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Psycho-physiological assessments of urban wilder nature: A systematic review and qualitative analysis with active learning screening

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Systematic Review

Keywords: non-park urban greenery, mental wellbeing, greenness, systematic literature review, wilder greenery, restorative environments, physio-psichological assessments, neuroscientific methods

Posted Date: February 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8888566/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Rapid global urbanization is linked to a rising prevalence of mental health disorders. While the restorative effects of urban nature are known, there is an overlooked potential in highly natural vegetation within non-park urban green spaces, such as street verges and vacant plots. This systematic literature review aims to identify and analyze the mixed-method frameworks currently applied to empirically assess the psycho-physiological implications of highly natural urban greenery on mental wellbeing.

Methods

This systematic review and qualitative analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidance. Records were retrieved from three major academic databases: Scopus, PubMed, and Web of Science, using a Boolean search string based on the Population, Intervention, Comparison, Outcome, and Study design (PICOS) criteria. Eligibility was limited to peer-reviewed empirical studies published between 2015 and 2026, written in English, Spanish, or Polish. After initial screening and removal of duplicates, an active learning-assisted screening tool, ASReview LAB was applied to efficiently screen the remaining records. The final set of 22 eligible records, which featured outdoor settings, mixed-methods, and objective psycho-physiological data, underwent a qualitative analysis.

Results

The qualitative synthesis included 22 primary studies. These records provide evidence of combined methodological frameworks, integrating physiological and psychological measurements, to assess the benefits of highly natural urban greenery within non-park contexts. The findings highlight the therapeutic function of green or natural infrastructure in offering non-pharmacological options for addressing health issues and emotional challenges, such as anxiety, depression, and cardiovascular issues

Conclusions

There is a growing trend in integrating psychological evolutionary theories and neuroscientific frameworks to understand the health-promoting benefits of exposure to urban greenery. This review synthesizes existing knowledge to inform future research avenues and evaluate current planning methodologies for cognitive restoration and mental wellbeing in non-standard urban green spaces.

Systematic Review Registration

PROSPERO ID: 1309399 (Under review)

BACKGROUND

Rapid global urbanization has fundamentally transformed human habitats with the United Nations projecting that 70% of the world's population will live in urban areas by 2050 (United Nations, 2018). This demographic shift coincides with a rising prevalence of mental health disorders, including anxiety, depression, and chronic stress (World Health Organization, 2017). Conversely, high quality urban greenery within open areas plays a central role in fostering mental wellbeing (Wolch et al., 2014; Mensah et al., 2016), promoting healthy ageing (de Keijzer et al., 2020) and, shaping public health (Buttazzoni et al., 2021; Gawlak & Ptak-Wojciechowska, 2024). Accordingly, theoretical frameworks such as Attention Restoration Theory (ART) (Kaplan & Kaplan, 1989), Stress Recovery Theory (SRT) (Ulrich, 1983), and Prospect-Refuge Theory (P-R) (Appleton, 1996) provide the conceptual basis to understanding how green spaces and natural vegetation facilitate the recovery of depleted cognitive resources and the reduction of psychological strains, such as stress and anxiety (Hartig et al., 2014; Bratman et al., 2019).

However, not all green is equal (Wood et al., 2018); the level of naturalness, or the degree to which greenery is perceived as wild or ecologically intact, significantly moderates its health-promoting potentials (Carrus et al., 2015). Despite this, empirical studies often treat greenery as a monolithic category. For instance, aggregate metrics such as NDVI (Normalized Difference Vegetation Index) allow quantifying greenery over a map but fail to capture the qualitative nuances of different degrees of greenness (Dallimer et al., 2012, Zhang, L. et al., 2021). On the other hand, methodological approaches using still images of greenery do not offer the immersive stimuli of real-world scenarios (Yuan et al., 2023), while simulation techniques such as virtual reality are similarly questioned (Ünal et al., 2022) with recent studies have highlighting the lack of reliability of digital landscape to provide physiological measures that validate effects from exposure (Frost et al., 2022; Lee et al., 2022; Spano et al., 2022). As cautiousness is required when analysing the health benefits of greenery through laboratory analysis, there is a growing interest in measuring physiological responses from dynamic experiences in green urban environments, where the experiences of participants within the context can be more ecologically valid (Huynh et al., 2025; Cerwén & Hägerhäll, 2025).

In this paper we recognized that cities are composed of complex greenery, often thriving in forgotten interstices, road verges, informal gardens and vacant spaces, that also play a vital role in securing access to nature in densely populated areas (Nesbitt et al., 2019; Sikorski et al., 2021). While recreational and conservation parks have been extensively studied (Mensah et al., 2016), non-park urban greenery (NPUG) is often overlooked (Ke et al., 2023). This type of greenery thrives in fringes such as interstices, road verges, informal gardens and vacant plots that are not only in close proximity to urban dwellers (Zhou et al., 2021) but play a vital role in enhancing access to nature in dense urban areas (Nesbitt et al., 2019; Sikorski et al., 2021). Consequently, NPUG offers an untapped potential for the analysis of restorative daily experiences from exposure to wilder or highly natural greenery (Wu and Kim, 2021; Stanford et al., 2022).

Nevertheless, a delicate balance exists between planning for cues of "caring" (signals that a landscape is maintained) or "rewilding" (highly-natural urban habitats) (Nassauer, 1995). While naturalness and biodiversity are ecologically desirable, the perceptual complexity of NPUG can occasionally evoke biophobia, potentially diminishing its restorative effects (Gobster et al., 2007; Southon et al., 2017), whereas highly maintained spaces may alleviate anxiety, they often lack the "soft fascination" required for deep psychological restoration (Kaplan, 1995). Moving toward a phenomenological approach to human emotion (Frost et al., 2022; Menardo et al., 2019), recent empirical studies have shifted from the predominantly linear green quantity paradigm to an integrated framework of landscape optimization and dose thresholds (Jiang et al., 2014; Zhao & Zhang, 2024). This dose-response perspective examines the salutogenic effects triggered by specific levels and conditions of green space exposure (Shanahan et al., 2015). Such a shift provides the methodological foundation to evaluate the multifaceted health value of wilder urban greenery through integrated psycho-physiological measurements.

Accordingly, it is necessary to identify and review empirical studies that have applied these mixed-use methodologies to assess highly natural vegetation in non-standard urban green areas. This inquiry will enable us to pinpoint current practices and propose new methodological variations to evaluate the effects of high naturalness or wildness on mental wellbeing from NPUG. Consequently, the primary purpose of this paper is to rigorously address this research question through a Systematic Literature Review (SLR), retrieving empirical studies for a qualitative analysis of mixed-use methodologies. This type of review is performed to ascertain the quality of existing practices, and ultimately address uncertainties or variations within our field of study (Munn et al., 2018). Our focus is to specifically inform the perceptual and objective implications of highly natural NPUG and means to analyse them simultaneously. This comprehensive approach aims to synthesize existing knowledge and identify avenues for future research in this evolving field.

METHODS

We started the SLR by defining the main research problem or purpose of the review (Stern et al., 2014), which in turn guided key aspects of the process such as data collection criteria and document retrieval filters. Accordingly, we are interested in understanding: *which mixed-method frameworks are currently applied to empirically assess the psycho-physiological implications of highly natural non-park urban greenery on mental wellbeing.*

The objective of collecting these records is to bring together wilder nature and mental wellbeing through the analysis of empirical studies focusing on neuroscientific approaches to NPUG that applied mixed-methods in real-world scenarios. This problem area is theoretically positioned within the phenomenology of salutogenesis as it relates greenery exposure to health promotion

(Mittelmark & Bull, 2013). Consequently, the research problem has three key elements outlining the area of query. Firstly, identifying psycho-physiological methods within the scope of the research problem. Secondly, analysing how these are evaluating or assessing the influence of highly natural greenery or wild green infrastructure in non-park spaces. Lastly, understanding the philosophy of wellbeing within the phenomenon of salutogenesis. We have further articulated this query into three specific research questions:

- RQ1: What neuroscientific methods and tools are currently applied to empirically measure the psychological and physiological impacts of exposure to wilder urban environments?

- RQ2: How is the level of naturalness or wildness within NPUG evaluated when analysing its outcomes on mental wellbeing indicators?

- RQ3: Through which means the perceptual quality of naturalness mediates the relationship between urban greenery and restorative experiences?

These questions target the methodological approaches, the analytical characteristics, and the cognitive outcomes of NPUG as a phenomenon.

Systematic literature search

We opted for the PICOS (Population, Intervention, Comparison, Outcome, and Study) criteria to break down the main objective of the SLR into keywords and help formulate research questions (Petticrew & Roberts, 2006). For "Population" we have defined people or subjects within an urban setting. For the "Intervention" we have defined the exposure to the specific environmental quality of greenery in terms of its naturalness. We used the “Comparator” category as an exclusion category on what not to include in the search. “Outcome” corresponds to the psychological and physiological indicators and tools to measure the effects on mental wellbeing. And “Context” refers to the location where the research takes place.

While the main objective of the PICOS model is to define inclusion/exclusion criteria (Booth et al., 2022), we also used the categories to organise the retrieved records and perform the in-depth analysis in the results section (Stern et al., 2014). The complete overview of the PICOS model is as follows:

Table 1. PICOS model adapted from

Component	Selected SLR definition	Main Keywords	Synonyms & Related Terms
Population / Problem	People in urban areas or highly built environments	**Urban, City**	Metropolitan area, town, built environment, dense urban area, Non-Park Urban Greenery
Intervention / Exposure	Exposure to wild greenery or informal or ruderal or green open space with high level of wildness or naturalness.	**Natural, wild, green, ruderal, informal, biodiverse, rewilded areas, unmanaged, ecological**	Naturalness, wildness, ecological quality, ruderal species richness, unmanaged vegetation, rewilding, spontaneous flora. **Context**: Plot, vacant land, wasteland, roadside, street, sidewalk, verge, green wall, green roof, brownfield, pocket park, garden.
Comparator	Parks, maintained or planned green spaces with low-naturalness or high level of built infrastructure.	*(Omitted from the Boolean search string)*	Parks, conservation areas, lawns, built environment, therapeutic garden.
Outcome	Psychological effects and physiological indicators and mental or cognitive wellbeing benefits.	**Mental, Cognitive, Psychological, Wellbeing, Health**	Cognitive, perception, psychological, restoration, wellbeing, mental health
Study design	The setting, materials, and methods comprised in the empirical design of the study	Within-subject field experiment, real-world, urban walk, in-situ, urban interstices	**Physiological:** Heart Rate Variability (HRV), Cortisol level, EDA (Skin conductance), Mobile/Wearable sensing data. **Psychological:** Perceived Stress Scale (PSS), ROS (Restoration Outcome Scale), Positive and Negative Affect Schedule (PANAS), Attention Restoration, Perceived Restorativeness Scale (PRS), Stress reduction.

We used the set of main keywords from the PICOS model to create a Boolean search string (BSS) and retrieve records using a combination of operators as follows:

1. **Problem: Urban environment** (or city) **Non-Park Urban Greenery** (or informal)
2. **Intervention: Wild** (natur* or wild*) **Greenery** (green* or vegetation or ecological) **Space**
3. **Outcome: Mental** (psycholog* or cogni* or physiological) **Wellbeing** (health* or wellbeing)
4. **Study design: Psycho-physiological** (methods)

The main objective of the BSS is to retrieve studies assessing the restorative implications for mental wellbeing of highly natural non-park urban green spaces. As part of its design, it is worth mentioning that there is no need to account for American and British English as the selected databases automatically include common spellings in their results namely, “wellbeing” or “well-being”. Additionally, we employed the asterisk (*) as a wildcard for truncation to replace multiple characters at the end of a word and finding broader variations. For example, natur* includes results for nature, natural, and naturalness.

We performed a comprehensive search across three major academic databases: Scopus, PubMed and Web of Science (WoS). The search strategy combined the keywords above using Boolean operators targeting papers by titles, abstracts and keywords to maximize retrieval as follows:

Table 2. Preliminary set of BSS retrievals with a total of 1,119 records

Preliminary Boolean Search String	Database	Records
TITLE-ABS-KEY (("urban" OR "city") AND ("green*" OR "non-park" OR "informal" OR "ruderal" OR "vacant land" OR "wasteland" OR "roadside" OR "verge" OR "brownfield" OR "pocket park") AND ("wild*" OR "natur*" OR "rewilding" OR "biodivers*" OR "unmanaged" OR "ecological" OR "vegetation") AND ("wellbeing" OR "mental" OR "health*" OR "restoration" OR "cognitive" OR "psychological") AND ("physiological" OR "biometric" OR "heart rate" OR "skin"))	Scopus	438
[All Fields] (("urban" OR "city") AND ("green*" OR "non-park" OR "informal" OR "ruderal" OR "vacant land" OR "wasteland" OR "roadside" OR "verge" OR "brownfield" OR "pocket park") AND ("wild*" OR "natur*" OR "rewilding" OR "biodivers*" OR "unmanaged" OR "ecological" OR "vegetation") AND ("wellbeing" OR "mental" OR "health*" OR "restoration" OR "cognitive" OR "psychological") AND ("physiological" OR "biometric" OR "heart rate" OR "skin"))	PubMed	312
TS=(("urban" OR "city") AND ("green*" OR "non-park" OR "informal" OR "ruderal" OR "vacant land" OR "wasteland" OR "roadside" OR "verge" OR "brownfield" OR "pocket park") AND ("wild*" OR "natur*" OR "rewilding" OR "biodivers*" OR "unmanaged" OR "ecological" OR "vegetation") AND ("wellbeing" OR "mental" OR "health*" OR "restoration" OR "cognitive" OR "psychological") AND ("physiological" OR "biometric" OR "heart rate" OR "skin"))	WoS	369

The total sum of retrieved records from Scopus (438), PubMed (312), and WoS (369) was 1119 (n=1119). These encompassed peer-reviewed empirical studies, book chapters and conference papers examining the relationship between NPUG and psychological wellbeing or cognitive restoration, in urban contexts and cities.

To ensure the objectivity of our findings, a secondary set of eligibility criteria was applied, filtering the publications to those dated from 2015 to 2026. This period was selected to capture only the latest advances and methodological innovations within our discrete body of knowledge. Furthermore, given the language proficiencies of the research team, we selected papers written only in English, Spanish, and Polish. Consequently, a second BSS with these refined criteria resulted in the following records:

Table 3. Final set of BSS retrievals with a total of 1011 records

Final Boolean Search String	Database	Records
TITLE-ABS-KEY (("urban" OR "city") AND ("green*" OR "non-park" OR "informal" OR "ruderal" OR "vacant land" OR "wasteland" OR "roadside" OR "verge" OR "brownfield" OR "pocket park") AND ("wild*" OR "natur*" OR "rewilding" OR "biodivers*" OR "unmanaged" OR "ecological" OR "vegetation") AND ("wellbeing" OR "mental" OR "health*" OR "restoration" OR "cognitive" OR "psychological") AND ("physiological" OR "biometric" OR "heart rate" OR "skin")) AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND (LIMIT-TO (LANGUAGE , "Spanish") OR LIMIT-TO (LANGUAGE , "English"))	Scopus	376
(("urban"[All Fields] OR "city"[All Fields]) AND ("green*"[All Fields] OR "non-park"[All Fields] OR "informal"[All Fields] OR "ruderal"[All Fields] OR "vacant land"[All Fields] OR "wasteland"[All Fields] OR "roadside"[All Fields] OR "verge"[All Fields] OR "brownfield"[All Fields] OR "pocket park"[All Fields]) AND ("wild*"[All Fields] OR "natur*"[All Fields] OR "rewilding"[All Fields] OR "biodivers*"[All Fields] OR "unmanaged"[All Fields] OR "ecological"[All Fields] OR "vegetation"[All Fields]) AND ("wellbeing"[All Fields] OR "mental"[All Fields] OR "health*"[All Fields] OR "restoration"[All Fields] OR "cognitive"[All Fields] OR "psychological"[All Fields]) AND ("physiological"[All Fields] OR "biometric"[All Fields] OR "heart rate"[All Fields] OR "skin"[All Fields])) AND ((english[Filter] OR polish[Filter] OR spanish[Filter]) AND (2015:2026[pdat]))	PubMed	290
TS=(("urban" OR "city") AND ("green*" OR "non-park" OR "informal" OR "ruderal" OR "vacant land" OR "wasteland" OR "roadside" OR "verge" OR "brownfield" OR "pocket park") AND ("wild*" OR "natur*" OR "rewilding" OR "biodivers*" OR "unmanaged" OR "ecological" OR "vegetation") AND ("wellbeing" OR "mental" OR "health*" OR "restoration" OR "cognitive" OR "psychological") AND ("physiological" OR "biometric" OR "heart rate" OR "skin")) and 2015 or 2016 or 2017 or 2018 or 2019 or 2020 or 2021 or 2022 or 2023 or 2024 or 2025 or 2026 (Publication Years) and English (Languages)	WoS	345

The final sum of retrieved records from Scopus (376), PubMed (290), and WoS (345), after excluding 108 records outside ur scope (n=1011). In the next section we elaborate on the process of identifying relevant academic records for the study (Moher et al. 2009). Accordingly, we firstly performed a screening of results based on titles and abstracts following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021). It is worth mentioning that the guidelines are not a methodology, allowing us to follow PRISMA statement design for reporting without performing a meta-analysis (SWiM) (Campbell et al,, 2020) or a strict quantitative synthesis (Lau et al., 1997). Secondly, we applied the active learning-based screening tool ASReview LAB as part of a scholarly effort to automate and optimize our systematic review pipeline (Wallace et al., 2013), through machine learning. Finally, we proceeded to select the most relevant records based on full-text eligibility.

Identification and screening

We opted for PRISMA SWiM to ensure transparency and rigor in data selection while ensuring a broader set of comprehensive records (Campbell et al,, 2020). As mentioned before, we identified a total of 1011 records across the three databases. Subsequently, we performed a preliminary screening from which 320 duplicated records were removed, as these were found across multiple databases. This step was performed by creating a helper column (D) and searching through the values from columns B & C (Title and Abstract) to identify the duplicates:=OR(COUNTIF(B:B, B2)>1, COUNTIF(C:C, C2)>1). Subsequently, 320 screened duplicates were removed (n=691). Additionally, 7 irrelevant records were removed as these were out of the scope (5) or incomplete (2) (n=684).

Active learning-based screening

To efficiently manage and screen the large volume of records retrieved, we opted for ASReview LAB (v2.2) and used the AI tool in accordance with the guidelines of the SAFE procedure for practical heuristic stopping in active learning-based screening. ASReview is an open source tool under an Apache 2.0 license that is available as software on Python (Van de Schoot et al., 2021). This machine learning tool for active learning-assisted screening ranks records based on relevance probability, presenting the most likely relevant records to the screener first while learning from the inclusion/exclusion decisions simultaneously (Van de Schoot et al., 2021). This method has been shown to identify 95% of eligible studies after screening less than 40% of the total records (Van de Schoot et al., 2021). Consequently, the tool reduces significantly the workload without compromising accuracy. Accordingly, the SAFE procedure allowed us to determine when to stop the active learning-aided screening while adhering to the PRISMA guidelines (Page et al., 2021). SAFE was designed to enable finding a reasonable percentage of relevant records in the dataset rather than aiming for screening 100% of the dataset (Boetje & van de Schoot, 2024).

As part of the procedure, it is necessary to identify key papers to train the model and to evaluate the results by two independent screeners, as per PRISMA recommendations (Page et al., 2021). The SAFE procedure consists of four phases as follows:

Table 4. Graphical overview of the SAFE procedure for applying a practical stopping heuristic for active learning-aided systematic reviewing, adapted from Boetje & van de Schoot, 2024.

Phase	Activity	Purpose	Stopping heuristic
Screening	Screen a random set for training data.	To calibrate the inclusion criteria and estimate a number of key records	• Screen a minimum of **5%** of the total records; • Find at least **one** key record.
Applying	Apply active-based learning screening	To efficiently screen the data and find relevant records	• All key records have been marked as relevant; • At least twice the estimate of the number of relevant records have been screened; • A minimum of **10%** of the total dataset has been screened; • No extra relevant records have been identified in the last **50** records.
Finding	Find more relevant records with a deep learning model.	To ensure no records are missed due to the choice of the active learning mode.	• No extra relevant records are identified in the last **50** records.
Evaluating	Evaluate quality	To avoid incorrectly excluded relevant records	• No extra relevant records are identified in the last **50** records.

As a starting point, we de-duplicated the dataset (n=684) and exported it as a single .csv file with the the following information as column headers: Authors, Title, Abstract, Year, Keywords, Indexed Keywords, DOI, PubMed ID, Language and Type. This dataset was uploaded to ASReview LAB to perform the active learning-based screening.

For the first phase, we selected a random subset of 5% records (n=35) for screening and identified 3 relevant records with the default review settings (ELAS u4) (Boetje & van de Schoot, 2024). This is recommended to prepare the model for the next phase and provide prior knowledge.

For the second phase, we uploaded the full data set (n=684) and applied the SVM (Support Vector Machine) classifier and TF-IDF (Term Frequency-Inverse Document Frequency) as feature extractor. This model iteratively retrained itself after every screening decision, dynamically re-ordering the remaining unseen records (Boetje & van de Schoot, 2024). Moreover, we added the three relevant records labeled in phase one as prior knowledge. In accordance with the SAFE procedure, the stopping heuristic was achieved after screening 239 records (~35%) of the total dataset, identifying twice the estimate of the number of relevant records and reviewing 50 non-relevant consecutive records (n=65). After reaching this stopping threshold we switched to a different AI model and continued to the third phase.

As part of the third phase, we used again the full data set of 684 records with the labeled records from phase 1 and 2 as prior knowledge (n=65). We then applied a customized learning model using OneHot as feature extractor and the Naive Bayes classifier (Boetje & van de Schoot, 2024). The stopping heuristic was set at 50 non-relevant and only 1 new record was identified as relevant during this phase (n=66).

In accordance with the SAFE procedure, for the final phase of screening we focused on identifying any excluded but relevant records from the previous phases (Boetje & van de Schoot, 2024). We added all the records labeled as irrelevant and used the 10 highest and 10 lowest-ranked papers from phase 2 as prior knowledge. In accordance with the PICOS criteria, the selected key papers are contextualised empirical studies on NPUG and mental wellbeing with a focus on high levels of naturalness. Conversely, the 10 lowest-ranked papers clearly belonged to the "**C**omparator" criteria as these studies focused on traditional parks, clinical drug trials or virtual reality simulations. For this fourth phase of active learning-based screening, we utilized the SVM and TF-IDF model configuration which has been validated for systematic reviews (see phase 2). The stopping heuristic for this fourth phase was set at 50 non-relevant records, and none were identified as relevant during the screening. It is worth mentioning that as part of this third screening, 2 additional duplicate records and 2 incomplete records were removed (n=62). With the exception of the initial phase, the stopping criterion screening was always conducted by one human reviewer. To ensure no relevant studies were missed, we applied a stopping rule based on diminishing returns. Screening was terminated after observing 50 consecutive non-relevant records in the prioritized queue.

Inclusion

We followed-up, with a second-round of screening of titles and abstracts of the remaining records (n=62) and identified 4 records out of the scope (n=58). Subsequently, one researcher performed an in-depth review to identify eligible studies for inclusion/exclusion (n=20).

A second researcher performed an independent screening and identified 7 potential records for full-text review. As a last step, we performed an in-depth review of the remaining records (n=27) with disagreements resolved through discussion and obtained the final selection of records for full-text review and analysis (n=22). For this phase we followed the PICOS structure and defined an inclusion/exclusion criterion to select the relevant studies (Stern et al., 2014). Accordingly, all of the included records comply with the following guidelines:

Table 5. Inclusion/Exclusion criterion for full-text eligibility

Inclusion criterion	*Exclusion criterion*
• Outdoor settings and/or public space	•Indoors, simulation, virtual reality or laboratory
• Mixed-methods approach	• Traditional parks, gardens
• Psychological and physiological objective data	• Single method
• Experiences of people within NPUG	• Theoretical approach or medical review
• Highly natural or wilder urban greenery	• Clinical, biological or pharmaceutical trial

The following PRISMA flow diagram charts the process of screening and selecting records at each phase, from initial identification (n=1119), screening (n=684), active-learning screening with SAFE (n=62), in-depth eligibility discussion (n=58), and inclusion for full-text qualitative analysis (n=22):

RESULTS

In the following section we elaborate on the full-text qualitative analysis of the included records (n = 22) from data extraction, quality assessment and discussion of results. We performed a qualitative review as we aim to to understand the meaning of phenomena and their relationships (Stern et al., 2014). Accordingly, we firstly synthetised relevant data in accordance with PICOS and discussed our findings. The overall discussion starts with a review of the participants and problem data (Population), type of intervention or exposure to NPUG (Intervention), results and empirical findings (Outcomes), and the study design or methodology for each experiment (Study).

It is worth mentioning that the selected records are based on primary studies related to the main research problem. These showed evidence of combined methodological frameworks to assess the psycho-physiological implications of highly natural greenery on mental wellbeing, within non-park urban contexts. Furthermore, the studies were executed in a variety of countries but half of them took place in mainland China or the Special Administrative Region of Hong Kong (11). The remaining studies were performed in cities within the United Kingdom (2), the United States (2), and one study per location in Austria, Germany, Iran, Japan, Poland, Taiwan, and Tanzania, respectively.

As a starting point of our qualitative synthesis, we used the PICOS framework to categorize the main characteristics of each study and guide our analysis across heterogeneous study designs and methodologies. The following table provides an overview of all the analysed records:

Table 6
Summary of reviewed studies.

Authors, Year, Title	Population	Intervention	Comparison	Outcomes	Study
Weng et al., 2025 **Restorative effects of small urban parks: a multi-method study using eye-tracking and psychophysiological measures in Fuzhou, China**	55 participants (adults)	Exposure to four types of small urban parks (Pocket, Linear Waterfront, Community, Small Comprehensive).	Comparison of four park types; Gender comparison.	Small comprehensive parks showed strongest restoration Gaze fixation on vegetation was the most positive predictor	Multi-method approach (Eye-Tracking, SCL/HRV, PRS) in high-density. **Focus on landscape elements and park type**.
Zhang et al., 2025 **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**	80 participants (young adults 18–28)	Exposure to pocket parks	Community Parks.	Well-designed **pocket parks achieved restorative effects comparable to community parks.** Quality over size is critical.	Comparative experiment (PANAS, POMS, ROS) in high-density. **Focus on small-scale green spaces**.
Zhuo et al., 2025 **Assessing the Effects of Exposure to Green Rooftop Spaces on Perceived Restorativeness: A Field Study in Xiamen, China**	35 participants (college students)	Exposure to four types of rooftop spaces (various degrees of naturalness).	Pre/Post exposure.	All rooftop green spaces reduced the stress. **Higher naturalness led to better restoration.** Positive perception linked to cognitive restoration.	Physiological (SBP, DBP, HR, HRV) and psychological (PRS, BPOMS) methods. Focus on non-traditional urban greenery.
Kim et al., 2020 **Typology and perception of informal green space in urban interstices: A case study of Ichikawa city, Japan**	144 participants (students= Male 51.4% and Female 48.6%)	Evaluation of the perception of **Informal Green Space (IGS).**		Students recognize IGS and perceive multiple benefits from **unimproved land and street verges as potential green space**	Survey of Informal Green Space (IGS) perception in a post-industrial satellite town in Japan.
Aras et al., 2024 **Is Greener Better? Quantifying the Impact of a Nature Walk on Stress Reduction Using HRV and Saliva Cortisol Biomarkers**	17 participants (18–60 years) with N = 15 used for a key part of the HRV analysis	A walk on "The Green Road" (a nature setting) at Walter Reed National Military Medical Center in Bethesda, Maryland.	A walk along an "urban corridor."	104% increase in RMSSD and 47% increase in SDNN (HRV) led to low stress. Lower cortisol after the walk, 53% compared to a 37% reduction from the urban walk. Mood and vigor were more robust for the Green Road walk.	Randomized, field-based trial with HRV, pre- and post-walk saliva cortisol and self-reported mood scores. **Quantitative data supports stress reduction effects of nature exposure.**
Tu et al., 2026 **Dose-response relationship between green walking distance and pedestrians' restorative outcomes: A pilot study with**	36 participants (young adults)	Green environment walk.	Short vs. Long distance.	The longest walk (2.5km) was associated with the greatest overall improvements. **Non-linear dose-response** suggested, shorter walks (1.5km) showing more benefits.	Randomized controlled crossover experiment: physiological (EDA, SCL, SCR) and psychological (PANAS, PRS) measures with real-time microclimate monitoring.

Authors, Year, Title	Population	Intervention	Comparison	Outcomes	Study
microclimate measurements					
Yu et al., 2024 **Assessing momentary stress responses to dynamic real-time greenspace exposure: Unveiling algorithmic uncertainty and the temporality of exposure context**	210 participants (residents)	Dynamic greenspace exposure metrics in real-time.	Temporal vs. cumulative exposure.	**GVI is the most effective measure for stress reduction.** Cumulative exposure has a better (smaller dose)	Ecological Momentary Assessment (EMA) for stress and real-time GPS and NDVI, GVI, GSAR.
Duan et al., 2024 **Human Physiological Responses to Sitting and Walking in Green Spaces with Different Vegetation Structures: A Seasonal Comparative Study**	400 participants (students)	Exposure to green spaces with different vegetation structures	Sitting vs. Walking & Winter vs. Summer.	Walking leads to a better physiological recovery effect than sitting. **Single-layer grassland and composite woodlands** had the most significant physiological recovery.	Comparative experiment using physiological measures (pNN50). Vegetation structure and perception method (immersive vs. passive).
Zhu et al., 2024 **An Investigation of the Restorative Benefits of Different Spaces in an Urban Riverside Greenway for College Students—A Simple Autumn Outdoor Experiment**	30 participants (college students)	Exposure within waterfront space, underwood space, and lawn space.	Three space types.	Waterfront space had the best restorative effect (greatest physiological/mental health recovery). Restorative factors differ by space type.	Outdoor experiment: physiological (BP, HR) and psychological (POMS) data. focus on type and naturalness gradient.
Cao et al., 2024 **Effects of Urban Greenway Environmental Types and Landscape Characteristics on Physical and Mental Health Restoration**	100 participants (Adults)	Experiment on three types of urban greenways in Roads, Parks, and Rivers.	Comparison of three greenway environment types.	Urban Park-type greenways offer the greatest physical and mental recovery. **Plant diversity positively impacts mental health.**	Physiological (BP, Pulse) and Psychological (PRS, PANAS) indicators. Focus on greenway types and specific landscape characteristics.
Chang et al., 2016 **The effect of biodiversity on green space users' wellbeing-An empirical investigation using physiological evidence**	Not specified (biofeedback)	Exposure to settings with varying degrees of biodiversity	Comparison of settings based on biodiversity	Physiological responses remain largely unchanged. **Increased biodiversity (wildness)** does not negatively influence physiological well-being.	151 physiological measures to assess the influence of biodiversity (as an indicator of naturalness/wildness). And insect population.
Roe et al., 2020 **The Urban Built Environment, Walking and Mental Health Outcomes Among Older Adults: A Pilot Study**	11 participants (elderly mean age 65)	Walking in an urban quiet “green” district (with front gardens and street trees.	Urban "Gray" district	Significant positive health benefits from walking in the Urban Green district on emotional well-being (happiness)	Pilot study using wearable sensors (HRV, noise/air quality) and cognitive scales. Focus on street-level greenery.

Authors, Year, Title	Population	Intervention	Comparison	Outcomes	Study
Moser et al., 2025 **Understanding the influence of urban characteristics on cyclists' stress measured through wearable sensors: A quantitative open data approach**	89 participants (cyclists with a mean age of 47 years)	Cycling trips on green urban segments.	Comparison of roads with different characteristics (green vs. built).	Infrastructure, traffic, and other road users are of higher importance than green space availability in predicting cyclist stress.	Wearable sensors (EDA) and open spatial data (OSM, SVI, GVI). Focus on stress in active mobility.
Gidlow et al., 2016 **Where to put your best foot forward: Psycho-physiological responses to walking in natural and urban environments**	38 participants (mean age 40.9)	30-min walks in natural green environments	Urban vs. Green vs. Blue.	Stress reduction occurred in all environments (**salutogenic effect**). Green and Blue environments conferred cognitive benefits 30 min after exposure and restoration experiences.	Randomized, cross-over, field trial using physiological (cortisol, HRV) and psychological (mood, cognitive) measures. **Comparing different naturalness categories.**
Reeves et al., 2019 **The application of wearable technology to quantify health and wellbeing co-benefits from urban wetlands**	36 participants	Counterbalanced exposure to: Urban Wetland (Blue-Green Space)	Urban Wetland vs. Indoor Space vs. Urban Site.	Urban Wetland exposure led to increased positive feelings and decreased negative feelings for stressed individuals.	EEG for physiological stress response. **Pre-existing stress levels act as moderator.**
Janeczko et al., 2020 **When urban environment is restorative: The effect of walking in suburbs and forests on psychological and physiological relaxation of young polish adults**	75 participants (young adults)	Walking in urban environments: with greenery and deciduous Forest.	Urban Greenery (Suburbs) vs. Forest.	Suburban Greenery and Forests had positive physio-psychological effects. A short walk in the suburbs was found as positive as a forest walk	Randomized experiment physiological (HR, BP) and psychological (POMS, PANAS, ROS, SVS). Focus on effects of **highly green urban areas**.
Nian et al., 2025 **Effects of environmental factors on multisensory perceptions of comfort, safety, and pleasure in autumnal urban riverfront spaces**	72 participants (1207 questionnaire responses)	Exposure to autumnal urban riverfront space, with real-time microclimate and visual data collection.	Comparison of low, middle, and high levels of various environmental factors.	High Green View Index (GVI) positively influences pleasure, comfort, and safety. **Naturalness Pleasure Vote** (NPV) was positively associated to woody plants and green view	Interplay between objective environmental factors (GVI) and multisensory perceptions in a real-world setting.
Xu et al., 2024 **Restorative Effects of Pocket Parks on Mental Fatigue among Young Adults: A Comparative Experimental Study of Three Park Types**	80 participants (young adults 19–25)	Field experiment in different types of pocket parks.	Comparison of three pocket park types and 10 environmental features.	Vegetation color, coverage, resting facility comfort, and plant species were more predictive of mental fatigue recoverability than other factors like privacy.	Focus on mental fatigue recovery and influence of specific perceptual environmental features (color, coverage, comfort) within small green spaces.
Kanelli et al., 2024	108 participants	Exposure and motives for visiting **Campus**	Regression analysis comparing	Positive relationship between the need to be close to nature to	NDVI and subjective/perceptual

Authors, Year, Title	Population	Intervention	Comparison	Outcomes	Study
Can Campus Green Spaces Be Restorative? A Case Study from Tanzania	(students or staff)	**Green Spaces (CGSs).**	factors (e.g., motives, age, NDVI).	relaxation or well-being. **Restoration associated with NDVI**	factors in an LMIC context.
Dehove et al., 2024 **Exploring the influence of urban art interventions on attraction and wellbeing: an empirical field experiment**	130 participants	Exposure to a parklet displaying Greenery on two distinct street contexts.	Art vs. Green intervention.	**No evidence found for the impact of decoration on wellbeing.**	Used mobile eye-trackers and physiological devices.
Peng et al., 2024 **Chronic impacts of natural infrastructure on the physical and psychological health of university students during and after COVID-19: a case study of Chengdu, China**	16 participants (aged 20–30)	Impact of green street type on urban stress and relaxation.	car-oriented, or pedestrian	Key stress reducing factor in green space is vegetation naturalness with climatic comfort and natural sounds	EEG headset to measure stress, PRS, Urban design qualities questionnaires
Sadeghpoor et al., 2024 **Streets and Stress: A Pilot Study on How Quality and Design of Streets Impacts on Urban Stress**	300 participants (students aged 18–25)	Impact of Natural Infrastructure on physical and psychological health	Different types of natural infrastructure (GI, BI, HI)	Forest for physiological benefit while grass areas for psychological benefit.	TSST + Physiological measurements (blood pressure, heart rate) + POMS and STAI + Climate data

Population composition and characteristics

The total combined population is 2,213, with a mean of 100.5 participants per study. There is however a wide variation of participants per study, ranging from 11 (Roe et al., 2020) to 400 (Duan et al., 2024), with approximately half of the methodological designs aiming at 80 or fewer participants.

Overall, the methods primarily focused on young adults and university students: 75 young adult students in Warsaw, Poland (Janeczko etal., 2020), 16 participants (aged 20–30) for the evaluation of green streets (Peng et al., 2024), 80 participants aged 19–25 years using pocket parks in Nanjing, China (Xu et al., 2024; Zhang et al., 2025), 35 college students in Xiamen, China studying the effects of green rooftop spaces (Zhuo et al., 2025), and a larger scale study on streets, green infrastructure and stress that sampled 300 students from Tarbiat Modares University in Teheran, Iran (Sadeghpoor et al., 2024). It is worth mentioning that the study on the Dar es Salaam University campus surveyed 108 students (18–25 age) and highlighted that significant restoration outcomes were found also in students from low/middle-income communities (LMIC) (Kanelli et al., 2024).

Several studies targeted broader adult urban demographics, often assessing their general response to different environments. For instance, the large-scale assessment of greenspace exposure and momentary stress on 221 Hong Kong residents (mean 44 years) (Yu et al., 2024), a study on the impact of street greenery on 89 cyclists (mean 47 years) (Moser et al., 2025), and a multi-method study on small urban parks with 55 participants from Fuzhou, China (Weng et al., 2025). This latter identified gender as a significant factor in restorative perceptions and physiological responses (mean 41 years) (Weng et al., 2025). Despite some of the studies having older participants (e.g., 75 year old cyclists in Moser et al., 2025), only one pilot study focuses on an age-vulnerable group by exploring walking and mental health outcomes in a small sample of 11 older adults (mean 65 years) living in an independent care facility (Roe et al., 2020). Another study that comprises an older group was the randomised cross-over trial in the UK that had a sample of 38 unstressed individuals with a mean age of 40.9 ± 17.6 years (Gidlow et al., 2015).

While insights are relevant for the young adult demographic, the generalizability of these findings to broader gender or age groups, particularly older adults, remains limited.

Non-Park Greenery types and interventions

We were able to highlight the methods within non-traditional and smaller-scale urban green spaces (UGSs), namely in relation to three types of NPUG: pocket parks, green-blue spaces and non-standardized greenery. Small-scale parks, including street corners, interblock, and intrablock spaces are repeatedly examined in the records. It has been established that well-designed pocket parks can achieve restorative effects comparable to larger community parks, underscoring the imperative of prioritizing high quality vegetation in their design (Zhang et al., 2025). This was the same case in relation to the restorative mechanisms of various small urban parks that were found to be influenced by the characteristics of their integrated natural landscapes (Weng et al., 2025). Specific elements within pocket parks like vegetation colour, coverage, and plant species were highly predictive of mental fatigue recoverability (Xu et al., 2024).

Moreover, greenways and riverfront green spaces that comprise linear NPUG offer unique restorative benefits. The methods used to evaluate NPUG with this characteristic uncovered that urban greenways generally provided the greatest physical and mental recovery benefits (Cao et al., 2024). However, the blue element of the waterfront often exhibits superior restorative effects compared to underwood or lawn spaces (Zhu et al., 2024). This was also the case of the unique environment of Urban Wetlands in which blue-green spaces merge as one and showed to be highly influential on stress recovery, particularly in individuals with pre-existing high stress (Reeves et al., 2019).

Regarding non-standardized greenery, the methodological designs aiming at green rooftop spaces demonstrated their stress-reduction effects, when featuring a higher degree of naturalness (Zhuo et al., 2025). The value of unplanned and structurally distinct green spaces is also recognized. IGSs in urban interstices such as wasteland and street verges were positioned to serve as supplementary sources of greenery (Dehove et al., 2024; Kim et al., 2020). Accordingly, students recognized IGSs as a potential green space and perceived multiple benefits from unimproved land and street verges (Kim et al, 2020). Similarly, NPUG and street art were found equally impactful on wellbeing within parklets and urban acupuncture interventions (Dehove et al., 2024).

Moreover, we were able to identify that the methodological frameworks are linked to measurable characteristics of the vegetation structure. For instance, the composition of vegetation significantly impacts recovery as evidenced when comparing different structures of composite woodlands and single-layer grassland. Methods targeting the tree-shrub-grass layering structure revealed the most significant physiological recovery effects (Duan et al, 2024). In relation to greenways, plant color and layer diversity were found to have a significant positive impact on mental health benefits (Cao, et al., 2024) whereas in riverfront spaces, the restorative effects were linked to the aesthetic appeal of the natural revetment or the green wall along the river (Zhu et al., 2024). In pocket parks, vegetation color and coverage were highly predictive of mental fatigue recovery (Weng et al., 2025; Xu et al., 2024). From a technical standpoint, these studies relied on eye-level GVI as the most robust measurement to assess the stress-reducing effect of such a variety of characteristics and compositions of NPUG.

Outcomes and key findings

As mentioned before, the restorative efficacy of NPUG is intrinsically linked to its characteristics and natural quality. Accordingly, the reviewed methodological designs aim at providing evidence of functional equivalence. For example, studies on Pocket Parks (Xu et al., 2024; Zhang et al., 2025; Weng et al., 2025) and Green Rooftops (Zhuo et al., 2025) demonstrated that high naturalness within these smaller green spaces can be translated into more restorative effects comparable to larger parks (Zhang et al., 2025). Furthermore, walks in urban green suburbs were found to be no less attractive than walks in a forest in terms of physiological and psychological relaxation (Janeczko et al., 2020).

Regarding the concerns associated with the ecological validity of static image-based studies, the reviewed methodological designs integrated neuroscientific tools that capture the immersive experience and support Ecological Momentary Assessment (EMA) with physiological and psychological data. For instance, GVI was shown to be the most robust metric for assessing the stress-reducing effect in urban environments, particularly at eye-level (Dehove et al., 2024; Nian et al., 2025; Yu et al., 2024). The visual accessibility

and density of greenery from the pedestrian's perspective, rather than overhead cover like NDVI or OSM, is a crucial variable not only influencing salutogenic outcomes but also guiding the studies to measure it (Yu et al., 2024; Gidlow et al., 2016; Kanelli et al., 2024).

Research on IGS (Kim et al., 2020) confirmed that non-standard spaces like street verges and unimproved land are perceived as valuable sources of greenery and contribute to wellbeing, establishing their necessity as supplementary greenery in dense areas. In this study, the authors highlighted that the use of IGS was often hampered by resident concerns over lack of maintenance and perceived unsafety. Furthermore, environmental qualities critically influenced stress mitigation in urban public spaces (Sadeghpoor et al., 2024). Specifically, factors such as green space and vegetation together with climatic comfort demonstrated the most positive effects on reducing stress (Sadeghpoor et al., 2024). Furthermore, other therapeutic effects of various types of natural infrastructure (NI) such as thermal comfort, air quality (negative ion concentration), and light levels, affect physical and psychological wellbeing equally (Peng et al., 2024). Confirming that a wilder, unmanaged appearance can evoke negative perceptions, potentially diminishing the salutogenic benefits despite the high ecological value. Nonetheless, the level of biodiversity as an indicator of ecological health or wildness was directly tested in one study (Chang et al., 2016). Using physiological measures to assess the presence of greater biodiversity did not negatively impact the physiological wellbeing of the subjects (Chang et al., 2016). This outcome suggests that a more ecologically intact (wilder) setting does not necessarily diminish the restorative capacity of NPUG.

Methodological approaches to the context

The full-text synthesis of the empirical studies from the SLR revealed several interdisciplinary trends, moving beyond aggregate metrics of green quantity to employ more sophisticated data-driven methodologies and mixed-methods designs, to address specific psychological and physiological impacts, as well as immersive and eye-level methodologies, to quantify various degrees of greenness within various types of NPUG. We have organised these findings into three categories: dynamic perceptual and spatial tracking methods, neuroscientific tools for real-world exposure; and assessing the moderating role of environmental stressors.

Dynamic Perceptual and Spatial Tracking

Eye-Tracking technology was utilized to objectively quantify visual attention and engagement with specific landscape elements. The findings from the multi-method study on small urban parks demonstrated that the proportion of gaze fixation on vegetation was the most salient positive predictor of both perceived restoration and physiological relaxation (Weng et al., 2025). Similarly, it was determined through gaze fixation that the role of non-green urban interventions are more present in the participant’s visual field (Dehove et al., 2024). Regarding wellbeing, it was found that the effects of more natural NPUG are not affected by the context in parklets and that applying even more precise analyses of the viewing behavior confirmed the trend (Dehove et al., 2024). Despite evidence suggesting that restoration effects could be evaluated through NDVI only (Kanelli et al., 2024).

As mentioned before, perceptual and measurable greenness is key. The reviewed studies emphasize the importance of features that directly influence human perception. For instance, the proportion of gaze fixation on vegetation was identified as a salient positive predictor of both restorative experience and physiological relaxation (Weng et al., 2025). Furthermore, even small pockets of nature, such as front gardens and street trees in an urban quiet 'green' district, demonstrated significant positive health benefits on emotional well-being and stress physiology (Roe et al., 2020).

Methods focused on the temporality of exposure and Ecological Momentary Assessment (EMA) were intrinsically combined with GPS tracking. Leveraging real-time data combined with EMA was the necessary link to instantaneous stress responses to specific segments of the urban environment (Yu et al., 2024; Moser et al., 2025). This approach is essential for establishing non-linear dose-response relationships for wilder greenery as demonstrated by the cumulative benefits of shorter vs. longer walks in wilder nature (Yu et al., 2024; Tu et al., 2026).

Neuroscientific Tools for Real-World Exposure

The reviewed studies coincide in moving beyond the virtual towards real-world experience while identifying a critical knowledge gap in the proper combination of instruments to evaluate environmental stressors or determine which type of space design is most effective in reducing stress levels (Sadeghpoor et al., 2024). The methodological landscape for studying the restorative impacts of

nature, particularly NPUG, has seen a substantial evolution through the systematic integration of advanced physiological and spatial tracking technologies. More sophisticated approaches combining objective physiological measures such as Heart Rate Variability (HRV), Skin Conductance Level (SCL), and Electrodermal Activity (EDA) together with dynamic spatial tracking and Ecological Momentary Assessment tools (EMA), represents a significant methodological advancement found across the reviewed studies. These integrated frameworks assess restorative effects in real-world scenarios, allowing researchers to correlate immediate context-dependent physiological responses with real-world exposure to green spaces.

Conversely, electroencephalogram (EEG) wearable tools like headsets are advisable to effectively identify pre-existing stress levels (Sadeghpoor et al., 2024; Reeves et al., 2019). Latent stress acts as a moderator of greenery during empirical analysis which might hinder the results of the spatial evaluations. Nevertheless, it is also recommended to use single-channel devices as some participants might experience anxiety about using a bigger EEG device such as a portable multichannel (Sadeghpoor et al., 2024) or Non-invasive physiological monitoring for contextualizing stress during activities

Furthermore, electrodermal Activity like the SCL and SCR, along with HRV, were systematically employed across multiple methodological frameworks (Aras et al., 2024; Weng et al., 2025; Yu et al., 2024; Roe et al., 2020). These markers directly quantify arousal and stress activation. For instance, reduced SCL was a primary objective outcome for enhanced restoration during green walks (Tu et al., 2026; Weng et al., 2025). Cardiovascular measures like direct Blood Pressure (BP) and Heart Rate (HR) served as reliable indicators of recovery, with studies on riverside greenways (Zhu et al., 2024) showing significant reductions following exposure. Furthermore, a study on healthy aging confirmed the positive impacts of green routes on blood pressure and oxygen saturation (Roe et al., 2020).

Diastolic blood pressure, mean heart rate, mean pulse rate, and blood oxygen saturation were used to demonstrate psychological health. For instance, more natural NPUG was more effective in improving the emotional state than simple grass areas (Peng et al., 2024) showing effectiveness in improving mood disturbance and reducing feelings of unease. Overall, the integration of objective physiological measures with dynamic spatial tracking technologies like GPS, constitutes a substantial methodological leap forward in the research in the design of the reviewed methods. Prior empirical work focusing on the cognitive and stress-alleviating benefits of urban greenery has already demonstrated a strong reliance on these mixed-use methodologies, effectively utilizing them to provide a more ecologically valid and nuanced understanding of the human-nature interaction (SOURCES).

The Moderating Role of Environmental Stressors

While the presence of greenery is consistently associated with promoting psychological restoration, it is crucial to recognize that these beneficial effects are significantly modulated by non-green environmental factors. This interaction often highlights a perceptual conflict between the desired ecological function of a space and the necessity for human comfort and a low-stress environment. For instance, empirical studies employing real-time physiological sensors have demonstrated that high levels of acute environmental stressors, such as persistent noise and air pollution, can substantially interfere with and negatively counteract the restorative process typically induced by nature exposure (Roe et al., 2020; Tu et al., 2026). Furthermore, in contexts demanding active focus and mobility, such as cycling along urban routes, non-green stressors such as traffic, infrastructure and other users, were found to be of greater predictive importance for stress levels than the mere availability or proximity of green space (Moser et al., 2025). This emphasizes that the perceived quality of the environment, not just the quantity of nature, is paramount.

In contrast to the concerns raised by some traditional self-report studies, physiological evidence offers a reassuring perspective on ecological best practices. Specifically, studies using objective measures of physiological wellbeing suggest that greater levels of biodiversity (i.e., species richness) do not negatively influence restorative outcomes. This key finding serves as a practical guideline, encouraging urban designers and landscape architects to freely utilize ecological best practices and aim for high biodiversity without the concern of inadvertently diminishing the restorative benefits for users (Chang et al., 2016).

A consistent finding across the literature is that fine-grained, three-dimensional measures of visual greenery, such as GVI (Yu et al., 2024; Zhu et al., 2024) and the specific presence of rich landscape elements (e.g., mature trees, complex groundcover, water features), are far stronger predictors of psychological restoration than crude, two-dimensional area metrics from OSM or percentages from NDVI (Kanelli et al., 2024). These findings fundamentally support the argument that within NPUG, users can perceive, differentiate, and respond physiologically to subtle degrees of wildness or naturalness. This necessitates a critical methodological shift for future empirical research: studies must move beyond reliance on satellite-derived metrics and instead

utilize eye-level, fine-grained, and often dynamic metrics (e.g., street-view image analysis, virtual reality, eye-tracking) to accurately capture the complexity and immersive quality of the stimuli that truly drive the restorative process. This aligns precisely with the core principles of Attention Restoration Theory (ART), which posits that the visual quality of "soft fascination"—a captivating yet undemanding stimulus—is the paramount element for restoration (Weng et al., 2025). Consequently, the integration of dynamic, ecologically-informed methods for capturing Salutogenic evidence demonstrably outperforms the limited predictive power of broad, satellite-derived metrics like NDVI and Green Space Area Ratio (GSAR).

DISCUSSION

In relation to the first research question (RQ1), the analysis of neuroscientific methodologies reveals a key empirical shift from simulated or laboratory settings to real-world experiments. Nevertheless, using multiple methods for environmental quality evaluation is still neglected in academia (Sadeghpoor et al., 2024). The systematic integration of physiological measures such as HRV, SCL, EDA, and/or EEG, together with dynamic spatial tracking (GPS/EMA) or eye-tracking constitutes a significant methodological advancement for the study of NPUG. The application of mixed-use designs for methodological evaluations offer two critical benefits: securing objective validation and defining dose-exposure thresholds. Objective validation moves beyond self-declared questionnaires by offering neuroscientific, objective evidence (SRT validation) of stress reduction *in situ* (Gidlow et al., 2015; Reeves et al., 2019). The efficacy of this is demonstrated by studies showing dramatic mental health improvements in high-stress populations (Aras et al., 2024) and older adults (Roe et al., 2020).

Furthermore, some of the most recent studies (2024–2025) employ advanced psychophysiological methodologies to objectively quantify outcomes. These biomarkers and measurement tools adopt a multi-method, multi-sensory approach integrating twofold physiological measurements such as EEG, HRV, EDA, salivary cortisol) together with real-time environmental data (noise, air quality, microclimate) to isolate the specific environmental and sensory stressors/restorers (Aras et al., 2024; Reeves et al., 2019; Moser et al., 2025).

We were able to confirm the beginning of a critical move from quantitative measures of green space towards metrics that capture the perceived naturalness and quality of the immersive experience in NPUG. This complex approach to greenery is related to the specific evaluation of naturalness (RQ2). Simple green cover metrics were often found to be insufficient or less effective than those representing the human-level visual experience across several methodological designs (Dehove et al., 2024; Weng et al., 2025). Some studies are explicitly dedicated to capture and validate immersive experiences through measurement tools. Eye-level GVI was consistently identified as the most robust, reliable, and effective metric for quantifying the impact of visible greenness on physiological and psychological fixation and attention. Experimental research with eye-level GVI also helped understanding how specific water features, vegetation structures (e.g., tree-shrub-grass composite woodlands), and the configuration of activity areas are perceived across different locations and seasons (Cao et al., 2024; Duan et al., 2024; Weng et al., 2025). Accordingly, our analysis reveals that relationships between urban greenery and restorative experience in these studies were significantly mediated by perceptual qualities that influence feelings of comfort, safety, and attention restoration (Chang et al., 2016; Weng et al., 2025). This strong empirical evidence reinforces the importance of visible greenness as a key environmental factor in urban planning and public health studies. The superior performance of the Eye-level GVI compared to other metrics such as NDVI highlights its ability to capture the aspect of green space exposure most pertinent to the immediate human perceptual experience and, consequently, its therapeutic effect. This underscores a crucial insight that not just the presence, but the visibility and accessibility of green elements are paramount for effective stress-reducing benefits within NPUG.

The perceptual quality of naturalness acts as a critical mediator between exposure to urban greenery and restorative experiences (RQ3). The reviewed methodological designs consistently measured outcomes revolving around stress reduction and physiological/psychological restoration. More importantly, they also provide further validation to the possibility of measuring stress reduction from immersive experiments, exemplified by means of increased RMSSD and reduced cortisol levels across various space types of NPUG. Accordingly, establishing exposure thresholds allows for the precise measurement of the dose-response relationship (Yu et al., 2024), suggesting that the restorative effect is non-linear and cumulative, often peaking within a 12-to-40 minute window. This establishes an evidence-based foundation for guiding the planning of small NPUG, where the focus must be on maximizing the duration of effective exposure within limited space. Studies are beginning to explore the dose-response relationship like short vs. long walking distances in green environments, and the differential benefits of space types. The most

common and robust data-driven tool for validating the theoretical stress recovery (SRT) was the deployment of real-time biofeedback measures as dose-response. For instance long walks (2.5km) yield the greatest improvements, suggesting a potential non-linear threshold effect (Yu et al., 2024). On the other hand,

Furthermore, the findings highlight the therapeutic function of green or natural infrastructure in offering non-pharmacological options for addressing health issues and emotional challenges, such as anxiety, depression, and cardiovascular issues (Peng et al., 2024; Yu et al., 2024). This finding validates our initial objective that recent research interest is focused on objective physiological markers (Salutogenic outcomes). Defining dose-response relations between greenery and wellbeing is crucial when designing methods to capture involuntary, rapid psycho-physiological responses to environmental stimuli.

Conversely, the role of other landscape elements needs to be equally approached when it comes to measuring the restorative mechanisms of space. Throughout the different analyses, we were able to determine that the effects of NPUG can be context-dependent. For instance, while fixation on artificial facilities showed negative or context predictive relationships (Weng et al., 2025); another study highlighted the often-overlooked role of "hardscape activity areas" in promoting restoration (Zhang et al., 2025). This gap can also be extended to the exclusion of seasonal dynamics, with many studies relying on summer data (Duan et al., 2024; Kanelli et al., 2024). Based on the evidence, we have been able to also pinpoint that climate factors like thermal conditions, air pollution as well as traffic regulations have an important influence on the restorative outcomes that are independent of green space availability (Moser et al., 2025; Sadeghpoor et al., 2024; Tu et al., 2026). These empirical findings revealed a significant differential in stress response across the tested environments: participants exhibited the highest levels of stress in the motorist-oriented streets and the lowest levels in streets dominated by green spaces. From a practical perspective, these findings have potential implications for informing planning policy, especially considering the inclusion of greenery in the design of public spaces. A key conclusion highlights the relative efficacy of different design interventions, suggesting that the presence of diverse green spaces has a more substantial effect on stress reduction than eliminating vehicle traffic (Sadeghpoor et al., 2024).

Another significant limitation across the studies is the use of small and homogeneous population samples. Several studies explicitly acknowledge their limited participant numbers or specific demographics, such as a study with (Weng et al., 2025; Zhuo et al., 2025). Our analysis suggests that the outcomes can be significantly modulated by personal characteristics like gender. For instance, female participants showed greater sensitivity to psychological and physiological responses (Weng et al., 2025), or pre-existing stress levels hindering the reliability of the data collection process (Reeves et al., 2019). Failing to recruit a fully representative sample results in limited generalisability (Gidlow et al., 2015). Furthermore, the limited inclusion of older adults in the analysed works represents a significant research gap that offers a potential avenue for further investigation on restorative potentials. As evidenced, future studies should include larger and more demographically diverse samples (e.g., age, socioeconomic background, occupation) to improve statistical accuracy and external validity (Roe et al., 2020).

CONCLUSIONS

In the present SLR, we analysed 20 primary empirical studies and identified the most effective mixed-method frameworks for assessing the psychological and physiological impacts of highly natural NPUG on mental wellbeing. The consensus across the analyzed literature is that the most robust methodology involves a dual approach: integrating objective, evidence-based physiological and neuroscientific measurements with subjective, self-reported psychological evaluations, often conducted in ecologically valid, real-world field settings. The findings consistently show that the restorative potential of urban green spaces is significantly moderated by their degree of naturalness, moving research beyond a simple "green quantity-health" paradigm toward a nuanced, integrated framework.

Regarding novel neuroscientific methods applied to measuring the impacts of wilder urban environments, our analysis pinpoints a methodological shift from simulated or laboratory environments to real-world experiments. This answered our first specific research question in relation to the ecological importance of assessing NPUG from a human point of view. The most frequently and effectively applied neuroscientific and physiological tools include HRV, serving as a key indicator of autonomic nervous system balance and stress reduction, and Saliva Cortisol Biomarkers for objective stress hormone measurement. While methods involving external measurements like SCL/EDA and SBP, DBP, HR are also valid, our collected evidence suggests that these are not the most effective tools. These objective measures are consistently paired with validated self-evaluation psychological tools, such as the PRS, ROS, and mood scales like PANAS and POMS, forming the core of the effective mixed-method frameworks.

Furthermore, our second inquiry regarding the evaluation of naturalness. We were able to conclude that outcomes on mental wellbeing indicators were primarily measured through comparative experimental designs that categorize and contrast different types of NPUG. Rather than relying on simple aggregate metrics, studies select specific settings with varying, pre-assessed degrees of naturalness, wildness, or ecological quality. For instance, comparing highly natural IGSs or green rooftops against more maintained or conventional urban parks or gardens. This type of comparative evaluation is structured around contrasting but measurable psycho-physiological outcomes of exposure to NPUG. The findings from our analysis indicate that studies contextualized in spaces categorized as highly natural, ruderal or wild often achieved restorative effects comparable to or stronger than traditional parks, confirming the relevance of this differentiated evaluative approach.

Overall, these findings demonstrate that the perceptual quality of naturalness acts as a critical mediator between exposure to urban greenery and restorative experiences. This mediation occurs primarily through two interconnected means: cognitive perception and visual attention. This finding aligns with the theoretical notion of soft fascination within wilder environments and answered our specific research question. Objective data from eye-tracking studies indicate that gaze fixation on vegetation serves as the strongest positive predictor of this restorative effect. In other words naturalness in NPUG enhances the perceived restorativeness and directs attention in a manner that facilitates the recovery of depleted cognitive resources, thereby mediating the overall beneficial impact on mental wellbeing.

This SLR reinforces existing evidence documenting a positive association between greenery and mental health for residents, students, and older adults. Our findings offer a foundation for the design of evidence-based and data-driven environment assessment by highlighting the critical role of greenery in determining exposure thresholds for walking time exposure within NPUG. Considering NPUG when planning and designing cities, especially in the context of promoting healthy and active aging, is a perspective that supports the implementation of wild or highly-natural greenery provision schemes, as a practical implication for future studies.

Abbreviations

SLR: Systematic Literature Review

NPUG: Non-Park Urban Greenery

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

PICOS: Population, Intervention, Comparator, Outcome, Study

SWiM: Synthesis without Meta-analysis

ART: Attention Restoration Theory

SRT: Stress Recovery Theory

P-R: Prospect-Refuge Theory

NDVI: Normalized Difference Vegetation Index

RQ: Research Question

HRV: Heart Rate Variability

EDA: Electrodermal activity

PSS: Perceived Stress Scale

ROS: Restoration Outcome Scale

PANAS: Positive and Negative Affect Schedule

PRS: Perceived Restorativeness Scale

BSS: Boolean search string

WoS: Web of Science

SAFE: Screening, Applying, Finding, Evaluating

SVM: Support Vector Machine

TF-IDF: Term Frequency-Inverse Document Frequency

AI: Artificial Intelligence

VR: Virtual Reality

SCL: Skin Conductance Level

POMS: Profile of Mood States

*SBP:*Systolic Blood Pressure

DBP: Diastolic Blood Pressure

HR: Heart Rate

BPOMS: Brief Profile of Mood States

IGS: Informal Green Space

SCR: Skin Conductance Response

EMA: Ecological Momentary Assessment

GPS: Global Positioning System

GVI: Green View Index

GSAR: Green Space Area Ratio

pNN50: Percentage of successive normal cardiac interbeat intervals > 50 msec

BP: Blood Pressure

OSM: Open Street Map

SVI: Street view imagery

GVI: Green View Index

EEG: Electroencephalogram

SVS: Subjective Vitality Scale

LMIC: Low Medium Income Countries

RMSSD: Root Mean Square of Successive Differences

SDNN: Standard Deviation of Normal-to-Normal intervals

CGSs: Campus Green Spaces

UGSs: Urban Green Spaces

Declarations

Acknowledgements

Not applicable.

Authors contributions

Study conceptualization: M S-B. Methodological design and implementation considerations: M S-B, A P-W. Manuscript writing and submission preparation: M S-B, A P-W. Investigation: M S-B, A G & A P-W. Writing, review and editing: M S-B, A G & A P-W. Supervision, Funding acquisition, Validation and Resources: A G.

Funding

This work was supported by the Ministry of Science and Higher Education of Poland. [Grant number 112/SBAD/0114]

Data availability

All data extracted from the reviewed studies and used in this systematic review and qualitative-analysis are included in this published article and its supplementary information files. No new individual participant data were collected. Additional materials are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Figures

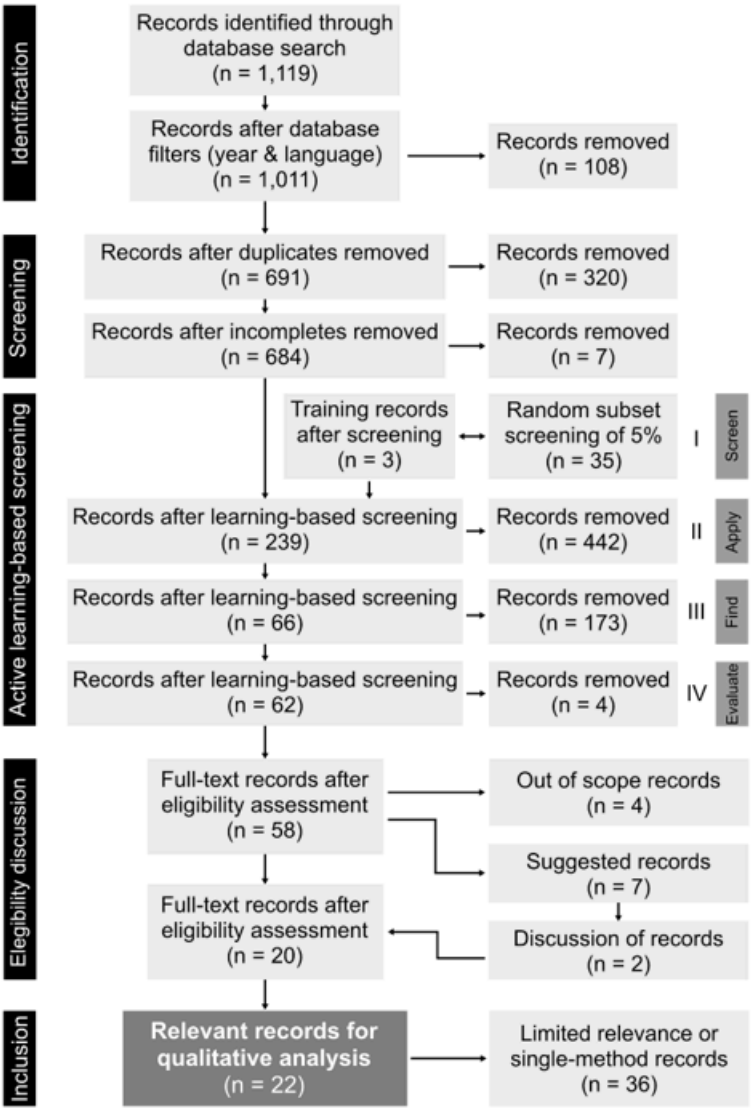


Figure 1

PRISMA flow diagram

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