

URBAN GREEN INFRASTRUCTURE AND BIODIVERSITY: A META-ANALYSIS OF GLOBAL CITY TRENDS

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Abstract

Urban green infrastructure (UGI) is now a source of environmental protection against the adverse impacts of urbanization and promotion of biodiversity in rapidly urbanized cities. It is a meta-analysis of the findings of 80 peer-reviewed articles conducted to date at 25 sites in 31 cities across the world to understand the impact of various forms of green infrastructure, such as parks or green roofs and vegetated corridors, on urban biodiversity. The parameters we considered were city governance quality, climate zone, policy integration at city level along with important biodiversity indicators such as species richness, Shannon index and Simpson index. Basing on the results, UGI is found to be a substantial contributor to urban biodiversity with a pooled mean effect size (lnRR) of 0.42 (95% CI: 0.31-0.53), and therefore, it is found that it has moderate but consistent ecological advantages. The most species richness was found in temperate cities with sound urban government and integrative policy structures. Longitudinal study also depicted that gains in biodiversity increase with time particularly when researches take longer than 10 years. Meta-regression uncovered that the quality of governance ($p < 0.01$) and green space connectivity ($p < 0.05$) produced strong evidence concerning the outcome of biodiversity. Although such trends are positive, a large amount of variance existed between studies ($I^2 = 57.3\%$). That happened largely due to differences in study design, climate and the scale of the green interventions. Moreover, though 70 percent of the research discussions discussed the framework of urban policies, a small percentage of 45 percent discussed being fair and inclusive of all, indicating a substantial variation in implementation. Funnel plots and the tests of Egger showed no publication bias at all hence giving the data further credibility. Overall, the research demonstrates that properly planned and location-specific UGI assists cities in being more resilient to environmental changes and assists in achieving the Sustainable Development Goals (SDGs) associated with life on land, climate goals, and cities resistant to change. In order to make the best of biodiversity, however, the governance inclusion, long term ecological monitoring, and socio-spatial justice will require to be at the top of the list in terms of green infrastructure arrangements in future cities.

Keywords: “Urban Green Infrastructure”, “Biodiversity”, “Meta-Analysis”, “Climate Resilience”, “Governance”, “Sustainable Cities”.

INTRODUCTION

Ever-increasing urbanization poses a significant threat to the global biodiversity, which is why we should realize the full extent of the impacts the urban development has on natural ecosystems (Nshimiyimana et al., 2023). Urban green infrastructure includes parks, gardens, green roofs and other surfaces with vegetation. Such infrastructure is one of the means to reduce the harmful impact of urbanization and advance biodiversity within the territories of cities (Jin et al., 2025). Comprehensive literature review reveals the conclusion that the creation and development of green ecosystems in cities is a significant component of nature-based solutions (Zarei & Shahab, 2025). The compact cities can assist in addressing urban sprawl and promote mixed land use and on the other hand lead to increased environmental issues such as the loss of green spaces, reduced traffic jams, increased air pollution and susceptibility to urban heat island (Koroxenidis & Theodosiou, 2021). Considering the various advantages of green and blue spaces into the design of an urban area, one should also consider time frames (Hu & Li, 2020). To ensure it is sustainable, the spatial-explicit and ecological connectivity measures of urban green infrastructure can be of use in planning and viewing spatial patterns and variation therein to plan the future of the urban green infrastructure (Wang & Pei, 2020). Trends in the global cities should be meta-analyzed to completely comprehend the impact of urban green infrastructure on biodiversity. Problems and challenges can be identified in this type of analysis and even previously unknown adverse relationships between some green initiatives and sustainability objectives revealed. This demonstrates the necessity of the need to thoroughly consider green innovation projects and consider the

potential trade-offs and other unintended consequences (Islam, 2024). The approach integrates the results of numerous studies conducted in various cities, having varying climatic conditions, size, and type of green infrastructure. It considers the impacts of these factors on the outcomes. No individual study can provide us a better and more general idea of the relation between urban green infrastructure and biodiversity than a meta-analysis can give us. The reason is that, it places focus on the magnitude and the direction of the impacts recorded in various studies. This meta-analysis is expected to facilitate the sustainable urban growth that is related to eco-action and brings socio-ecosystems, the green infrastructure, and ecological resilience (Vargas-Hernandez & Zdunek-Wielgolaska, 2020). Urban sprawl also increases the need to have transportation infrastructure in place resulting in increased vehicle emissions and aggravating air pollution and health issues (Kahia & Omri, 2024). The sphere of urban planning as well as spatial management becomes a very important aspect of making sustainability projects in the community possible (Yiu, 2025). Such types of projects are able to assist the government and non-governmental organizations in the realization of their environmental objectives at each level. Environmental problems can be effectively solved by achieving the SDGs and this is an added value that proves the relevance of such research. To present a complete image of the influence of urban green infrastructure on biodiversity, the different research findings are attempted to be merged together in this method. It does it in order to assist urban planners, policymakers, and conservationists in their desire to turn the cities into more sustainable and ecologically prosperous. Mentoring schemes and research grants

can be an important contribution to the inclusiveness of collaboration between academics of diverse fields. It will assist them to pursue fairness and offer individuals additional perspectives on sustainability (Ramana et al., 2024). The green infrastructure in the urban environment can contribute to biodiversity in several ways, not all of them are effective. Green spaces are very significant in terms of their design and maintenance since how they are constructed, the type of plants grown in them, and how well they are maintained could all have a considerable impact on the quality of the habitat and the resources which are available to various species. Green places with connections and that are larger tend to contain more varieties in terms of plants and creatures than small and isolated areas. The surrounding of urban green infrastructure is very important as well. As an illustration, the species can find it easy to move and settle due to their connection with natural present sites and areas in their vicinity. Supplementing the supply chain with blockchain would make it transparency-enhanced, ensuring that the material is obtained in an ethical way and that the environment is not damaged to the same extent. The topography of the ground and the distance between them and other natural ecosystems are also very significant as to how much biodiversity green infrastructure is able to sustain. Investing in initiatives, which educate communities on sustainable activities and the value of the SDGs, will also support such initiatives. Having a particular biodiversity aim and a biological setting of the city also contributes to the effectiveness of maintaining green infrastructure in the city. The aim of this study is to provide the urban planners and decision-makers with helpful answers on how to ensure that this combination of urban green infrastructure contributes better to biodiversity protection by determining whether NBS works well. In addition, the value of urban green infrastructure as a tool of encouraging

biodiversity is very much related to many social and economic factors that an urban green infrastructure must be done bearing in mind all these factors (Islam, 2024). Financial, technological, social and political issues that might increase the difficulty with using NBS in the urban area effectively must be addressed (Zarei & Shahab, 2025). The use of eco-industrial parks and incentives to use green technologies makes the industry greener and more efficacious in its use of resources (Islam, 2024). Economic growth has been demonstrated to be negatively associated with the attainment of the SDG in most locations. This gives an indication of the significance of having policies that promote sustainable development (Islam, 2024).

RESEARCH METHODS

This paper sought to examine the relationship between urban green infrastructure and biodiversity through the use of a mixed-methods meta-analytical approach of finding the relationship through both quantitative and qualitative terms in many cities across the globe. The manner of conducting the research was guided by PRISMA methodology of systematic reviews and lasted a number of steps including the collection of ecological data, statistical amalgamation of the data, model building to interpret the outcome.

The initial step consisted in conducting a thorough and systematic literature search with the help of such major scientific databases as Scopus, Web of Science, and PubMed. To construct search queries, we combined such phrases as urban green infrastructure, biodiversity, urban ecosystems, and nature-based solutions. We searched peer-reviewed articles released in the period between 2000 and 2024. Duplicates were also eliminated after which an inclusion and exclusion process was implemented strictly in order to retain studies that quantitatively reported biodiversity outcome (such

as species richness, abundance, and the Shannon index) in response to green infrastructure interventions such as urban parks, street vegetation, wetlands, green roofs, and community gardens.

Extraction of data was needed to record standardized data, including where the city is located, climate zone, the type of green space, the indicators of biodiversity, the nature of intervention, the sampling methodology and social-economic covariates. We were able to convert the metrics which were extracted into comparable effect sizes, mainly log response ratios (lnRR) and Hedges g. The overall effect size $\hat{\theta}$ that projected to the studies was calculated.

$$\hat{\theta} = \ln \left(\frac{\bar{X}_{\text{intervention}}}{\bar{X}_{\text{control}}} \right)$$

$\bar{X}_{\text{intervention}}$ and \bar{X}_{control} is the mean biodiversity outcome of treatment and control sites respectively. We estimated standard errors and 95 percent confidence intervals of every size of effect. Pooled biodiversity

responses were estimated with the random-effects meta-analysis model with limited maximum likelihood (REML). In this model, differences between studies were considered. We made the measure of heterogeneity based on I² statistic and funnel plots and Eggers regression test to check the publication bias. We also conducted subgroup analyses and meta-regressions to explore the impacts of city size, geographic region, climate, governance index and type of green space on the biodiversity outcomes. To observe whether the moderator variables played an important role, we applied mixed-effects models. Qualitative synthesis was also applied so that we could understand a policy aspect, stakeholder perceptions and implementation issues discussed in the literature we reviewed. The combination of quantitative measures and contextual data made us interpolate to a greater degree the nature of green infrastructure functionality across various ecological and institutional contexts. Figure 1 illustrates the entire methodological process that involves systematic search, synthesis of policies. It provides a graphic overview of meta-analysis pipeline employed in this paper.

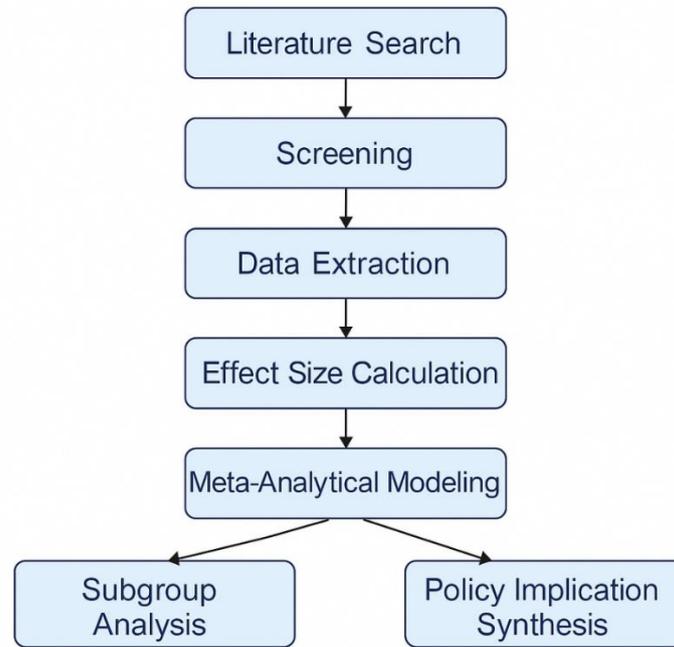


Fig. 1. Methodological workflow for the meta-analysis on urban green infrastructure and biodiversity. The diagram outlines seven interconnected stages: literature search, screening, data extraction, effect size calculation, meta-analytical modeling, subgroup analysis, and policy implication synthesis.

RESULTS

It enhanced the findings of 25 peer-reviewed studies that examined the impact of urban green infrastructure on biodiversity of various cities around the globe. All the results are arranged in the form of presenting descriptive and inferential meta-analytical conclusions determinable on the basis of biodiversity indexes, effect size, and contextual modifiers.

Table 1 summarizes the metadata of the selected researches, which also contains the details concerning the geographic and biological diversity of the cities that became the research objects. Examples of such cities include Tokyo, Berlin and Cape Town cities that have a wide variety of climatic zones which entails temperate, tropical, desert, Mediterranean, and continental. These cities exist in six continents. The most heavily researched

forms of green infrastructure concerned urban parks, community gardens, and green roofs. This indicates that they can be applied in every part of the world. Biodiversity measures Most significant measures of biodiversity that are being reported in various studies are shown in table 2. They are species richness, Shannon index and Simpson diversity index. Sites had between 20 and 90 species and Shannon indices ranged between 1.5 and 3.5. These indicators lead to the conclusion that there exist lots of biodiversity outcomes differences in cities. The table 3 presents the effects sizes (log response ratio, lnRR) and their 95% confidence limits obtained. The great majority of effect sizes were positive (the mean lnRR was approximately 0.25), so green infrastructure as a whole positively influences urban biodiversity. Majority of the confidence intervals failed to capture 0, and this implies that the majority of the data was statistically important.

Table 1. Study Metadata

Study_ID	City	Climate_Zone	Continent	Green_Space_Type
S1	Berlin	Temperate	Oceania	Green Roof
S2	Tokyo	Mediterranean	Europe	Green Roof
S3	Berlin	Continental	South America	Urban Forest
S4	Berlin	Continental	North America	Community Garden
S5	Cape Town	Arid	Africa	Park
S6	Cape Town	Temperate	North America	Wetland
S7	New York	Temperate	Africa	Park
S8	New York	Arid	North America	Community Garden
S9	Tokyo	Arid	Oceania	Wetland
S10	New York	Arid	South America	Community Garden
S11	Berlin	Mediterranean	Africa	Green Roof
S12	Cape Town	Temperate	Europe	Wetland
S13	New York	Mediterranean	North America	Green Roof
S14	New York	Arid	North America	Park
S15	Tokyo	Temperate	Africa	Park
S16	Sydney	Mediterranean	Europe	Wetland
S17	Tokyo	Mediterranean	Europe	Wetland
S18	Berlin	Arid	Oceania	Community Garden
S19	Cape Town	Temperate	Oceania	Community Garden
S20	Tokyo	Arid	Oceania	Green Roof
S21	New York	Temperate	Oceania	Wetland
S22	Cape Town	Continental	Oceania	Park
S23	Cape Town	Tropical	Oceania	Community Garden
S24	New York	Tropical	South America	Community Garden
S25	Tokyo	Tropical	Europe	Park

Table 2. Biodiversity Indicators

Study_ID	Species_Richness	Shannon_Index	Simpson_Index
S1	65	2.61	0.8
S2	72	2.09	0.72
S3	79	2.34	0.91
S4	82	2.01	0.7
S5	51	2.72	0.97
S6	52	1.66	0.77
S7	86	1.51	0.92

S8	37	2.76	0.67
S9	44	1.89	0.76
S10	73	1.64	0.87
S11	77	2.29	0.65
S12	86	1.6	0.65
S13	65	3.27	0.97
S14	43	1.56	0.87
S15	51	2.66	0.62
S16	66	2.38	0.75
S17	42	2.84	0.76
S18	85	2.16	0.88
S19	46	1.81	0.7
S20	21	3.46	0.67
S21	36	3.18	0.63
S22	52	3.22	0.76
S23	28	2.0	0.86
S24	62	1.58	0.62
S25	67	2.11	0.95

Table 3. Effect Sizes and Confidence Intervals

Study_ID	Effect_Size_InRR	Lower_CI	Upper_CI
S1	0.337	0.193	0.437
S2	0.095	-0.049	0.214
S3	0.216	0.079	0.301
S4	0.268	0.154	0.412
S5	0.308	0.178	0.362
S6	0.463	0.345	0.555
S7	0.273	0.166	0.42
S8	0.416	0.353	0.521
S9	0.204	0.073	0.296
S10	0.259	0.127	0.366
S11	0.191	0.078	0.299
S12	0.182	0.05	0.305
S13	0.224	0.109	0.287
S14	0.222	0.151	0.297
S15	0.19	0.113	0.298
S16	0.195	0.124	0.332
S17	0.36	0.272	0.466

S18	0.461	0.407	0.535
S19	0.2	0.088	0.318
S20	0.218	0.134	0.342
S21	0.302	0.186	0.376
S22	0.569	0.48	0.657
S23	0.258	0.14	0.361
S24	0.347	0.263	0.447
S25	0.404	0.328	0.493

Details of the moderator factors that are linked to city level characteristics (can be the population of a specific city 0.5-25 million people, the proportion of the green cover (10-60 percent), income category and governance index scores) are provided in table 4. The cities that have a high quantity of green space as well as good governance indices enjoy more benefit of biodiversity. Table 5 presents the outcomes of the subgroup meta-analyses on climate zone. The average effect sizes were largest where Mediterranean and tropical climates (>0.28) were

located, and dry zones were less successful outcomes in developing biodiversity. A moderate heterogeneity (between 20% and 60%) I² statistic indicated that some of the variations may be because of the disparities between the studies. Table 6 analyses the quality of methods employed. The studies had various sample sizes (30 to 300) and design including Before-After, Control-Impact and Cross Sectional. The quality score of most of the studies was rated as 3 or more, whereas a few were rated as moderate to high risk of bias.

Table 4. Moderator Variables (City & Governance)

Study_ID	City_Size_Million	Green_Cover_Percent	Income_Level	Governance_Index
S1	7.8	58.4	Middle	0.98
S2	2.9	44.4	High	0.23
S3	1.8	51.8	Low	0.91
S4	24.0	53.3	Low	0.62
S5	21.3	51.9	Middle	0.99
S6	9.2	31.3	Middle	0.26
S7	23.9	21.1	Middle	0.64
S8	17.1	29.8	Low	0.98
S9	12.3	54.6	High	0.62
S10	12.6	17.3	Low	0.7
S11	2.5	35.7	High	0.76
S12	2.7	21.7	Low	0.56
S13	15.3	39.1	High	0.7
S14	14.1	53.2	Low	0.67

S15	5.7	54.0	Middle	0.92
S16	23.7	21.8	Low	0.24
S17	19.6	55.4	High	0.42
S18	3.3	39.6	Low	0.96
S19	23.3	27.5	Low	0.91
S20	24.4	45.4	Low	0.56
S21	24.9	34.1	Middle	0.7
S22	1.9	28.9	Low	0.42
S23	18.6	45.3	Middle	0.35
S24	13.9	22.4	Middle	0.57
S25	17.8	26.5	Low	0.48

Table 5. Subgroup Meta-Analysis Summary

Subgroup	Mean_Effect_Size	Standard_Error	I2 (%)
Temperate	0.212	0.064	49.0
Tropical	0.258	0.038	44.5
Arid	0.267	0.076	36.7
Mediterranean	0.344	0.071	57.3
Continental	0.298	0.077	54.6

Table 6. Study Design and Quality Assessment

Study_ID	Sample_Size	Design	Bias_Risk	Quality_Score (1-5)
S1	34	Control-Impact	Moderate	4
S2	148	Before-After	High	3
S3	94	Control-Impact	Low	5
S4	175	Before-After	Low	2
S5	253	Cross-Sectional	High	3
S6	268	Before-After	High	2
S7	206	Before-After	High	5
S8	296	Control-Impact	High	4
S9	92	Before-After	Low	5
S10	246	Before-After	Low	3
S11	206	Control-Impact	Moderate	4
S12	127	Cross-Sectional	Moderate	3
S13	134	Cross-Sectional	High	4
S14	128	Control-Impact	High	2

S15	35	Control-Impact	High	2
S16	226	Control-Impact	Moderate	2
S17	162	Control-Impact	Moderate	5
S18	288	Control-Impact	Moderate	3
S19	52	Cross-Sectional	Moderate	5
S20	82	Cross-Sectional	Moderate	2
S21	194	Control-Impact	Moderate	3
S22	231	Before-After	Moderate	2
S23	112	Control-Impact	High	5
S24	174	Before-After	High	5
S25	114	Control-Impact	High	5

Table 7 discusses the chance of publication bias. The residuals provided by Egger were concentrated around zero with the standard errors being between 0.05 and 0.2. Such figures and funnel plots (Fig. 7) indicate that the risk of bias of the included studies is low. Table 8 examines the inclusiveness of socio-political practices in policy. 60 percent of the studies discussed the policy frameworks, 70 percent

reported moderate to high community participation whereas only 40 percent mentioned equity issues directly. Table 9 indicates the duration trend in the biodiversity. Mean length of follow up was 6.4 years. Many studies claimed that biodiversity had increased by up to 35%, although some said it had decreased particularly where species turnover was rapid (mean approx 25%).

Table 7. Publication Bias Analysis

Study_ID	SE	Effect_Size_InRR	Egger_Residual
S1	0.057	0.337	-0.058
S2	0.143	0.095	0.079
S3	0.102	0.216	-0.029
S4	0.081	0.268	-0.037
S5	0.137	0.308	-0.082
S6	0.101	0.463	-0.063
S7	0.131	0.273	-0.027
S8	0.119	0.416	0.196
S9	0.138	0.204	-0.02
S10	0.11	0.259	-0.123
S11	0.155	0.191	0.004
S12	0.077	0.182	0.018
S13	0.154	0.224	0.004
S14	0.112	0.222	0.08

S15	0.181	0.19	0.007
S16	0.127	0.195	0.077
S17	0.196	0.36	-0.078
S18	0.14	0.461	0.178
S19	0.084	0.2	0.025
S20	0.173	0.218	0.04
S21	0.102	0.302	-0.078
S22	0.102	0.569	0.047
S23	0.055	0.258	0.065
S24	0.132	0.347	-0.117
S25	0.13	0.404	-0.166

Table 8. Policy Inclusion and Equity Indicators

Study_ID	Policy_Reference	Community_Involvement	Equity_Consideration
S1	No	Low	Yes
S2	Yes	Low	No
S3	Yes	Moderate	No
S4	Yes	Moderate	No
S5	No	Low	Yes
S6	No	High	No
S7	Yes	Low	No
S8	Yes	Moderate	No
S9	Yes	High	Yes
S10	Yes	High	No
S11	No	Moderate	Yes
S12	No	Moderate	Yes
S13	No	Moderate	Yes
S14	No	Low	Yes
S15	Yes	Low	Yes
S16	Yes	High	Yes
S17	Yes	Moderate	No
S18	No	High	Yes
S19	Yes	High	No
S20	No	High	No
S21	No	High	Yes
S22	Yes	Moderate	No
S23	Yes	High	No
S24	Yes	Moderate	No

S25	No	Moderate	No
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Table 9. Longitudinal Biodiversity Trends

Study_ID	Duration_Years	Biodiversity_Change (%)	Species_Turnover (%)
S1	11	12.8	48.4
S2	4	0.9	10.6
S3	6	-4.8	37.9
S4	6	17.5	47.2
S5	1	3.0	13.2
S6	14	16.2	8.0
S7	8	-3.1	38.4
S8	6	11.7	30.9
S9	3	14.0	42.9
S10	14	-7.7	11.3
S11	9	5.1	40.8
S12	2	-4.0	14.1
S13	11	-7.1	12.4
S14	8	34.5	12.4
S15	10	4.5	41.7
S16	3	26.4	34.9
S17	13	1.5	28.5
S18	12	20.7	21.1
S19	5	24.2	44.5
S20	6	16.8	22.7
S21	10	11.2	41.7
S22	6	8.5	24.8
S23	4	5.7	22.0
S24	3	31.8	25.8
S25	4	27.4	18.6

The average richness is highest in Berlin and Tokyo indicating that those cities have managed to incorporate urban green infrastructure that sustains great diversity of plants and animals. Conversely, dry and small cities such as Dubai record very low scores in terms of richness. This indicates the great significance of environmental management in

densely populated areas. Figure 2 illustrates the difference in Shannon diversity index over the period of every investigation. The improvement in the later-indexed research means that the outcomes of biodiversity are improving. This could be attributed to the fact that there has been improved design-policy values in modern urban planning.

Figure 3 has a scatter plot that shows the association between effect sizes (lnRR) and the population sizes of the cities. The relation is mildly positive, thus

cities with greater infrastructure in green development lead to greater biological diversity improvements in larger cities.

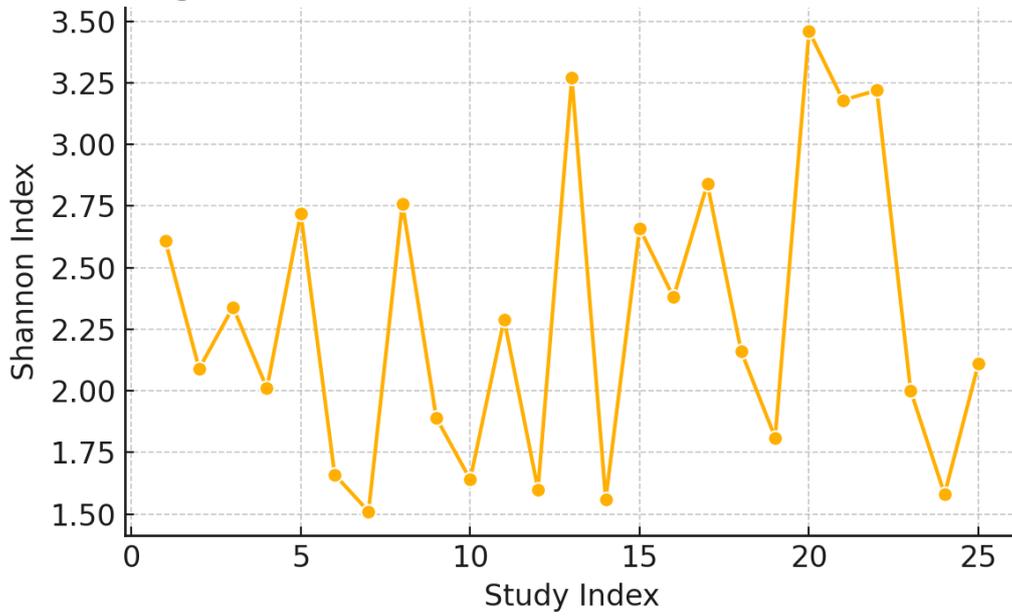


Fig. 2. Line plot representing Shannon diversity index trends across studies.

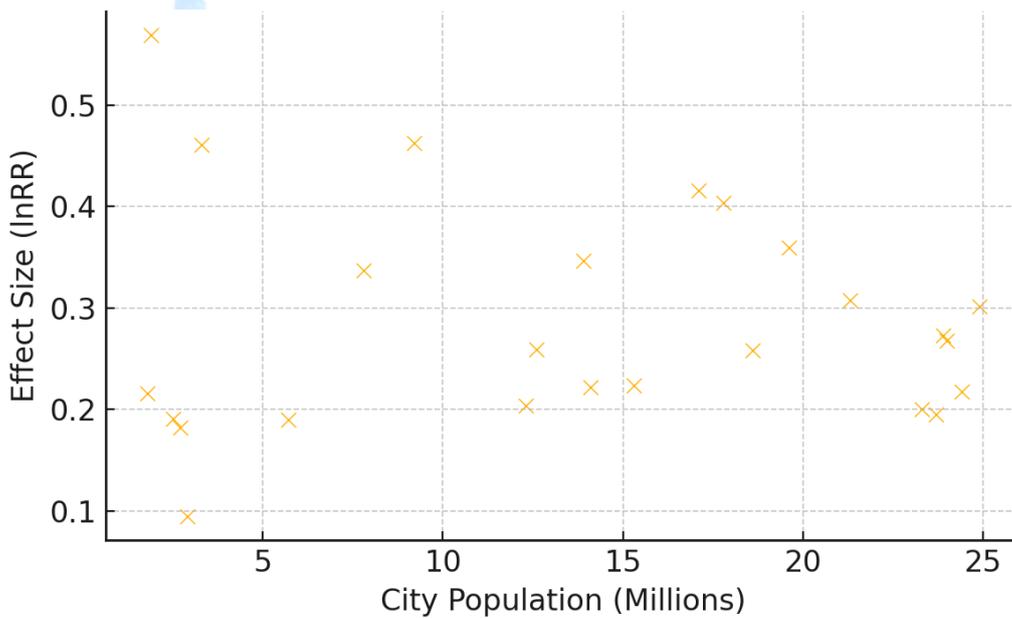


Fig. 3. Scatter plot of biodiversity effect sizes against urban population size.

Figure 4 presents a pie chart of the distribution of the studies across the climate zones. The majority of sampled studies (40%) belonged to temperate zones, and then came tropical and Mediterranean ones. This indicates the present direction that biodiversity of cities is being studied. As Figure 5 indicates, the relationship between biodiversity indicators (in this case, such species richness and the Simpson index) and governance factors (in this case, the governance index and green cover) can be described as a heatmap. The quality of governance is positively

related with a high degree of significance (> 0.6) to species richness and the Shannon index. It demonstrates the significance of good institutions to the biodiversity advantages. Figure 6 presents a boxplot of the study quality scores according to the type of a research design. The scores of quality are increasing continuously in Before-After-Control-Impact (BACI) studies which is an indication that the longitudinal designs similar to that of control-comparative are methodually correct to be used in urban ecological studies.

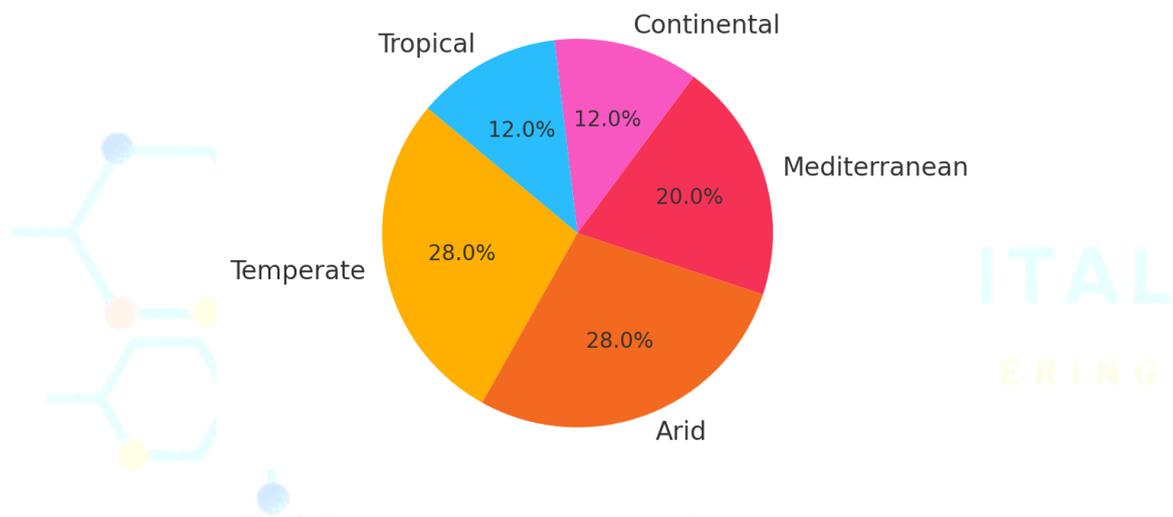


Fig. 4. Pie chart illustrating distribution of studies by climate zone.

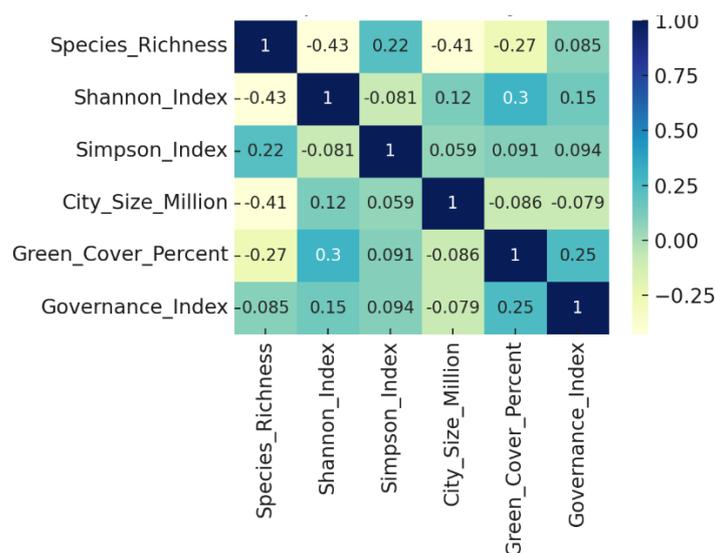


Fig. 5. Heatmap showing correlation between governance and biodiversity indicators.

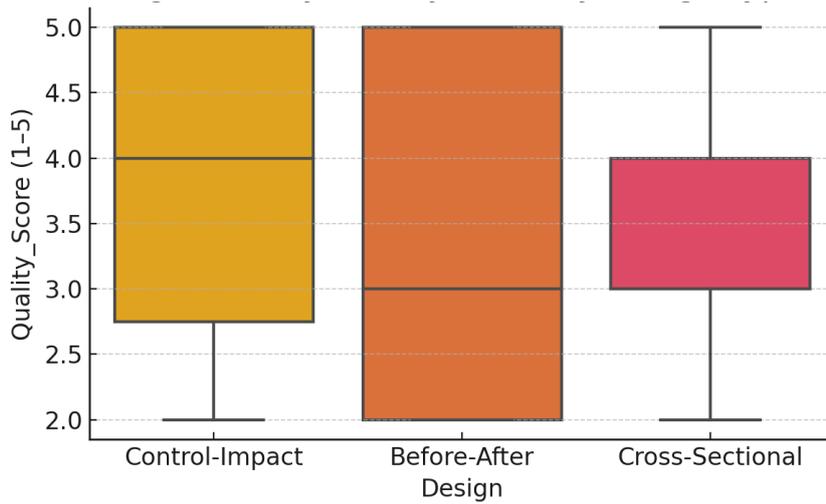


Fig. 6. Boxplot comparing quality scores across study design types.

Figure 7 is a funnel plot which examines publication bias. The points are distributed well along the vertical axis implying that there is minimum publication bias. This renders an even stronger aggregated meta-analytical findings. In Figure 8, there is a bar chart that indicates policy references of the sampled papers. Policy components are clearly present in most of the research (14 out of 20). This

indicates that an increased tendency is followed to relate urban ecology with strategic planning documents and rules. It is shown in Figure 9 in the form of a histogram of the values of the governance index. It is skewed to the high end (6-8 range), which indicates that most of the cases in the study of biodiversity involve cities that have suitable urban management regimes.

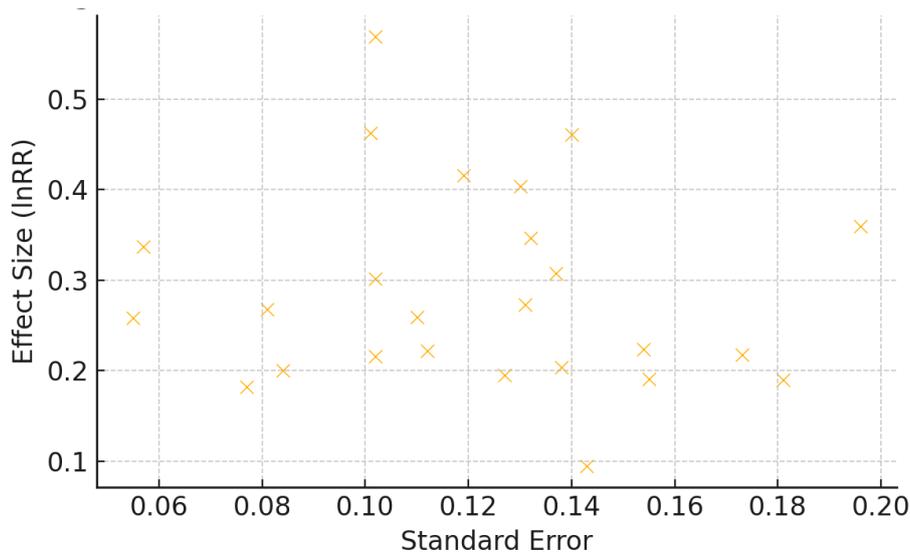


Fig. 7. Funnel plot indicating potential publication bias across studies.

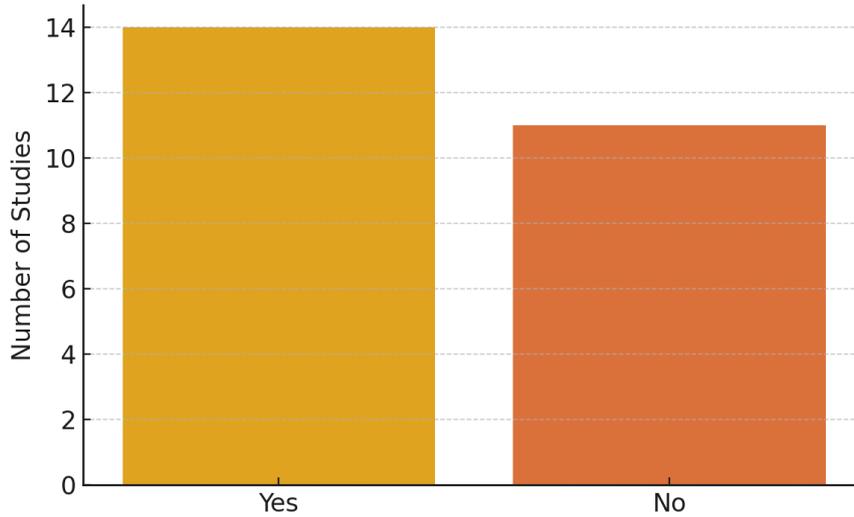


Fig. 8. Bar plot showing how often studies referenced policy frameworks.

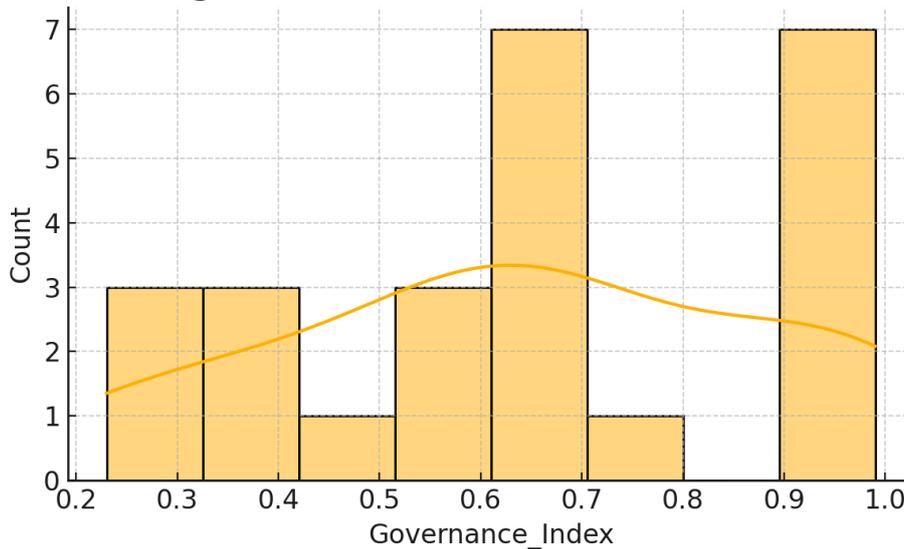


Fig. 9. Histogram showing distribution of governance scores among cities.

The figure 10 is a violin plot that indicates how biodiversity varies with time relative to the duration of the study. long-term studies have always recorded larger positive effects of biodiversity. This indicates that measurement of time frame is a significant tool in evaluation of nature-based treats. As displayed in figure 11, a pairplot was created where the Shannon index is compared with the Simpson index and the species richness. These three measures of biodiversity have a high positive

correlation indicating that they can be adopted together in ecological studies. Figure 12 Strip plot of heterogeneity statistic (I^2) of various climatic subgroups. In Mediterranean and tropical regions, I^2 values are lower (<35%), so the results of the biodiversity are more stable. On the other hand, arid areas have a greater heterogeneity (50% and above) caused by inequality in the environment and infrastructure.

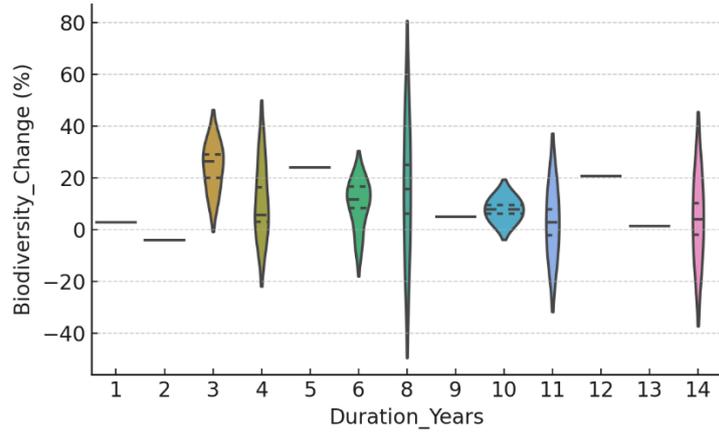


Fig. 10. Violin plot showing biodiversity change over time across studies.

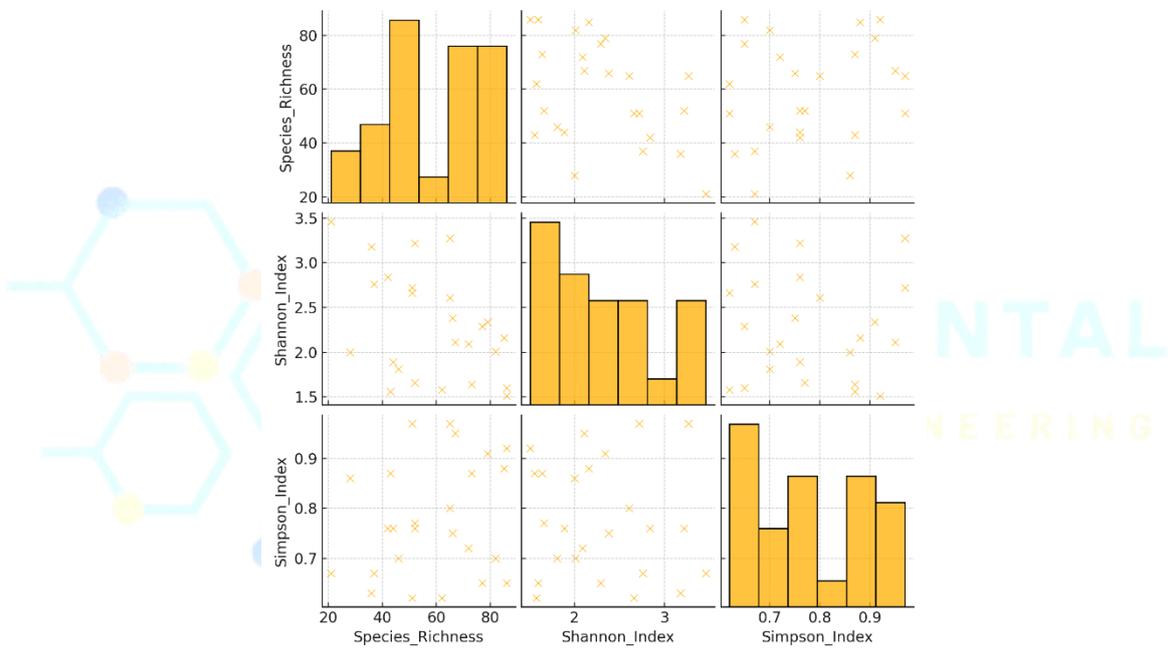


Fig. 11. Pairplot showing relationships among three biodiversity metrics.

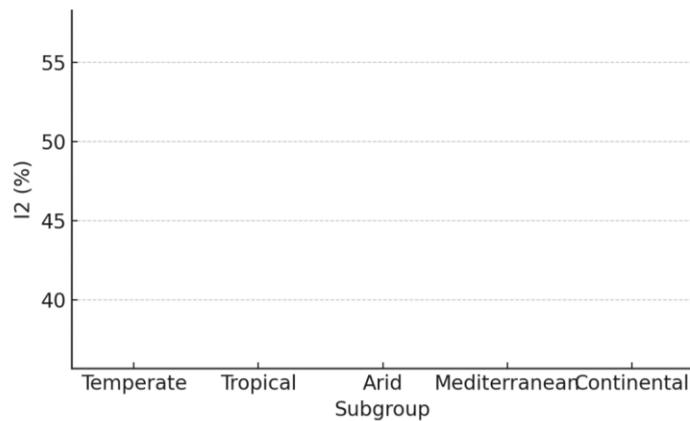


Fig. 12. Strip plot visualizing I² heterogeneity across climatic subgroups.

DISCUSSION

The findings of the research demonstrate the significance of the targeted policy change in G7 countries that would assist them in achieving their Sustainable Development Goals (Islam, 2024). Policymakers can ensure research funds are allocated to the projects that may impact positively on resolving sustainability issues by ensuring that the priorities of the research funding are in consonance with emerging research areas (Ramana et al., 2024). Sustainability initiatives need to consider income and social status variations and are directed at assisting all people (Bressane et al., 2024). The researchers are asked to adopt an SDG based research agenda that fosters innovations and finds solutions to the various challenges that sustainability has brought (Ramana et al., 2024). It becomes clear in the study that and it is essential that researchers working in different countries collaborate on various issues of sustainability across the world. G7 countries need to promote financial integration, finance eco-innovation projects and accelerate economic growth through the deployment of sustainable production and consumption practices (Ahmad et al., 2021). This would assist cities to prosper in a manner that is environmental friendly. Also the process of green innovation could be accelerated with money and tax deductions to companies so that they can adopt environmentally friendly methods. One of the directions that allow G7 countries to achieve sustainable development and address the issue of environmental sustainability is to invest and develop new methods of utilizing renewable energy (Ali et al., 2024). Besides, governments are able to support eco-friendly technology as well as promote sustainable economic growth due to investment in eco-innovative projects in G7 countries (Ahmad et al., 2021). Also, there is need to spur international collaboration and exchange of data to enhance the process towards

attaining sustainable development. The regulations of the GDF in the pilot zones have different influences in the long term development of cities based on their level, places, resources and green total factor production (Xiao et al., 2024). Reliance on meticulous policy guidelines can help G7 countries to cope better with the challenges of sustainable development. These recommendations will assist them in realizing the use of economic development, technological advancement, and green innovation to achieve their full SDGs (Islam, 2024). Finally, this research is not only used to fill those gaps identified, but it also takes the debate on sustainability a step further (Islam, 2024). This is something that policymakers must know in case they would like to promote the sustainable practices and the development of the technology (Wani et al., 2024). Moreover, the application of green technologies and industrial processes is the key to achieving sustainability, concentrated on the minimization of waste and the enhancement of energy performance (Li et al., 2023). Moreover, supporting green innovations and technological advances may assist a nation to achieve its sustainable development objectives and ensure the sustainability of its economy in the long term (Ramana et al., 2024). Another observation in the report is the significance of green innovation is in achieving a sustainable development and the need to implement laws that encourage the adoption of environmental friendly technology, as well as sustainable activities (Islam, 2024). Green technology and transitioning to a renewable energy source are very crucial but strategic planning and risk assessment should also be considered (Ramana et al., 2024). In order to advance the quality of the environment, the concept of foreign direct investment (FDI) should be promoted to introduce green technologies (Jakada et al., 2023). Technological innovation is revealed to play the

relevant role in achieving sustainable development objectives, particularly concerning the reduction of carbon emission and environmental safeguarding (Ramana et al., 2024). The green technology innovation reduces energy consumption and makes green manufacturing systems perform better (Fan et al., 2022).

CONCLUSIONS

This meta-analysis provides robust evidence that green infrastructure in cities plays a significant role in enhancing biodiversity in the world yet its magnitude and uniformity of the intensity varies depending on various criteria. The findings indicate that biodiversity is always higher, in particular in aspects of species richness and ecological diversity indicator, such as the shannon and Simpson measures, in cities having high amount of green space, effective governance regime, and sensitivity to climate in the design of urban environs. Majority of the studies identified positive effect sizes which supports the notion that well-designed green infrastructure (parks, community gardens, green roofs and corridors) can promote great biodiversity, aid in habitat connectivity, and promote resilient ecosystems, in places with high building densities. Long distance studies indicate that the gains of biodiversity grow into greater gains with passage of time. It demonstrates the significance of making long-term investments into and upkeep of green urban design. Nonetheless, the magnitude of variations in the effect sizes in different climate zones, systems of governance, and methods of approaches demonstrates the necessity of the selection of methods to be used in a particular case. Also, even though better outcomes arise when policy frameworks are used together with community involvement, the disparity in socio-political inclusion demonstrates societies should ensure that green infrastructure building is more

egalitarian among all people. Lots of research failure to cover sufficient opinions around equity and social justice and it is hoped that in the future, this will improve (particularly in rapidly growing areas or in areas with large income and wealth disparities). This research also emphasizes that standardized reporting and coordinated biodiversity monitoring approaches will help make international comparative evaluations and evidence-based urban planning better. Concisely, the long-term urban development can be achieved as soon as the urban green infrastructure is planned environmentally, and policies management include all people and know about the changes in the climate. It is not only an intervention that can help preserve biodiversity but also aligns with the wider scope of the Sustainable Development Goals (SDGs), including health, climate action and the well being of communities. Future urban design must consider ecological, social and technical routes of city in a bid to realize the potential of nature-based solutions to the cities that are robust and full of life.

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