nature cities

Article

https://doi.org/10.1038/s44284-025-00285-z

A generalized relationship between dose of greenness and mental health response

Received: 21 February 2024

Accepted: 27 June 2025

Published online: 25 July 2025

Check for updates

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Exposure to green spaces is a boon to urbanites. Over the last four decades, an increasing number of researchers have shown interest in exploring the relationship between the dose of greenness and mental health response. Early studies suggested a linear dose–response relationship, making it challenging to identify the most beneficial doses of greenness. However, findings from a rapidly growing body of recent research indicate the possible existence of a generalized curvilinear pattern. Despite this, these studies have used varying measures and contexts, resulting in inconclusive evidence. Without fully understanding the nature of the relationship, we do not know how to allocate green landscape resources to maximize mental health benefits. This study aimed to identify a generalized pattern to describe the dose–response relationship between urban greenness and mental health. Through a meta-analysis of all relevant studies, we found sufficient samples to generalize the dose–response curve for greenness intensity. Our analysis revealed that a quadratic pattern best fits most of the published greenness curves, and we identified the highly beneficial and best doses of eye-level greenness and top-down greenness. This study identifies and rationalizes a generalized quadratic pattern describing the dose of greenness–mental health response curves, addressing a critical knowledge gap across multiple fields. In practice, a moderate 'dose' of urban greenness exposure provides the most salubrious supply of mental health benefits.

Cities and countries worldwide are struggling to address mental health problems[1–3]. The World Health Organization estimates that one in eight people experience mental health issues, but only 28% of these people receive treatment[4]. City planning and design can be a cost-effective and easily accessible approach. Green landscape exposure has been shown to promote mental health[5–9]. However, studies in different contexts report disparate findings, making it difficult for researchers and practitioners to understand and make use of these findings. A more general understanding of the relationship between greenness exposure and mental health responses is needed.

For many decades, environment and public health studies have reported that greater levels of greenness exposure lead to better mental health outcomes, which include, but are not limited to, mental fatigue[10], mental stress[11–13], anxiety[14,15], depression[16,17] and cognitive capability[18–21]. Early evidence suggested a linear relationship between dose (measured quantity of greenness exposure) and mental health,

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 https://doi.org/10.1038/s44284-025-00285-z

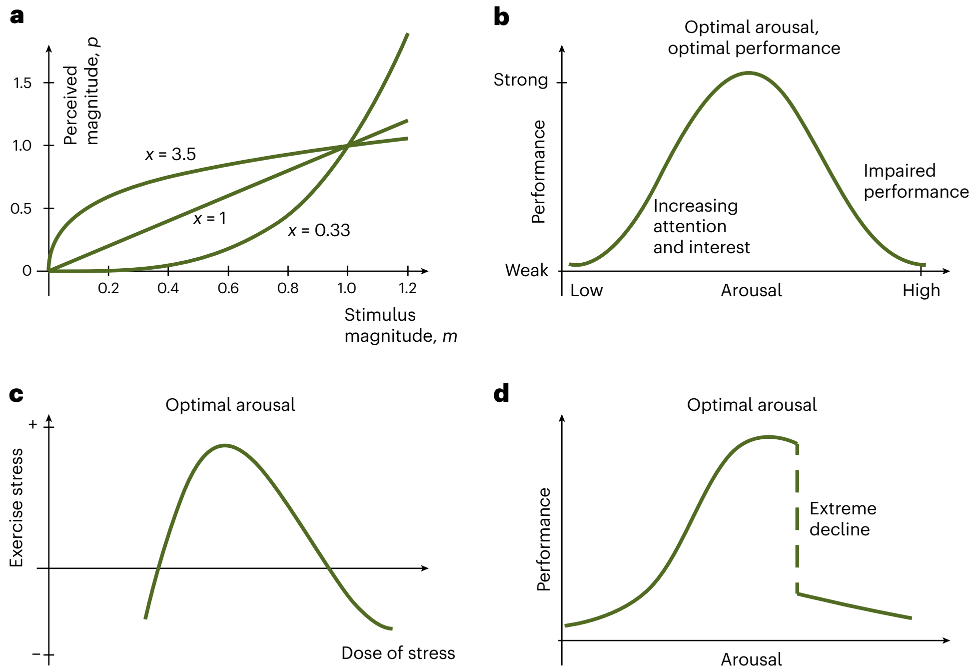

Fig. 1 | Four circumstantial doses of green landscapes–mental health curve theories. **a**, Stevens's power law (power-curvy pattern). **b**, Yerkes–Dodson law (inverted-U pattern). **c**, Hormesis theory (inverted-U pattern). **d**, Catastrophe model (catastrophic pattern). 'Dose' refers to the measured quantity of greenness exposure.

making it challenging to identify the most beneficial doses of greenness. Although a 'greener is always better for mental health' conclusion has helped promote urban forestry and greening in cities, its scientific and practical value is limited. With incomplete knowledge of the relationship, we cannot know how to optimize urban forestry resources to maximize mental health benefits. However, findings from a rapidly growing body of recent research indicate the possible existence of a generalized curvilinear pattern[22]. A priori, a nonlinear relationship is more plausible when talking about an exposure and an individual health effect, because of saturation effects, diminishing returns to scale or dose and so on. Many notable linear associations might be better described as curvilinear associations, noting that not all studies report whether log transformation was attempted. Biased research design can influence the shape of a dose–response curve and reasonable fit can be achieved from a linear model regardless of a curvilinear distribution.

Recent studies report curvilinear associations between green and health[15,23]. For example, Barton and Pretty[24] found that an inverted-U pattern curve can best describe the relationship between green exercise and mental status. In ref. 25, an inverted-U pattern curve has been shown to best describe the relationship between eye-level greenness and reduction in mental stress. In ref. 22, on the other hand, a power function was found to best describe the relationship between eye-level greenness and landscape preference.

Despite the growing trend of studies reporting the curvilinear dose–response results[26,27], these studies have investigated different greenness exposures (different types and ranges) and different mental health responses (different types and measurements) within different environmental and social contexts[23], resulting in inconclusive evidence. Due to the fragmented understanding of the relationship, we are unable to optimally allocate green landscape resources for maximizing mental health benefits.

To address the critical gap for research and practice, this study investigated the possibility of establishing a generalized curvilinear pattern through a meta-analysis of all published dose–response studies in the past 40 years (1985–2025). We aimed to not only describe a generalized dose–response curve pattern but also set up the theoretical ground.

Achieving this goal first requires a close examination of relevant theoretical models to identify possible patterns for the dose–response curves, and understand the underlying cause–effect mechanisms behind those patterns. Four theoretical models, based on physical and psychological responses to external stimuli, shed light on expected dose–response curves describing the relationship between nature and mental health. They suggest that it may be possible to identify a general law. The four theoretical models (Fig. 1a–d) include Stevens' power law (power pattern), Yerkes–Dodson law (inverted-U pattern), hormesis theory (inverted-U pattern) and catastrophe model (catastrophic pattern), respectively.

Stevens' power law is a milestone theory in the field of psychology that fits a general dose–response curve to summarize scattered findings in different stimulus–response studies[28]. Through the analysis of data collected from multiple experimental studies, multiple psychological responses to external stimuli were found to follow a power function equation[29].

The Yerkes–Dodson law and the hormesis theory fit an inverted-U shape to describe the dose–response of environmental exposure on human physical health[30]. The shape is consistent with a theory that a small dose creates a low, deficient benefit and a high dose creates an inhibitive or even negative impact; in contrast, a moderate dose creates the best benefit[31,32].

The catastrophe model indicates the possibility of a 'cliff' in which performance may plummet after arousal reaches a certain threshold. It reveals that when psychological arousal is at a low level, the relationship between arousal and performance can be described with an inverted-U pattern. However, when psychological arousal is high and physiological arousal increases to a certain point, performance may show a sharp decline[33].

Considering the fact that exposure to greenness is a process of receiving and responding to external stimuli, it is plausible to propose a holistic curvilinear pattern to summarize the relationship between greenness exposure (dose) and mental health outcomes (response). Our rationale is supported by three points.

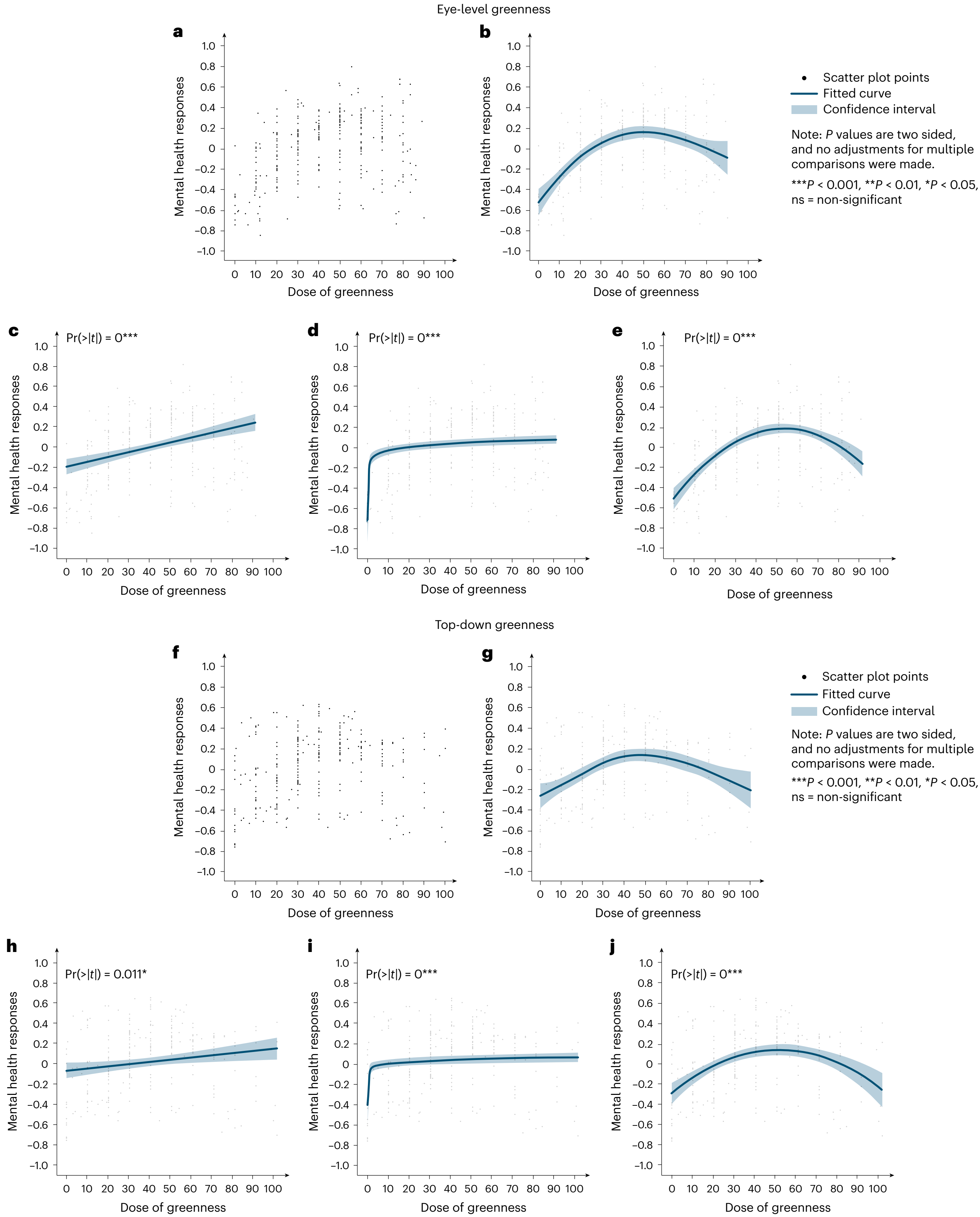

Fig. 2 | Meta-analysis of curve refitting between dose of greenness and mental health performance. **a**–**e**, Results of eye-level greenness. **f**–**j**, Results of top-down greenness. Results of the scatter plots of all the standardized collected points (**a** and **f**). Non-parametric GAM curve refitting (**b** and **g**). Results of three parametric models (**c**–**e** and **h**–**j**). Both GAM model and the comparison of three models show that the inverted-U curve described by the quadratic equation is the best fit for greenness (Table 1 provides the statistical information). Data points are represented as dots, with the fitted curve shown as a dark blue line, and the confidence interval depicted as a shaded region. Statistical significance levels: ***$P < 0.001$; **$P < 0.01$; *$P < 0.05$; ns, non-significant.

First, humans' mental responses to environmental features can be modeled as psychological responses to external information. Exposure to the physical environment, including green landscapes and other environmental features, have immediate and accumulated impacts on people's mental health states in daily life as people perceive and process environmental information[34,35]. It is reasonable to expect there to be regularities in the way the exposure–response dynamic operates and the varying functional forms summarized in the 'Threshold doses for two types of greenness' section present candidate hypotheses.

Second, humans' mental responses to nature manifest themselves as biological changes in the human body[36], as suggested in the optimal arousal theory, hormesis theory and catastrophe law. Studies have examined nature's impact on mental health using several biological indicators, including salivary cortisol (an indicator of mental stress state), inflammatory cytokine (an indicator of depression) and blood glucose (an indicator of depression and fear). Some studies have identified the impacts of greenness at the human system or receptor level. Studies have noted the impacts of greenness on different brain regions related to attention restoration[37] and stress reduction[38]. Walking in a forest has been found to be associated with improved natural killer cell and anticancer protein activity, which indicates stress relief and enhanced immune system function[39]. Many studies have demonstrated that visual contact with greenness can cause positive responses in the hypothalamic–pituitary–adrenal axis and the autonomic nervous system[39–43]. These studies suggest various kinds of exposure–response pattern, but do not all also seek to describe patterns of dose–response effects. Observational studies can capture associations, but it takes a specific research design to capture changes in marginal effects.

Third, studies suggest that there are underdose and overdose problems associated with contact with nature[24,44], like those identified in the fields of psychology, biology, medicine and public health. In these fields, research findings suggest that humans seek a state of equilibrium to help them survive and thrive. That is, humans prefer a moderate, rather than an extremely low or high dose of environmental stimulus, to achieve the best benefits. Researchers recognize that human beings can only judge whether a stimulus is beneficial when considering its dose. Dose also impacts people's responses to environmental features. For example, a barren place can cause a negative mental response such as disorientation, anxiety or stress, whereas a heavily canopied place may also elicit similar negative feelings[45]. These reasons combine to motivate a search for general theories and patterns governing the dose–response dynamics of green landscapes.

On the basis of the premises above, we ask two key questions. (1) to what extent can a nonlinear curve pattern describe all dose–response curves reported in the literature? (2) Can we identify threshold values for 'dose-of-greenness' models that can be associated with the best, highly beneficial and non-adverse effects?

By answering these questions, this study has the potential to deepen our understanding of the quantitative characteristics of dose-of-greenness relationships and provide practical guidance to policymakers and professionals in allocating green landscape resources to maximize mental health benefits. We consider this issue a fundamental one in the science of healthy cities.

Results

Characters of selected curves

For eye-level greenness intensity, we collected 35 curves and 276 points. For the top-down greenness intensity, we collected 34 curves and 251 points. The detailed graphics of the curves after standardization are listed in Supplementary Figs. 4 and 5. Figure 4 shows the process and results of the systematic review following PRISMA procedure. The detailed data collection process can refer to Methods.

The 69 curves have a relatively equal distribution of study location, spanning five continents. The number of curves from America, Europe and Asia are relatively equal (Supplementary Table 2). The curves describe ten types of mental health response (Supplementary Fig. 3).

Table 1 | Comparison of three parametric models for two types of greenness

Model type		AIC	BIC	Adj. R^2	Pr(>|*t*|)
Eye-level greenness					
(c)	Linear pattern	145.60	156.46	0.12	0.000***
(d)	Power pattern	140.73	151.59	0.13	0.000***
(e)	Inverted-U pattern	88.94	103.43	0.28	0.000***
Top-down greenness					
(h)	Linear pattern	158.25	168.82	0.02	0.01*
(i)	Power pattern	143.15	153.73	0.08	0.000***
(j)	Inverted-U pattern	127.44	141.54	0.14	0.000***

***$P<0.001$, **$P<0.01$, *$P<0.05$, ns means non-significant. P values are two sided, and no adjustments for multiple comparisons were made. AIC, Akaike information criterion; BIC, Bayesian information criterion.

Inverted-U pattern has the best fit

The scatter plots for both eye-level and top-down greenness of all the points indicate an inverted-U pattern, and the actual relationship plotted by the generalized additive model (GAM) model supports that assumption (Fig. 2a,b,f,g). To choose the best-fitting model, we compare three curvilinear models and find that the inverted-U pattern has lower Akaike information criterion and Bayesian information criterion values, lower P values and higher coefficient of determination (adjusted R^2) values (Fig. 2c–e,h–j and Table 1). For the inverted-U pattern curve models, eye-level greenness has a higher adjusted R^2 than top-down greenness (Table 1).

The best-fitting quadratic functions can be expressed as

$$\text{Eye-level greenness}: f(x) = -2.47x^2 + 2.60x - 0.49,$$

$$\text{Top-down greenness}: f(x) = -1.63x^2 + 1.66x - 0.27,$$

where x is the percentage of eye-level or top-down greenness (if the greenness level is 60%, x is 0.6).

Threshold doses for two types of greenness

Using the identified quadratic equations, we calculated the threshold doses for the two types of greenness (Fig. 3). For eye-level greenness, the dose for the best effect is 53.1%, the dose for the highly beneficial effect (top 5% of the positive effect) is from 46.2% to 59.5%, and the dose for the non-adverse effect is from 25.3% to 80.2%. For top-down greenness, the dose for the best effect is 51.2%, the dose for the highly beneficial effect is from 43.1% to 59.2%, and the dose for the non-adverse effect is 21.1%–81.7%. The best effect means the peak value of positive effects, and highly beneficial effect means the range of greenness that is associated with the top 5% of positive effects. The non-adverse effect refers to the range of greenness that is associated with effect greater than zero. The dose lower or higher than the dose for the non-adverse effect is associated with negative effect (effect < 0).

Discussion

This study yields two major findings. First, the inverted-U-shaped curve and the corresponding quadratic relationship can best summarize the dose–response curves reported by published empirical studies. Second, three threshold values of eye-level greenness and top-down greenness are identified.

Why does a quadratic pattern describe the relationship?

Our finding the quadratic pattern (inverted-U curve) best summarized the relationship between dose of greenness and mental health

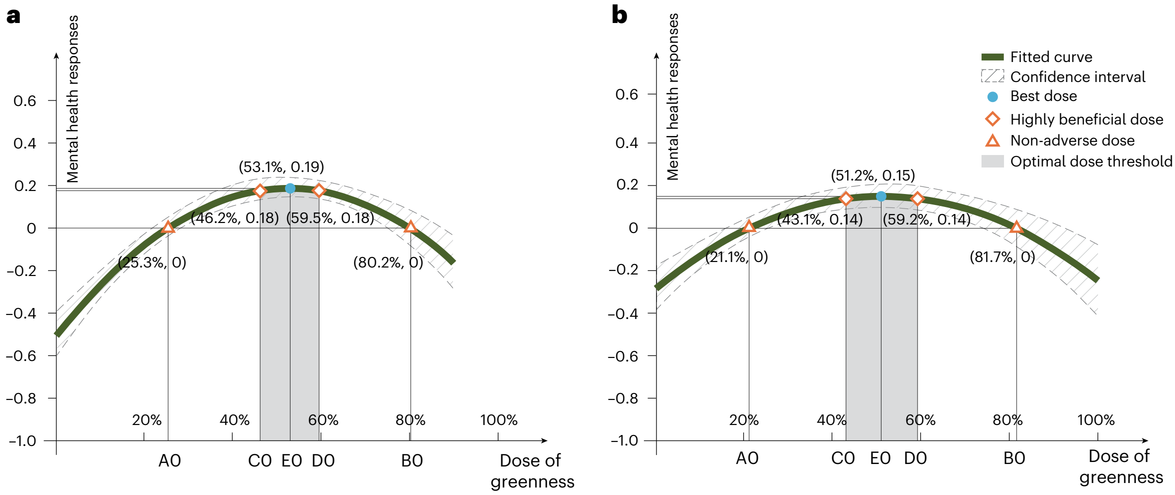

Fig. 3 | a,b, Meta-analysis of curve refitting and doses of the best, highly beneficial and non-adverse effects for eye-level greenness (a) and top-down greenness (b). The best effect means the peak value of effect. The highly beneficial effect matches the range of greenness that is associated with the top 5% of positive effect. The non-adverse effect matches the range of greenness that is associated with the non-negative value. The green line represents the refitted curve, with the dashed regions representing the confidence interval. The blue dot marks the best dose, the orange squares represent the start and end of the highly beneficial dose threshold, and the orange triangles represent the start and end of the non-adverse dose threshold.

Table 2 | Recommendations of implications for policymakers and practitioners that are based on threshold values of dose of greenness found in this study

	Best dose	Highly beneficial dose	Non-adverse dose	Adverse dose
Eye-level greenness	53.1%	46.2% ≤ x ≤ 59.5%	25.3% ≤ x ≤ 80.2%	x < 25.3% or x > 80.2%
Top-down greenness	51.2%	43.1% ≤ x ≤ 59.2%	21.1% ≤ x ≤ 81.7%	x < 21.1% or x > 81.7%
Mental health effect	Associated with the peak positive effect	Associated with the top 5% of positive effects	Associated with non-adverse effects	Associated with adverse effects
Recommendations	Best choice	Highly recommended choice	Baseline choice	Should avoid

responses might be explained through some combination of theories and empirical studies regarding different psychophysiological aspects.

Several studies have reported an inverted-U curve describing the relationship between dose of greenness and psychophysiological stress[43,46]. These studies often use evolutionary psychology to explain this relationship. A barren space with low levels of green landscape may make humans feel stressed because they present less access to natural resources and, therefore, do not support human survival. Other studies have supported this theory[38,47]. On the other hand, a higher density of greenness may not always lead to lower levels of stress and negative emotions. Studies suggest that highly dense greenness may have less natural light and more visual obstacles, leading people to feel stressed, anxious and worried about getting lost or being ambushed[43,48]. Thus, a moderate level of greenness may be best at reducing stress and other negative emotions. Similar interpretations can be found in other studies of greenness and mental stress and emotions[49–51].

From the perspective of attention, attention fatigue and cognitive function, several studies have reported inverted-U curve relationships between greenness and attention capabilities and cognitive performance. To explain this relationship, numerous studies argue that barren spaces with no or low doses of greenness consume rather than restore people's directed attention, which can cause fatigue and low cognitive performance[21,40,52–54]. Similarly, high doses of greenness may also consume directed attention, leading to mental fatigue and poor cognitive performance[27,55]. Some studies suggest that a high dose of greenness often has a higher level of complexity, which increases people's cognitive load, demanding greater mental effort to perceive, process and respond to the landscape[56,57]. A moderate dose of greenness leads to the best cognitive functioning because it provides a higher degree of perceptibility and contains fewer disturbance factors than landscapes with a higher dose of greenness. Two studies argued that an overly high dose of greenness was more likely to elicit negative impacts on attention and cognitive performance because the landscapes were more difficult to visually comprehend or because they had concealed or messy views[46,58]. Last, studies suggest that landscapes with overly high doses of greenness are more likely to have intense and diverse natural sounds, which may cause too much distraction and stimulation, further depleting directed attention and cognitive performance[59,60]. In conclusion, a moderate dose of greenness may be more beneficial than an overly high or low dose of greenness at restoring directed attention, reducing mental fatigue and promoting cognitive performance.

Studies have also used the quadratic pattern to describe the relationship between dose of greenness and other mental health outcomes, including depression, preference, schizophrenia, self-esteem and social isolation. Overly low and high levels of greenness may cause feelings of social isolation. Compared with a moderate dose of greenness, an overly low or high dose of greenness discourages physical and social activity, which may lead to poorer mental health[61–63]. Some studies show that an overly low or high dose of greenness can cause a sense of boredom, increasing the risk of schizophrenia symptoms, whereas a moderate dose of greenness can excite the users[64–66].

These studies are consistent with our findings and offer explanations that support our hypothesis that the quadratic relationship (inverted-U-shaped curve) may best summarize the relationship between dose of greenness and mental health responses. Mental health benefits may start to decrease when greenness reaches a certain point. A threshold value associated with this point may be considered a highly beneficial dose of greenness.

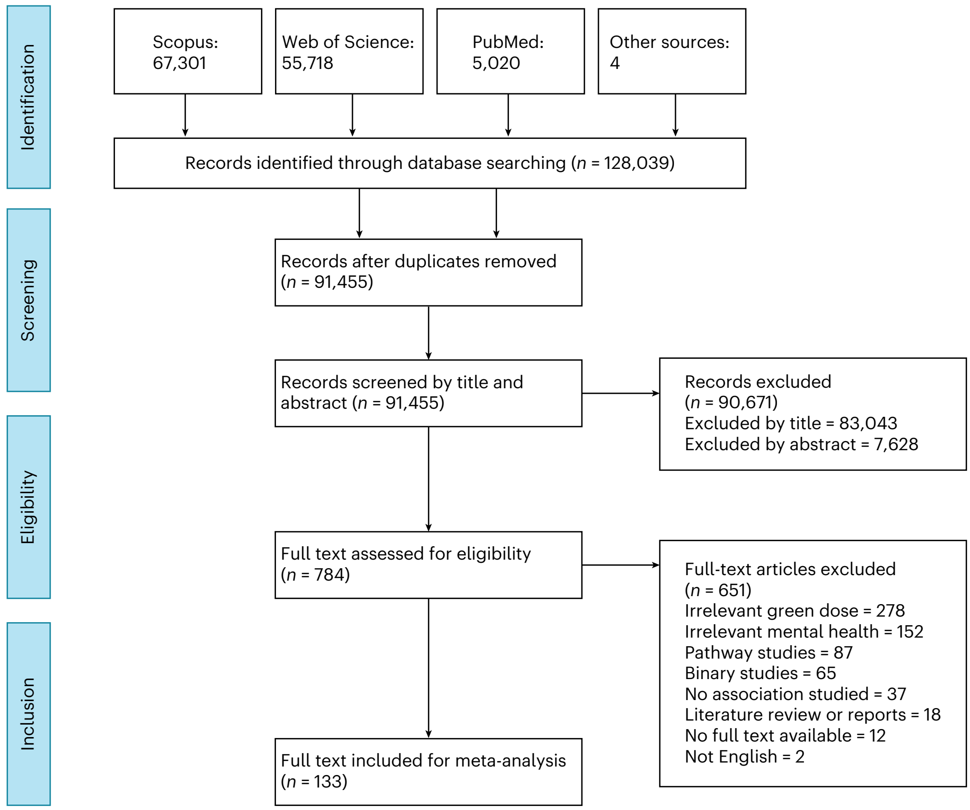

Fig. 4 | PRISMA process and results.

Theoretical contributions and implications of findings

In this study, we collected and synthesized various dose of greenness–mental health response curves. Our statistical analysis identified the inverted-U pattern as the dose–response curve that best describes the relationship between green landscapes and mental health responses. The selected curves included studies with significant or non-significant results, both positive or negative associations. All mental health performances used in the selected curves are the most common variables (Supplementary Fig. 3), and around 90% of them applied individual measurement. Also, all the dose of greenness of the selected curves measured the green intensity. These characteristics ensure that we controlled a decent level of generalizability and increased the reliability of findings.

This study summarizes and statistically analyzes a variety of dose–response curves to identify the quadratic relationship as the one that best describes the relationship between greenness and mental health responses. Moreover, this study identifies threshold values of dose of greenness that are associated with different levels of effect. Using these threshold values, we present recommendations for policymakers and practitioners (Table 2). We synthesized multiple theories and empirical evidence across diverse fields to develop an integrated theoretical framework and corresponding dose–response summary curve.

Why does it matter that the dose–response research can be summarized as an inverted-U pattern with a highly beneficial dose? Findings from numerous studies in different contexts are overwhelming for policymakers, designers and health practitioners. Our findings show how these curves follow a generalized quadratic relationship, which can be useful for policymakers, urban and landscape planners and designers, and public health professionals. Because the identified summary curve is quadratic, this suggests that both underdosing and overdosing are problematic. Instead, a moderate dose of greenness should be adopted as the highly beneficial dose of greenness in policymaking and practice. Second, it is important to identify threshold values of greenness in which mental health benefits are highly worthwhile. Threshold values help policymakers and practitioners provide minimum and maximum doses of greenness to guarantee people's mental health without wasting valuable land and other resources.

Limitations and suggestions for future research

As an initial effort to identify a generalized dose–response curve, this study has several limitations, which serve as opportunities for future research. More evidence should be synthesized to enhance the reliability and validity of the findings reported by this study.

First, we acknowledge the limitation brought by generalization. Although the curves selected for our meta-analysis have mitigated heterogeneity by controlling for the type of green landscape, mental health response and standardizing the dose–response curves, the application of the generalized quadratic pattern still faces the diverse characteristics of green exposure and mental health performance. It simultaneously highlights a critical need for future studies to incorporate curvilinear tests into their models. Despite the issue of heterogeneity, our study, which presents the result of reviewing 87,761 papers, provides a solid foundation that encourages environmental studies to include more robust data in future research to generate a more convincing generalized curve pattern.

Second, due to limited sample size or other reasons, this study only generated statistically reliable findings for dose of greenness, but not for diversity of green landscapes (another type of intensity), duration of greenness exposure and frequency of greenness exposure. This study represents a critical starting point for future investigations into the impact of greenness on mental health. It is necessary to expand the evaluation of greenness to include additional measures of dose of greenness. By doing so, researchers can begin to identify patterns and establish correlations that will enable them to draw more accurate conclusions about the relationship between greenness and mental health.

Third, this study used mean normalization as a means of standardizing the varied mental health responses collected from a diverse range of studies. This approach is a justifiable method considering the heterogenous nature of the mental health responses, with varying levels of severity among the selected studies. In particular, however, this method does not provide a full index of the mental health response size, and alternate measures would be needed to accurately depict the overall magnitude of mental health responses.

Fourth, we do not have a full range of eye-level greenness (0%–100%). Therefore, we do not have the actual data to directly describe the full dose–response curve. As such, we must rely on predictive methods to infer potential trends, rather than direct measurement. To better inform our analysis, it is crucial that future studies adopt a broader range of eye-level greenness and examine the effects of overly high doses. By expanding our experimental parameters, we can more fully elucidate the complex relationships between greenness and outcomes. Moving forward, it will be vital to test our predicted trends and explore the potential for a catastrophic pattern, as theoretical models suggest.

Fifth, this study only considered the four commonly reported dose–response curves (linear, power, inverted-U and catastrophic) that have been used to describe the association between green exposure and mental health in the field of environmental psychology. Other curvilinear functions such as sigmoid, logistic, Gompertz or exponential, which are rarely reported in our field (we found no studies in the literature that reported such curves), were not included in this study. We encourage future studies that work on the association between green exposure and mental health response to consider a more diverse range of curvilinear functions, such as S-shaped curves, to improve the accuracy of the dose–response synthesized results.

Also, this study did not further investigate the greenness intensity based on different landscape types, such as trees, grasslands and shrubs. Previous studies suggest that different green landscapes may affect mental health to different extents[22,56,66]. Thus, we suggest that future studies should synthesize findings from studies for each type of greenness. We also recommend searching for more causal evidence in the future.

Finally, despite including all studies that met our criteria documenting non-significant or negative results from academic journals to avoid overstatement, potential non-significant results may remain unpublished, or exist outside publication realms. The small number of non-significant results (4 studies out of 133) included may still contribute to overstating the findings. As a preliminary attempt to synthesize the curve pattern, we hope our results will encourage future studies to report both significant and non-significant results with detailed data analysis. With increasing evidence of the non-significant or adverse effects of dose exposure on mental health, the results can become more robust.

Methods

We adopted a twofold strategy to answer the questions. First, we conducted a systematic review of empirical studies (1985–2025) to identify both linear and curvilinear dose–response curves describing the relationship between greenness exposure (dose) and mental health (response). Second, we conducted statistical meta-analysis of the curve refitting on each identified dose–response curve and evaluated different curvilinear pattern models.

Data collection: systematic literature review

Strategy for collecting data. We conducted an analysis of dose–response curves reported in published empirical studies. To keep the data collection objective, we followed the principles and procedure of preferred reporting items for systematic reviews and meta-analyses (PRISMA). We searched three major scientific literature databases: Elsevier's Scopus database (from January 1, 1985, to March 30, 2025), Web of Sciences Core Collection (from January 1, 2001, to March 30, 2025) and PubMed (from January 1, 2005, to March 30, 2025). The time frames were determined by the earliest available data from each database. We built the search syntax based on two sides of the dose–response relationship (Supplementary Fig. 1), which are exposure of greenness and mental health. The 'topic' field of the search included at least one keyword from both sides simultaneously in an 'AND' relationship.

Criteria of eligible data. We filtered the dose–response curves from database records using screening and eligibility analyses suggested by the PRISMA guidelines. Two investigators reviewed the titles, keywords, abstracts and full texts for each record independently. Two other investigators were involved when disagreements appeared. To be selected, studies had to meet following six criteria: (1) explored associations between the dose of greenness and mental health responses; (2) assessed dose of greenness with objective metrics (for example, normalized difference vegetation index, tree canopy cover and per capita green area) or subjective metrics (for example, proximity to green space and perception of greenness); (3) measured the mental health responses with objective metrics (for example, brain waves, skin conductance levels and salivary cortisol) or subjective metrics (for example, subjective satisfaction with life and self-reported mental health); (4) had quantitatively measured the relationships between greenness and mental responses without using a binary or pathway study design, and provided data for meta-analysis; (5) had explicitly considered possibilities of both linear and curvilinear relationships in data analysis; (6) written in English. Figure 4 shows the results of the systematic review. Studies were excluded for the following reasons: irrelevant mental health performance variables including social contacts, physical behaviors, general health and esthetics (152 studies); irrelevant dose of greenness variables including perceived sensory dimensions, connectedness with nature, urban–rural classification, parking lots and landscape structures (278 studies); pathway studies (87); binary studies (65); studies without statistical associations (37); or other reasons (32 studies). In all, we identified 133 studies with linear or curvilinear dose–response relationships between greenness and mental health responses.

Quality and risk-of-bias assessments

We evaluated the potential bias and quality of evidence at the study level based on the PRISMA guidelines. We chose the bias evaluation based on the effective public health practice project quality assessment tool and the risk of bias in non-randomized studies—of exposure. These tools have been extensively used in reviews of quantitative studies with diverse methodologies, and are widely applied in reviews in the landscape and urban study field. In our research, we applied the four domains of bias based on the effective public health practice project quality assessment tool and risk of bias in non-randomized studies—of exposure relevant to the greenness and mental health responses, which are (see 'Data availability' for details) (1) study design, (2) exposure assessment, (3) outcome assessment and (4) confounders. We selected a series of rating criteria items for each domain based on effective public health practice project quality assessment tool and risk of bias in non-randomized studies—of exposure, and the weakness identified in previous review articles on the dose of greenness and mental health.

Two investigators independently conducted the bias evaluation, and a third investigator validated the results. For each domain, we assigned 'low (4 points)', 'probably low (3 points)', 'probably high (2 points)' or 'high (1 points)' risk levels based on the criteria (see 'Data availability' for details). We summed up the points for each bias domain as the quality score, and calculated the percentage of total possible quality points for each study. Finally, we classified the studies based on five quality levels: (1) excellent (>81% total possible quality points); (2) good (60%–80%); (3) fair (40%–60%); (4) poor (20%–40%); (5) very poor (<20%). On the basis of our analysis, most of the studies included are of excellent ($n = 19$, 44%) or good ($n = 18$, 42%) quality. Only one study is of poor quality (see 'Data availability' for details). We re-ran the model with only good or excellent quality for the sensitivity test: the results barely changed compared with the curve refitting with full dataset.

Statistical meta-analysis dose–response curve refitting

Curve data extraction. Using the 133 published dose–response articles, two independent investigators extracted the information that related to the dose–response curve refitting; any discordance in data extraction was resolved by discussion with a third investigator. The information includes title, citation, publication year, location (continent–country), study design type (causal–correlational), mental performance types, dose of greenness types (duration, frequency and intensity), environmental presentation methods, dose audit methods, green dose range, optimal green dose, satisfactory green dose, sample size, quality assessment result and other notes. The curves with citations alongside key information are provided in 'Data availability'. Data underlying each reported study were transferred into a common data table for statistical meta-analysis. We excluded papers that could not provide data for the meta-analysis. The full list of extracted data is provided in 'Data availability'. To minimize the heterogeneity issue, we divided the studies based on the dose of greenness types (intensity, frequency and duration) for further meta-analysis. Intensity is the most common greenness type, providing a sufficient sample size to run the curve-refitting statistical analysis (102 studies, 76.69%). Frequency refers to the self-reported frequency of visits to green spaces. Duration refers to the total time of visits to outdoor green spaces. The sample sizes for 'frequency' and 'duration' curves were too small to conduct reliable statistical meta-analysis. The 'duration' studies form only 8.27% of the dataset, and only 16 studies (12.03%) explored 'frequency'.

Thus, we included 69 curves that used 'intensity' as the dose of green landscape in the next curve-refitting step.

Curve data standardization. In the 69 selected curves, the measurement of green intensity included eye-level greenness and top-down greenness (35 eye-level greenness and 34 top-down greenness). Eye-level greenness suggests a visual perception of greenness by a person standing on the ground. Top-down greenness allows the measurement of percentage of green spaces measured from aerial images, and the percentage of each land cover class. Both eye-level and top-down green dose groups contained quantitative and qualitative greenness measures. Quantitative greenness measures identified precise percentages of greenness ranging from 0% to 100%. In qualitative studies, professional researchers examined images and divided them into three to five general levels of greenness. Also, 46 studies used quantitative approaches (66.7%) and 23 used expert classification (see 'Data availability' for details). To standardize the quantitative and qualitative greenness measures for comparison, we acquired the original virtual reality images from the articles and authors and used DeepLab v. 3 software to conduct pixel-level semantic segmentation to recalculate the greenness percentages ourselves.

Mental health performance variables varied widely across the studies by unit, scale and range. To avoid unequal contribution bias, we applied mean normalization of the mental health values with a common range from −1 to 1. The normalized results can be downloaded through the link in 'Data availability'.

$$x' = \frac{x - \mu}{\max(x) - \min(x)},$$

where x is the mental health value set used in a study, μ is the mean of the value set and x' is the normalized mental health value set.

Point collection for standardized curves. The next step of curve refitting applied the decile rank method to evenly collect points from the normalized raw curves. In principle, normalized curves can be represented by 13 points including 9 decile points, a starting point (0%), an ending point (100%), and the minimum and maximum numbers. However, not all studies included a full range of greenness (0%–100%); therefore, the actual point numbers to describe each of the curves varied. For example, if the research only studied a range of 35%–62% greenness, we only included six of the nine decile points, that is, 40%, 50% and 60%. We marked the theoretical points outside the actual curve range as 'NA' in the collection chart. None of the studies had the full range and 13 points to describe the standardized version of its curve and the smallest number of points was four.

Dose–response curve refitting. Finally, we used R Studio v. 10.2 to refit the full-range curve based on the combined standardized model curve dataset. The refitting process involved four steps. The first two steps represent and predict the dose–response relationship, and the last two steps identify the final best-fitting curve pattern.

Step 1 is the scatter plot of all the data points on a two-dimensional plane.

Step 2 applied non-parametric GAM to identify the actual relationship between dependent and independent variables and to predict the pattern with the best fit (linear, power or inverted U).

$$g(E(Y)) = \beta_0 + f_1(x_1) + f_2(x_2) + \ldots + f_m(x_m)$$

Step 3 applied the linear (M1), power (M2) and quadratic (M3) functions to refit alternative curves to the standardized combined data, measuring the P value. None of the 69 selected curves reported the catastrophic pattern results, and the GAM predictions in step 2 did not identify any catastrophic potentials, so we did not include the catastrophic curve refitting in step 3. $\mathrm{M1}: f(x) = ax + b$,

$$\mathrm{M2}: \log_b[b^x] = x,$$

$$\mathrm{M3}: f(x) = ax^2 + bx + c.$$

Step 4 compares the Akaike information criterion and Bayesian information criterion and adjusted R^2 to compare model fit.

Inclusion and ethics statement

All individuals listed as authors in this study have met the criteria for authorship as stipulated by Nature Portfolio journals, given their indispensable contributions to the conception, design and execution of the research. The roles and responsibilities of each collaborator were clearly delineated and agreed on. This study incorporates findings that hold local relevance, which were identified in close collaboration with our regional partners. Our research was neither substantially constrained nor prohibited in the researchers' context and does not lead to stigmatization, incrimination, discrimination or personal risk for the participants involved. Furthermore, we have given due consideration to local and regional research pertinent to our investigation in our citations, thereby ensuring a comprehensive and contextually sensitive representation of the relevant literature.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All datasets supporting the findings of this study are publicly accessible via GitHub at https://github.com/jli1102/Dose.git. The repository comprises five structured databases: (1) Data 1_Eligibility_784 studies; (2) Data 2_Inclusion_133 studies; (3) Data 3_Extraction_69 curves; (4) Data 4_Curve refitting results; (5) Data 5_Risk of Assessment results. Database 1 includes the full list of 784 eligible studies with key information after screening. The 'source' variable indicated the search iteration, with six iterations conducted: sources 0 and 1 searched Web of Science and Scopus from 1985 to 2021; sources 2 and 3 searched the Web of Science and Scopus from 2021 to 2022; sources 4 and 5 included additional studies from citations or alternative sources; source 6 searched the Web of Science and Scopus from 2022 to 2025 and PubMed from 1985 to 2025. Database 2 contains the full list of 133 studies for inclusion with key information, namely, study ID, title, first author, study year, continent, relationship (causal–correlational), mental health type, mental health description, dose type, dose measured range, optimal dose, satisfactory dose and checked (Y/N). Database 3 is the full list of 69 curves with extracted key information for the final curve refitting. The information included curve ID, citation, title, published year, continent, study design type, relationship, DV, DV description, IV presentation methods, dose audit methods, dose description, dose range, optimal dose, satisfactory dose and quality check results. Dataset 4 includes the standardized curve data points and curve-fitting results across four worksheets: eye-level dose curve data points and curve-refitting results; quality-verified eye-level curve-fitting results after risk-of-bias assessment; top-down dose curve data points and curve-refitting results; and quality-verified top-down curve-fitting results after risk-of-bias assessment. Database 5 contains results for the risk-of-bias assessment and quality check. The files have three worksheets: evaluation criteria; quality check results with total points; percent possible points, final quality results and summary chart.

Code availability

The code supporting the findings of this study, especially the R code in the file titled 'curve fitting code', is available via GitHub at https://github.com/jli1102/Dose.git.

References

1. Gong, P. et al. Urbanisation and health in China. *Lancet* **379**, 843–852 (2012).
2. Schumann, G. et al. Precision medicine and global mental health. *Lancet Glob. Health* **7**, e32 (2019).
3. Lai, K. Y., Kumari, S., Gallacher, J., Webster, C. & Sarkar, C. Nexus between residential air pollution and physiological stress is moderated by greenness. *Nat. Cities* **1**, 225–237 (2024).
4. *World Mental Health Report: Transforming Mental Health for All* (WHO, 2022).
5. Bratman, G. N. et al. Nature and mental health: an ecosystem service perspective. *Sci. Adv.* **5**, eaax0903 (2019).
6. Chen, B. et al. Contrasting inequality in human exposure to greenspace between cities of Global North and Global South. *Nat. Commun.* **13**, 4636 (2022).
7. Zhang, C. & Gong, P. Healthy China: from words to actions. *Lancet Public Health* **4**, e438–e439 (2019).
8. Xu, J. et al. Effects of urban living environments on mental health in adults. *Nat. Med.* **29**, 1456–1467 (2023).
9. Sullivan, W. C. & Chang, C.-Y. in *Making Healthy Places: Designing and Building for Health, Well-being, and Sustainability* (ed. Dannenberg, A. L.) 106–116 (Island Press, 2011).
10. Grahn, P. & Stigsdotter, U. A. Landscape planning and stress. *Urban For. Urban Green.* **2**, 1–18 (2003).
11. Beil, K. & Hanes, D. The influence of urban natural and built environments on physiological and psychological measures of stress—a pilot study. *Int. J. Environ. Res. Public Health* **10**, 1250–1267 (2013).
12. Ulrich, R. S. Natural versus urban scenes: some psychophysiological effects. *Environ. Behav.* **13**, 523–556 (1981).
13. Van den Berg, A. E. et al. Green space as a buffer between stressful life events and health. *Soc. Sci. Med.* **70**, 1203–1210 (2010).
14. Kweon, B.-S. et al. Anger and stress: the role of landscape posters in an office setting. *Environ. Behav.* **40**, 355–381 (2008).
15. Cox et al. Doses of nearby nature simultaneously associated with multiple health benefits. *Int. J. Environ. Res. Public Health* **14**, 172 (2017).
16. White, M. P. et al. Associations between green/blue spaces and mental health across 18 countries. *Sci. Rep.* **11**, 8903 (2021).
17. Min, K. B. et al. Parks and green areas and the risk for depression and suicidal indicators. *Int. J. Public Health* **62**, 647–656 (2017).
18. Kaplan, S. The restorative benefits of nature: toward an integrative framework. *J. Environ. Psychol.* **15**, 169–182 (1995).
19. Kaplan, S., Kaplan, R. & Wendt, J. S. Rated preference and complexity for natural and urban visual material. *Percept. Psychophys.* **12**, 354–356 (1972).
20. Ryan, R. L. Exploring the effects of environmental experience on attachment to urban natural areas. *Environ. Behav.* **37**, 3–42 (2005).
21. Matsuoka, R. H. Student performance and high school landscapes: examining the links. *Landsc. Urban Plan.* **97**, 273–282 (2010).
22. Jiang, B. et al. A dose–response curve describing the relationship between tree cover density and landscape preference. *Landsc. Urban Plan.* **139**, 16–25 (2015).
23. Shanahan, D. F. et al. Health benefits from nature experiences depend on dose. *Sci. Rep.* **6**, 28551 (2016).
24. Barton, J. & Pretty, J. What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environ. Sci. Technol.* **44**, 3947–3955 (2010).
25. Jiang, B. *Establishing Dose–Response Curves for the Impact of Urban Forests on Recovery from Acute Stress and Landscape Preference*. PhD thesis, Univ. Illinois (2013).
26. Suppakittpaisarn, P. et al. Does density of green infrastructure predict preference? *Urban For. Urban Green.* **40**, 236–244 (2019).
27. Jiang, B. et al. Moderate is optimal: a simulated driving experiment reveals freeway landscape matters for driving performance. *Urban For. Urban Green.* **58**, 126976 (2021).
28. Xiao, X. et al. On the use of log-transformation vs. nonlinear regression for analyzing biological power laws. *Ecology* **92**, 1887–1894 (2011).
29. Stevens, J. C. & Marks, L. E. Stevens power law in vision: exponents, intercepts, and thresholds. *Fechner Day* **99**, 82–87 (1999).
30. Cook, R. & Calabrese, E. J. The importance of hormesis to public health. *Environ. Health Perspect.* **114**, 1631–1635 (2006).
31. Calabrese, E. J. & Baldwin, L. A. Hormesis: U-shaped dose responses and their centrality in toxicology. *Trends Pharmacol. Sci.* **22**, 285–291 (2001).
32. Davis, J. M. & Svendsgaard, D. J. U-shaped dose-response curves: their occurrence and implications for risk assessment. *J. Toxicol. Environ. Health A* **30**, 71–83 (1990).
33. Hardy, L. Testing the predictions of the cusp catastrophe model of anxiety and performance. *Sport Psychol.* **10**, 140–156 (1996).
34. Frumkin, H. Healthy places: exploring the evidence. *Am. J. Public Health* **93**, 1451–1456 (2003).
35. Kaplan, R. Wilderness perception and psychological benefits: an analysis of a continuing program. *Leis. Sci.* **6**, 271–290 (1984).
36. Kuo, M. How might contact with nature promote human health? Promising mechanisms and a possible central pathway. *Front. Psychol.* **6**, 1093 (2015).
37. Kim, P. et al. The plasticity of human maternal brain: longitudinal changes in brain anatomy during the early postpartum period. *Behav. Neurosci.* **124**, 695 (2010).
38. Chang et al. The human posterior cingulate and the stress-response benefits of viewing green urban landscapes. *NeuroImage* **226**, 117555 (2021).

39. Li, D. et al. Moving beyond the neighborhood: daily exposure to nature and adolescents' mood. *Landsc. Urban Plan.* **173**, 33–43 (2018).
40. Li, D. & Sullivan, W. C. Impact of views to school landscapes on recovery from stress and mental fatigue. *Landsc. Urban Plan.* **148**, 149–158 (2016).
41. Ulrich, R. S. et al. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* **11**, 201–230 (1991).
42. Wang, X. et al. Stress recovery and restorative effects of viewing different urban park scenes in Shanghai, China. *Urban For. Urban Green.* **15**, 112–122 (2016).
43. Jiang, B., Chang, C. Y. & Sullivan, W. C. A dose of nature: tree cover, stress reduction, and gender differences. *Landsc. Urban Plan.* **132**, 26–36 (2014).
44. Shanahan, D. F. et al. The health benefits of urban nature: how much do we need? *BioScience* **65**, 476–485 (2015).
45. Markevych, I. et al. Exploring pathways linking greenspace to health: theoretical and methodological guidance. *Environ. Res.* **158**, 301–317 (2017).
46. Chiang, Y. C., Li, D. & Jane, H. A. Wild or tended nature? The effects of landscape location and vegetation density on physiological and psychological responses. *Landsc. Urban Plan.* **167**, 72–83 (2017).
47. Jiang, B. et al. Impacts of nature and built acoustic-visual environments on human's multidimensional mood states: a cross-continent experiment. *J. Environ. Psychol.* **77**, 101659 (2021).
48. Jansson, M. et al. Perceived personal safety in relation to urban woodland vegetation—a review. *Urban For. Urban Green.* **12**, 127–133 (2013).
49. Olszewska-Guizzo, A. et al. Window view and the brain: effects of floor level and green cover on the alpha and beta rhythms in a passive exposure EEG experiment. *Int. J. Environ. Res. Public Health* **15**, 2358 (2018).
50. Maas, J. et al. Is green space in the living environment associated with people's feelings of social safety? *Environ. Plan A* **41**, 1763–1777 (2009).
51. Xu, J. et al. Global urbanicity is associated with brain and behaviour in young people. *Nat. Hum. Behav.* **6**, 279–293 (2022).
52. Jiang, B., Schmillen, R. & Sullivan, W. C. How to waste a break: using portable electronic devices substantially counteracts attention enhancement effects of green spaces. *Environ. Behav.* **51**, 1133–1160 (2019).
53. Hartig, T. et al. Tracking restoration in natural and urban field settings. *J. Environ. Psychol.* **23**, 109–123 (2003).
54. Kuo, F. E. & Taylor, A. A potential natural treatment for attention-deficit/hyperactivity disorder: evidence from a national study. *Am. J. Public Health* **94**, 1580–1586 (2004).
55. Tennessen, C. M. & Cimprich, B. Views to nature: effects on attention. *J. Environ. Psychol.* **15**, 77–85 (1995).
56. Jiang, B. et al. Perceived green at speed: a simulated driving experiment raises new questions for attention restoration theory and stress reduction theory. *Environ. Behav.* **53**, 296–335 (2021).
57. Sweller, J. Cognitive load during problem solving: effects on learning. *Cogn. Sci.* **12**, 257–285 (1988).
58. Wallner, P., Kundi, M., Arnberger, A., Eder, R., Allex, B., Weitensfelder, L. & Hutter, H. P. Reloading pupils' batteries: impact of green spaces on cognition and wellbeing. *Int. J. Environ. Res. Public Health* **15**, 1205 (2018).
59. Jahncke, H., Eriksson, K. & Naula, S. The effects of auditive and visual settings on perceived restoration likelihood. *Noise Health* **17**, 1–10 (2015).
60. Preis, A. et al. Audio-visual interactions in environment assessment. *Sci. Total Environ.* **523**, 191–200 (2015).
61. Astell-Burt, T., Mitchell, R. & Hartig, T. The association between green space and mental health varies across the lifecourse: a longitudinal study. *J. Epidemiol. Community Health* **68**, 578–583 (2014).
62. Bertram, C. & Rehdanz, K. The role of urban green space for human well-being. *Ecol. Econ.* **120**, 139–152 (2015).
63. Krekel, C., Kolbe, J. & Wüstemann, H. The greener, the happier? The effect of urban land use on residential well-being. *Ecol. Econ.* **121**, 117–127 (2016).
64. Fong, K. C., Hart, J. E. & James, P. A review of epidemiologic studies on greenness and health: updated literature through 2017. *Curr. Environ. Health Rep.* **5**, 77–87 (2018).
65. Hartig, T. et al. Nature and health. *Annu. Rev. Public Health* **35**, 207–228 (2014).
66. Van den Berg, M. et al. Health benefits of green spaces in the living environment: a systematic review of epidemiological studies. *Urban For. Urban Green.* **14**, 806–816 (2015).

Acknowledgements

We are thankful for financial support from the University Grants Committee (UGC) of Hong Kong SAR, General Research Fund (GRF) number 17606621 (to B.J.), the European Union-funded Horizon Europe project 'environMENTAL' (101057429), co-funding by UK Research and Innovation under the UK Government's Horizon Europe funding guarantee (10041392 and 10038599), the National Key R&D Program of Ministry of Science and Technology of China (MOST 2023YFE0199700) and NSFC grant (82150710554) (to G.S.). The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

Author contributions

B.J. conceptualized the study. B.J., J.L. and X.L. contributed to the research design. B.J., J.L., P.S. and X.L. contributed to the collection and treatment of raw data. B.J., J.L., P.S. and X.L. contributed to the data analysis. B.J. and J.L. contributed to the write-up of the first draft. B.J., J.L., P.G., G.S., C.W. and P.S. contributed to the review and revision.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44284-025-00285-z.

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Peer review information *Nature Cities* thanks Fu Li, Masashi Soga and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Last updated by author(s): Jun 10, 2025

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☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used for data collection.
Data analysis	For the quality and risk of bias assessment, We chose the bias evaluation based on the Effective Public Health Practice Project Quality Assessment Tool (EPHPP) and the Risk of Bias in Non-randomized Studies - of Exposure (ROBINS-E). We uploaded the evaluation criteria based on EPHPP and ROBINS-E to the GitHub repository at: https://github.com/jli1102/Dose.git. The uploaded files had three worksheets: evaluation criteria, the quality check results with total points, percent possible points, final quality results, and the summary chart. For the dose-response curve refitting, we used R studio 10.2 to refit the full range curve based on the combined standardized model curves dataset. The R code has been organized into a file titled "curve fitting code" and deposited in the repository, which can be accessed at: https://github.com/jli1102/Dose.git

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Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All datasets supporting the findings of this study are publicly accessible via GitHub repository at: https://github.com/jli1102/Dose.git

The repository comprises five structured datasets: 1/ Data 1_Eligibility_784 studies; 2/ Data 2_Inclusion_133 studies; 3/ Data 3_Extraction_69 curves; 4/ Data 4_Curve refitting results; 5/ Data 5_Risk of Assessment results.

Database 1 included the full list of 784 eligible studies with key information after screening. The "source" variable indicated the search iteration, with six iterations conducted: Source 0-1 searched Web of Science and Scopus from 1985 to 2021; Source 2-3 searched the Web of Science and Scopus from 2021 to 2022; Source 4-5 included the additional studies from citations or alternative sources; Source 6 searched the Web of Science and Scopus from 2022 to 2025, and the PubMed from 1985 to 2025.

Database 2 contained the full list of 133 studies for inclusion with key information, which were study ID, title, first author, study year, continent, relationship (causal/ correlational), mental health type, mental health description, dose type, dose measured range, optimal dose, satisfactory dose, checked (Y/N).

Database 3 was the full list of 69 curves with extracted key information for the final curve-refitting. The information included Curve ID, citation, title, published year, continent. study design type, relationship, DV, DV description, IV presentation methods, dose audit methods, dose description, dose range, optimal dose, satisfactory dose, and quality check results.

Dataset 4 included the standardized curve data points and curve-fitting results across four worksheets: Eye-level dose curve data points and curve refitting results; quality-verified eye-level curve fitting results after Risk of Bias assessment; Top-down dose curve data points and curve refitting results; quality-verified top-down curve fitting results after Risk of Bias assessment.

Database 5 contained the results for the Risk of Bias assessment and quality check. The files had three worksheets: evaluation criteria, the quality check results with total points, percent possible points, final quality results, and the summary chart.

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This study aimed to identify a curvilinear pattern to describe the dose-response relationship between green landscape exposure and mental health responses. We adopted a two-fold strategy to for the study design. First, we conducted a systematic review of empirical studies (1985-2022) to identify both linear and curvilinear dose-response curves describing the relationship between green landscape exposure (dose) and mental health (response), and we included 69 curves in the next curve refitting step. We only included the studies that quantitatively measured relationships between greenness and mental responses. Second, we conducted statistical analysis of the curve refitting on each identified non-linear dose-response curve and evaluated different curvilinear pattern

models. We found that the inverted-U shape curve is the best pattern to summarize patterns of all published curves about greenness. Further, we found quadratic law is the model with the best fit, appropriately summarizing all available dose-response curves between greenness and mental health responses.

Research sample	We conducted an analysis of dose-response curves reported in published empirical studies. To keep the data collection objective, we followed the principles and procedure of Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA). We searched three major scientific literature databases: Elsevier's Scopus database (Jan. 1st, 1985-March. 30th, 2025), Web of Sciences Core Collection (Jan. 1st, 2001- March. 30th, 2025), and PubMed (Jan. 1st, 2005- March. 30th, 2025). Time frames were determined by the earliest available data from each database. Time frames were determined by the earliest available data from each database. Our research samples are representative because we included all existing studies on the association between greenness exposure and mental health responses with the PRISMA procedure. The three databases we selected are well-acknowledged, and we have extended the time frame to the most current 2025.
Sampling strategy	We included all the published empirical studies reporting dose of nature – mental health response in the three major scientific literature databases with the PRISMA procedure. We filtered the dose-response curves from database records using a screening and eligibility analyses suggested by Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. Two investigators reviewed titles, keywords, abstracts, and full texts for each record independently. Two other investigators were involved when disagreements appeared. To be selected, studies had to meet following six criteria: (I) explored associations between dose of greenness and mental health responses; (II) assessed dose of greenness with objective metrics (e.g., NDVI, tree canopy cover, per capita green area) or subjective metrics (e.g., proximity to green space, perception of greenness); (III) measured the mental health responses with objective metrics (e.g., brain waves (EEG), skin conductance levels (SCL), salivary cortisol) or subjective metrics (e.g., subjective satisfaction with life, self-reported mental health); (IV) had quantitatively measured relationships between greenness and mental responses without using a binary or pathway study design, and provided data for meta-analysis; (V) had explicitly considered possibilities of both linear and curvilinear relationships in data analysis; (VI) written in English.
Data collection	Using the 133 the published dose-response articles, two independent investigators extracted the information that related to the dose-response curve refitting, any discordance in data extraction was resolved by discussion with a third investigator. The information includes title, citation, publication year, location (continent/ country), study design type (casual/ correlational), mental performance types, dose of greenness types (duration, frequency, and intensity), environmental presentation methods, dose audit methods, green dose range, optimal green dose, satisfactory green dose, sample size, quality assessment result, and other notes. The curves with citations alongside key information can be found in Data Availability Statement. Data underlying each reported studies was transferred into a common data table for meta statistical analysis. We excluded the paper that could not provide the data for the meta-analysis.
Timing	We searched three major scientific literature databases: Elsevier's Scopus database (Jan. 1st, 1985-March. 30th, 2025), Web of Sciences Core Collection (Jan. 1st, 2001- March. 30th, 2025), and PubMed (Jan. 1st, 2005- March. 30th, 2025). Time frames were determined by the earliest available data from each database.
Data exclusions	To be selected, studies had to meet following six criteria: (I) explored associations between dose of greenness and mental health responses; (II) assessed dose of greenness with objective metrics (e.g., NDVI, tree canopy cover, per capita green area) or subjective metrics (e.g., proximity to green space, perception of greenness); (III) measured the mental health responses with objective metrics (e.g., brain waves (EEG), skin conductance levels (SCL), salivary cortisol) or subjective metrics (e.g., subjective satisfaction with life, self-reported mental health); (IV) had quantitatively measured relationships between greenness and mental responses without using a binary or pathway study design, and provided data for meta-analysis; (V) had explicitly considered possibilities of both linear and curvilinear relationships in data analysis; (VI) written in English. Studies were excluded for the following reasons: Irrelevant mental health performance variables including social contacts, physical behaviours, general health, and aesthetics (152 studies); Irrelevant dose of greenness variables including perceived sensory dimensions (PSDs), connectedness with nature, urban–rural classification, parking lots and landscape structures (278 studies); Pathway studies (87); Binary studies (65); Studies without statistical associations (37); or other reasons (32 studies). In all, we identified 133 studies with a linear or curvilinear dose-response relationships between greenness and mental health responses.
Non-participation	We did not include participants in the study.
Randomization	Randomization is not relevant to our study, as we applied the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) to collect data on dose-response relationships between nature exposure and mental health outcomes, it did not involve direct allocation of participants to groups or manipulation of variables.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging