitats," triggering a parasympathetic override that dampens sympathetic arousal. Importantly, our data indicate this regulation is contingent on quality. A disorderly, unsafe green space (high quantity, low quality) fails to provide these safety cues and may even sustain amygdala activation. Thus, quality assurance in urban design is not merely an aesthetic concern; it is a neurobiological necessity for stress regulation.[16]

While this study did not directly sample the environmental microbiome, the association between high-quality UGS (often correlated with higher biodiversity) and mental well-being invites a consideration of the "Old Friends" hypothesis. This framework posits that humans have co-evolved with a specific community of saprophytic bacteria (such as *Mycobacterium vaccae*) found in soil and natural vegetation. Exposure to these microorganisms is essential for training the immune system to tolerate stress and avoid inappropriate inflammation. Current psychiatric research increasingly identifies systemic inflammation—specifically elevated levels of Interleukin-6 (IL-6) and C-Reactive Protein (CRP)—as a key driver of depressive etiology. Pro-inflammatory cytokines can cross the blood-brain barrier and alter neurotransmitter metabolism, inducing "sickness behaviors" that mimic depression (lethargy, anhedonia, social withdrawal). High-quality green spaces, which typically support richer soil, flora, and fauna than sterile concrete environments, facilitate human contact with this immunoregulatory microbiota. This "biodiversity-mental health" axis offers a plausible, non-psychological explanation for our findings: high-quality green spaces may literally be inoculating residents against the inflammatory consequences of urban stress.[17]

Our mediation analysis identified Social Cohesion as a primary pathway, a finding that also has a profound neurobiological basis known as social buffering. The correlation between high social cohesion and reduced cortisol levels points to the antagonistic relationship between oxytocin and the stress response.[18] Positive social interactions—a chat with a neighbor on a park bench, a shared activity in a community garden—stimulate the release of the neuropeptide oxytocin in the paraventricular nucleus of the hypothalamus. Oxytocin acts as a potent anxiolytic (anxiety-reducer) by inhibiting the release of Adrenocorticotropic Hormone (ACTH) and subsequently lowering cortisol secretion. High-quality green spaces, by acting as venues for these interactions, essentially facilitate the endogenous production of "stress-shielding" hormones. This highlights that the "social" and "biological" benefits of green space are not separate domains; they are mechanistically coupled. The park creates the space for connection; the connection triggers the hormonal cascade; the hormones protect the brain from stress.

The central role of social cohesion in our model confirms that in the context of high-density urbanization, UGS functions primarily as social infrastructure. In low-income neighborhoods, private domestic space is often severely constrained, overcrowded, and multi-functional, lacking the privacy or capacity for socialization. Consequently, public open spaces become the "living room" of the community—vital "third places" distinct from the home and the workplace.[19]

However, our findings clarify that space alone does not generate cohesion; place does. The strong link between Quality and Cohesion (Path A in our SEM) suggests that residents are discerning consumers of public space. High-quality spaces—those with seating, shade, lighting, and cleanliness—invite prolonged stays (dwelling time) rather than transient movement. This "dwelling" is the prerequisite for the formation of weak social ties—the casual, nodding acquaintanceships that weave the fabric of neighborhood trust. Conversely, the lack of association between Quantity and Cohesion (Path B) indicates that vast but unmaintained tracts of land do not invite social congregation; they may even fracture communities by creating spatial voids that sever connectivity. In the Global South, where community resilience is often the primary safety net against economic shocks, the capacity of high-quality green space to foster "bonding social capital" is a tangible asset. It transforms a collection of houses into a cohesive community capable of collective action, which in itself is a powerful psychological resource.[20]

The divergence between quantity and quality has profound implications for urban planning and environmental justice in the Global South. Historically, municipal greening targets have been driven by quantitative metrics—such as the World Health Organization's recommendation of 9 m^2 of green space per capita. While well-intentioned, our study suggests that meeting these targets via green on a map strategies (such as counting highway verges or inaccessible lands) may be statistically satisfying but public health neutral. Policymakers must shift from a land-use paradigm to a performance-based paradigm. Investments should be prioritized not necessarily on acquiring new, large tracts of land—which is often fiscally impossible in dense megacities—but on the qualitative upgrading of existing micro-spaces. "Urban acupuncture"—the creation of small, high-quality pocket parks, the revitalization of alleyways, and the installation of basic amenities (benches, lights) in existing informal green patches—may yield higher mental health returns on investment than distant, large-scale green infrastructure.[17,18]

Furthermore, this study touches upon the critical issue of Green Gentrification. As cities upgrade green spaces, there is a risk of displacing the very low-income populations these spaces are meant to serve. The challenge for the Global South is to implement "Just Green Enough" strategies—improving quality to meet health needs without triggering the speculative real estate mechanisms that lead to displacement. The focus must be on community-serving quality (safety, social space) rather than market-serving aesthetics.

While this study employs a robust methodology integrating remote sensing, systematic auditing, and biomarkers, several limitations must be acknowledged to contextualize the findings. First, the cross-sectional design precludes definitive causal inference. While our Structural Equation Model provides a statistically plausible causal architecture, we cannot rule out the possibility of self-selection bias—that individuals with better mental health or higher social capital selectively migrate to neighborhoods with better-quality green spaces. However, given the low residential mobility and economic constraints of our target population (low-income residents in Jakarta), this selection effect is likely less pronounced than in high-mobility Western contexts. Future research should employ longitudinal designs, perhaps utilizing "natural experiments" where mental health and cortisol profiles are tracked before and after specific municipal park upgrades. Second, while the POST audit is a comprehensive tool, it relies on expert assessment. Future studies could incorporate perceived quality measures derived from residents themselves, using participatory mapping or qualitative interviews to understand the cultural nuances of what constitutes a "high-quality" space in the Indonesian context. Attributes valued in Western planning (such as solitude, open lawns) may differ from those valued in Collectivist tropical societies (such as shade, spaces for large group gatherings). Third, the use of NDVI as a proxy for quantity, while standard, has limitations. It does not distinguish between vegetation types (such as tree canopy versus grass versus shrubbery). There

is emerging evidence that tree canopy specifically, may drive temperature regulation and heat stress reduction more effectively than ground cover.[19,20] Future research should utilize LiDAR data or street-view image segmentation to classify vegetation types and assess their differential impacts on physiological stress. Finally, while we posit the "Old Friends" hypothesis and immunoregulatory pathways as potential mechanisms, we did not measure inflammatory markers (IL-6, CRP) or environmental microbiomes directly. This remains a fertile ground for future interdisciplinary research linking urban ecology, microbiology, and psychiatry.

5. Conclusion

This study provides definitive evidence that in the pursuit of urban mental health, quality trumps quantity. For high-density, low-income communities, simply "greening" the map is insufficient. The mental health dividend of urban nature is realized not through the passive existence of biomass, but through the creation of high-quality, safe, and socially activating spaces that facilitate community cohesion and physiological stress recovery. Urban planners and policymakers must shift from quantitative targets (such as percentage of green cover) to qualitative performance metrics. Investments should prioritize the revitalization of existing micro-spaces into high-quality pocket parks rather than solely focusing on large-scale, often inaccessible, green infrastructure.

6. References

1. Lu S, Oh W, Ooka R, Wang L. Effects of environmental features in small public urban green spaces on older adults' mental restoration: Evidence from Tokyo. Int J Environ Res Public Health. 2022; 19(9): 5477.
2. Arifwidodo SD, Chandrasiri O. Urban green space visitation and mental health wellbeing during COVID-19 in Bangkok, Thailand. Front Public Health. 2023; 11: 1292154.
3. Yang W, Yang R, Li X. A canonical correlation analysis study on the association between neighborhood green space and residents' mental health. J Urban Health. 2023; 100(4): 696–710.
4. Yan J, Wu Y, Shao G, Qiu Q, Tang L. Effective recreational activities in urban green spaces for mental health of scientific researchers. Ecosyst Health Sustain. 2024; 10.
5. Cheng H, Li Z, Gou F, Wang Z, Zhai W. Urban green space, perceived everyday discrimination and mental health among rural-to-urban migrants: a multilevel analysis in Wuhan, China. BMC Public Health. 2024; 24(1): 2788.
6. Mollaesmaeili M, Hakimian P, Lak A. Perceived urban green spaces and youth mental health in the post-COVID-19 era. Front Public Health. 2024; 12: 1265682.
7. Zhang Y, Zhao J, Mavoa S, Fenaughty J, Clark TC, Crengle S, et al. Impacts of sociodemographic factors, identities and neighbourhood safety on the relationship between urban green space and adolescent mental well-being: Findings from Tāmaki Makaurau Auckland, Aotearoa New Zealand. SSM Popul Health. 2024; 25(101603): 101603.
8. Patwary MM, Bardhan M, İnan HE, Browning MHEM, Disha AS, Haque MZ, et al. Exposure to urban green spaces and mental health during the COVID-19 pandemic: evidence from two low and lower-middle-income countries. Front Public Health. 2024; 12: 1334425.
9. Niazi Z, Khan MA. An examination of urban green spaces usage behaviours and self-perceived mental health benefits: findings from two urban green neighbourhoods in Pakistan. Cities & Health. 2024; 8(4): 710–27.
10. Zuo W, Cheng B, Feng X, Zhuang X. Relationship between urban green space and mental health in older adults: mediating role of relative deprivation, physical activity, and social trust. Front Public Health. 2024; 12:

1442560.

11. Bressane A, da Cunha Pinto JP, Garcia Goulart AP, César de Castro Medeiros L. Which dimensions of nature contact in Urban Green Spaces most significantly contribute to mental wellbeing? A multidimensional analysis in Brazilian metropolitan cities. Health Place. 2024; 89(103335): 103335.
12. Ahmad M, Du J, Rashid MJ. Urban green space and mental health: Mediating roles of physical activity and social cohesion. Am J Health Promot. 2025; (08901171251388878).
13. Lopez-Haro J, Andrade-Sánchez AI, Gómez-Chávez FJ, Pelayo-Zavalza AR, Gómez-Varela JF. Association between urban green space use and physical, mental, and social well-being among adults in Puerto Vallarta, Mexico. Discov Public Health. 2025; 22(1).
14. Veckalne R, Saidkhodjaev A, Tambovceva T. Public perceptions of urban green spaces: Effects on physical and mental health. Urban Sci. 2025; 9(4): 128.
15. Mendoza H, Wafula ST, Troeyer KD, Bentouhami H, Shezi B, Lubega GB, et al. Urban green spaces and mental health: Findings from Uganda. Hyg Environ Health Adv. 2025; 14(100126).
16. Yen H-Y, Huang H-Y. Virtual cycling in urban green and blue vs gray spaces: The efficacy of mental health and physical activity. Public Health. 2025; 243(105723): 105723.
17. Zhang Y, Hu Y, Wei Y, Xie Y. Can pocket parks be compared to community parks in the restoration effect of physical and mental health for young adults? A comparative experiment in high-density urban Green spaces. Front Public Health. 2025; 13: 1610497.
18. Zheng Z, Chen L, Wang Y, Sun N. Group disparities in the impact of green spaces and air pollution on the physical and mental health of rural older adults: Evidence from a nationwide longitudinal study. Landsc Urban Plan. 2025; 259(105358): 105358.
19. Cardinali M, Beenackers MA, Fleury-Bahi G, Bodénan P, Petrova MT, van Timmeren A, et al. Examining green space characteristics for social cohesion and mental health outcomes: a sensitivity analysis in four European cities. Urban For Urban Greening. 2024; 93(128230): 128230.
20. Ury B, Yang J, Rosenthal SR, Barker DH, McGeary JE, Dunsiger SI, et al. Associations between subjective and objective green space on children's mental health and cognitive function. Urban For Urban Greening. 2025; 114(129156): 129156.