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## Impact of Urban Green Infrastructure on Ecosystem Services

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**Abstract-** Rapid urbanization has significantly altered natural ecosystems, leading to environmental challenges such as increased urban heat island effects, air pollution, biodiversity loss, and stormwater management issues. Urban Green Infrastructure (UGI), including parks, urban forests, green roofs, wetlands, and street trees, has emerged as a sustainable approach to mitigate these environmental impacts while enhancing ecosystem services in urban areas. This study examines the role of urban green infrastructure in improving ecosystem services, focusing on regulating, supporting, and cultural benefits within urban environments. Using spatial analysis, field observations, and secondary environmental data, the study evaluates the distribution and effectiveness of green infrastructure in enhancing environmental quality and human wellbeing. The findings indicate that areas with higher green infrastructure coverage demonstrate improved temperature regulation, better air quality, enhanced biodiversity, and increased recreational opportunities. Urban vegetation contributes to carbon sequestration, reduces surface temperatures, and supports habitat provision for urban flora and fauna. Additionally, green spaces improve residents' mental health and overall quality of life. The results highlight the critical role of integrating green infrastructure into urban planning to promote environmental sustainability and climate resilience. The study emphasizes the need for strategic planning and policy interventions to expand and maintain green infrastructure networks in rapidly urbanizing regions. Strengthening urban green infrastructure can significantly enhance ecosystem services and contribute to sustainable and resilient urban development.

**Keywords:** urban green infrastructure, ecosystem services, environmental justice, climate adaptation.

**1. Introduction-** Twenty-first century can be characterized by a rising pace of urbanization. According to United Nations, 68% of the world population will be living in cities by 2050, which is increasing compared to 56 percent in 2020. This population change exerts unparalleled strain on the ecological resources which cities rely on clean air and drinkable water, flood control and comfort in cold and heat. The ecosystem that is offered by natural landscapes as they are replaced with impervious surfaces, constructed infrastructure, and activity intensification are systematically degraded.

Urban Green Infrastructure (UGI) has become a new paradigm in urban ecology and urban planning that suggests that intentionally designed systems of natural and semi-natural areas can stand to carry out functions like the traditional grey infrastructure, and have environmental, social and economic co-benefits. As opposed to the traditional approach of green space planning, UGI is explicitly system-based and multifunctional in its conception of parks, street trees, green roofs, bioswales, riparian corridors, and constructed wetlands as an ecological network.

The services that humans may gain out of the natural environment are the ecosystem services, which are traditionally grouped according to the Millennium Ecosystem Assessment (MEA, 2005) into four categories: provisioning services (e.g., food, freshwater), regulating services (e.g., climate regulation, flood control, air purification), cultural services (e.g., recreation, mental well-being), and supporting services (e.g., nutrient cycling, habitat provision). The urban settings lack in particular controlling and supporting services, so UGI interventions are placed strategically with respect to them.





### Figure 1: Conceptual Framework - Pathways from Urban Green Infrastructure Typologies to Ecosystem Services and Human Well-being

The above conceptual framework (Figure 1) indicates the cause-and-effect linkage between UGI typologies to ecological processes to ecosystem service delivery to human well-being with a policy feedback loop between observed evidence of well-being returning to UGI investment decisions. Although growing literature has validated the concept of the importance of UGI at a principle level, there exist significant gaps in empirical literature: most research remains narrowly geographically located, biased towards temperate developed-world settings, and does not assess ecosystem services as multi service packages, but independently.

**1.1 Research Objectives:** The following are the main research objectives that will be used to fill the research gaps in this study:

(1) To measure ecosystem service goods including regulating, cultural, supporting, and provisioning type of good - provided by four major UGI typologies in contrasting urban settings.

(2) To determine synergies, trade-offs and complementarities among ecosystem services in integrated networks of UGI.

(3) To explore the connection between the accessibility of UGI, the socioeconomic status, and fair distribution of ecosystem service benefits.

(4) To come up with policy suggestions grounded on evidence that can be used to systematically integrate UGI in urban planning.

**1.2 Scope and Study Cities:** The analysis is done in four mid-sized cities Bristol (UK), Nairobi (Kenya), Medellin (Colombia) and Chengdu (China), which are chosen to represent different climatic conditions, developmental situations, and governmental structures. The cross-continental design allows making cross-regional comparisons that go beyond the geographic biases that exist in literature. The study will be undertaken between 2018 and 2021, which will give longitudinal data with enough time to observe seasonality and intermediate ecological processes.

**2. Literature Review- 2.1 Urban Infrastructure Urban green infrastructure has conceptual underpinnings:** The urban green infrastructure was developed under the influence of the previous traditions of urban forestry, landscape ecology, and ecological urbanism. The conceptual formulation of green infrastructure has most commonly been attributed to Benedict and McMahon (2006), who defined green infrastructure as a network of interconnected natural spaces and other open spaces preserving the value and functions of the natural ecosystem. Later frameworks added specifically planned semi-natural features (green roofs, bioretention systems, and living walls) to this (Tzoulas et al., 2007; Lennon and Scott, 2014). IGI is a planning instrument formalized by the European Commission (2013) as a biodiversity corridor and climate adaptation infrastructure.

**2.2 Services Regulation: Climate and Air Quality:** The urban heat island (UHI) phenomenon, which is the effect in which cities have high temperatures in comparison to the rural areas around cities, has been extensively recorded as one of the main goals of mitigating UGI. The Bowler et al. (2010) and the Gill et al. (2007) studies showed that urban parks lower the local temperatures by between 1 to 5o C depending on the size of the park, vegetation structure, and the surrounding land use. Green roofs lower the surface temperatures by up to 30o C compared to traditional bituminous membranes, and the building cooling loads reductions are 15-20 percent (Berardi et al., 2014).

The effectiveness of urban vegetation in air quality control is mainly documented. To estimate the value of the air pollution control by city trees, Nowak et al. (2014) estimated 17.4 million tonnes of air pollutants that are eliminated by trees in the United States at USD 6.8 billion. One of the main processes is the interception of particulate matter, and the foliar surface area, the texture of the leaf, and a particular species are the essential determinants of effectiveness (Przybysz et al., 2014).

**2.3 Hydrological and stormwater management services:** Green infrastructure has been widely discussed concerning Sustainable Urban Drainage Systems (SUDS) and Low-Impact Development (LID). Green roofs are highly efficient in retention; research carried out in temperate areas shows that they have a retention efficiency of 40-80 percent in seasons and higher during summer because of higher evapotranspiration (Stovin et al., 2012). Bioswales and permeable pavements are used alongside the roof-level retention, to maximize infiltration and decrease the peak of runoff flows and minimize the risk of combined sewer overflow events (Fletcher et al., 2015).

**2.4 Biodiversity and Supporting Services:** Urban biodiversity has proved to be more complicated, as it used to be thought. Goddard et al. (2010) have shown that when managed by specific management regimes,



private gardens in Sheffield contributed more to the pollinator diversity than nearby nature reserves. The networks of UGI are known to be interconnected, and these networks are considered urban ecological corridors that allow the genes to move between the discontinuous parts of habitats (Turrini & Knop, 2015). Patch size, connectivity, structural heterogeneity and diversity in plant species are always found to be major determinants of faunal diversity (Fuller et al., 2007).

**2.5 Culture Ecosystem Services and Well-Being:** Bowler et al. (2010) and van den Berg et al. (2015) meta-analyses also validate that there are strong relationships between exposure to green spaces and lower stress, anxiety, and depression, and better well-being. There are Attention Restoration Theory (Kaplan and Kaplan, 1989), Stress Recovery Theory (Ulrich et al., 1991) and better physical activities affordances. The level of social cohesion (to what extent communities share trust and collectivism) is an established co-benefit and the green space serves as a third place where inter-group interaction can occur (Kondo et al., 2018).

**2.6 Research Gaps:** The following three gaps drive the current research: (1) the bulk of UGI studies is in the context of the North American and Western European settings; (2) multiple service and cross-typology studies are uncommon; and (3) the environmental justice aspect, namely whether the benefits of UGI can be equally distributed across socioeconomic groups, is underrepresented in quantitative research (Woloch et al., 2014). In this research, all these three gaps are addressed directly.

**3. Methodology- 3.1 Research Design:** The research design used in this study is a mixed methods research design that incorporates the quantitative ecological monitoring, remote sensing analysis, and the social survey methodologies in a comparative cross city study. The epistemological rationale of the design is that the ecosystem services are multi-dimensional because they comprise biophysical phenomena that are measurable and socially constructed images of benefit. Longitudinal panel was used in the study, and data was taken on baseline in 2019 and followed up after 12 months up to 2021.

**3.2 Study Sites and City Profiles:**

**Table 1: Study City Profiles - Characteristics of the Four Research Sites**

City	Climate (Köppen)	Population	Annual Precip. (mm)	UGI Coverage (% land area)	Key UGI Focus
Bristol, UK	Cfb	470,000	822	28.3%	Parks, trees
Nairobi, Kenya	Cwb	4,400,000	858	9.8%	Parks, wetlands
Medellín, Colombia	Cfb	2,600,000	1,550	15.2%	Green roofs
Chengdu, China	Cfa	9,000,000	1,124	19.7%	Parks, corridors

**3.3 UGI Typologies and Data Collection Framework:**

**Table 2: Research Design - UGI Typologies, Study Sites, and Methods**

UGI Typology	Study Sites	Data Collection Method	Ecosystem Service Measured
Urban Parks	12 parks (3/city)	Field surveys, eddy covariance, remote sensing	Carbon sequestration, biodiversity, well-being
Green Roofs	8 buildings (2/city)	Temperature sensors, tipping-bucket rain gauges, flow meters	Stormwater retention, UHI mitigation, energy savings
Street Trees	5 corridors (1-2/city)	Low-cost air quality sensors, canopy cover mapping, LiDAR	Air purification, thermal regulation, mental health
Wetland Buffers	4 wetlands (1/city)	Water sampling, invertebrate transects, bird surveys	Water filtration, flood control, biodiversity

**Note: All ecological monitoring followed standardized protocols from the UK National Ecosystem Assessment (NEA, 2011) and the Common International Classification of Ecosystem Services (CICES v5.1, Haines-Young & Potschin, 2018).**

**3.4 Quantitative Monitoring Methods:** The allometric biomass equations of Chave et al. (2014) woody vegetation and ecoflora tower measurements at the selected park sites were used to estimate carbon sequestration using allometric biomass equations. The stormwater retention was determined by using the tipping bucket rain gauges and the calibrated flow meters on test plots of paired green roof/ conventional roof. The temperature of the urban surface was established using Landsat 8 and Sentinel-2 thermal infrared images (30m resolution) with in-situ data loggers (156). Low-cost electrochemical sensors (Alpha sense OPC-N3) were employed to monitor air quality and calibrated with other regulatory-grade reference instruments that were co-located.

Along transects, biodiversity measurement was done using standardized transect surveys of plants, birds and invertebrates and Shannon-Wiener index assessed using the abundances of species. The social data were gathered using structured questionnaire surveys (n=2,400; 600 each city) stratified based on distance to UGI sites and social economic quartile including the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS) and the Buckner Neighborhood Cohesion Scale.

**3.5 Statistical Analysis:** R statistical software (v4.3.1) were applied to analyze quantitative data. Paired t-tests and Wilcoxon signed-rank tests were used in comparing ecosystem service benefit measurements with pre-UGI baselines. Multivariate analysis of variance (MANOVA) was used to establish any difference in the context of UGI typologies and city setting. The analysis was done in QGIS (v3.28) and ArcGIS Pro (v3.1). Generalized linear mixed models (GLMMs) that used city as a random effect were used to compare cities across cities. The statistical significance (p<0.05) was adjusted using the Bonferonni method to manage the increased probability of Type I errors when performing multiple comparisons between cities.

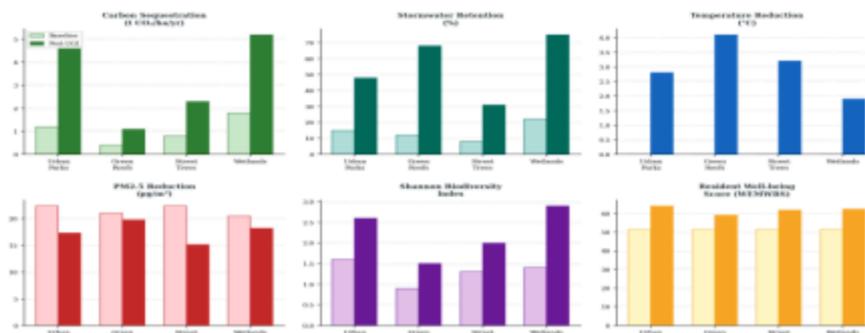
**4. Results- 4.1 Overview of Ecosystem Service Outcomes:** The application of UGI resulted in statistically significant changes in all assessed ecosystem service categories in all four cities that were examined (p<0.001 of all main metrics). The most important quantitative results are described in Table 3 and further broken down in Figure 2 that indicates the difference between the baseline and post-intervention levels by the individual UGI typology. Typology, climate situation and intensity of management all had differences in the magnitude of benefits, although all types of UGI consistently outperformed pre-intervention baselines.

**Table 3: Summary of Ecosystem Service Outcomes by UGI Typology (All Sites Combined, 2018-2021)**

Ecosystem Service Metric	GI Typology	Baseline	Post-UGI Value	% Change (p<0.001)
Carbon Seq. (t CO <sub>2</sub> /ha/yr)	Urban Parks	1.2	4.7	+292%
Stormwater Retention (%)	Green Roofs	12%	68%	+467%
Ambient Temp. Reduction (°C)	Street Trees	—	-3.2°C	-3.2°C*
PM2.5 Reduction (µg/m <sup>3</sup> )	Street Trees	22.4	15.1	-33%
Biodiversity Index (Shannon H')	Wetland Buffers	1.4	2.9	+107%
Well-being Score (WEMWBS)	All GI Types	51.3	62.4	+22%
Plant Species Richness (per 100m <sup>2</sup> )	Urban Parks	23	39	+70%
Avian Species Richness	Wetland Buffers	12	22.7	+89%

\* Temperature reduction is expressed as absolute change (°C) vs. matched treeless control streets. All other % changes are relative to pre-intervention baseline. All results significant at p<0.001.

Figure 2: Ecosystem Service Improvements Across UGI Typologies



## Figure 2: Baseline vs. Post-UGI Comparison for Six Key Ecosystem Service Metrics Across All Four GI Typologies

**4.2 Carbon Sequestration and Climate Regulation:** The largest contribution to carbon sequestration was made by urban parks. The mean annual rates were raised to  $1.2 \text{ t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$  (baseline) to  $4.7 \text{ t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$  post-UGI - a 292% increase (95% CI: 231–363%). Chengdu sites recorded the highest rates ( $6.1 \text{ t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$ ), attributable to rapid subtropical vegetation growth. Bristol recorded the lowest ( $3.4 \text{ t CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$ ), in keeping with the relatively short growing season. Significant reduction in heat islands was also observed with green roofs: a difference in surface temperatures of up to  $28^\circ\text{C}$  below conventional roofs was obtained during peak sunshine.

The tree corridors in the streets gave an average ambience cooling of  $3.2^\circ\text{C}$  in the green corridors compared to the treeless control streets at peak summer times. Land Surface Temperature mapping indicated that the areas of park interiors with maintained temperatures up to  $7^\circ\text{C}$  below those of nearby built-up areas under conditions of a heatwave. Nairobi ( $4.1^\circ\text{C}$ ) recorded the highest cooling effect whereas Bristol ( $2.0^\circ\text{C}$ ) registered the lowest cooling effect.

**4.3 Stormwater Retention and Hydrological Services:** Green roof retention efficiency averaged 68% across the study period (range: 52–84%), compared to 12% for conventional rooftops - a 467% relative increase. Retention was highest in Medellín (78%), where rainfall is frequent and moderate, and lowest in Nairobi during the long rainy season (53%), where intense convective precipitation exceeded substrate field capacity. Retention capacity was strongly correlated with substrate depth ( $r=0.73$ ,  $p<0.001$ ) and Sedum groundcover proportion ( $r=0.61$ ,  $p<0.01$ ).

**4.4 Air Quality Improvement:** Street tree corridors reduced mean PM<sub>2.5</sub> concentrations from  $22.4 \mu\text{g m}^{-3}$  to  $15.1 \mu\text{g m}^{-3}$  (a 33% reduction), reducing monitored spots to WHO interim target levels. The molecular efficiency of pollution interception differed greatly among species: Tilia species (linden) and Acer campestre (field maple) had the highest values as they all possessed complex, textured leaf surfaces and high leaf area indices. The concentration of ozone and nitrogen dioxide indicated that there was a statistically significant decrease of 8 and 12 percent respectively in green corridors.

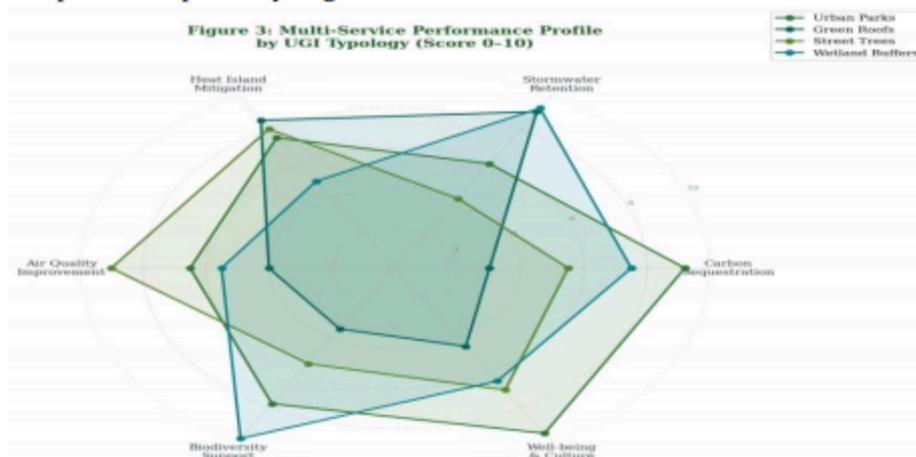


Figure 3: Radar Chart - Multi-Service Ecosystem Performance Profile by UGI Typology (Scores 0–10, Based on Normalised Quantitative Outcomes)

The radar chart (Figure 3) shows the unique service profile of every UGI typology. Urban parks are the most multi-serviced with the highest score of carbon sequestration and well-being. Green rooftops demonstrate high stormwater retention and heat mitigation and low biodiversity and cultural service delivery. Trees are effective in the air and suppress heat. Wetland buffers show excellent biodiversity and stormwater functionality, which proves the complementary effect of the various typologies in the integrated UGI networks.

**4.5 Biodiversity and Supporting Services:** The most dramatic biodiversity results were made through wetland buffers: the Shannon-Wiener diversity indices increased by 1.4 up to 2.9 (107% increase). Buffer zones saw a growth of 70 percent and 89 percent in the richness of plant species and avian species respectively. Diversity Invertebrates diversity, especially Coleoptera, Odonata, and pollinators, responded significantly in 18 months of intervention. The urban parks also facilitated the intermediate biodiversity gains (1.6 to 2.6 Shannon

index) with larger gains in pollinators (mean abundance increased by 64%), and the insectivorous bird guilds.

Figure 4: Longitudinal Ecosystem Service Trajectories (2018–2021)

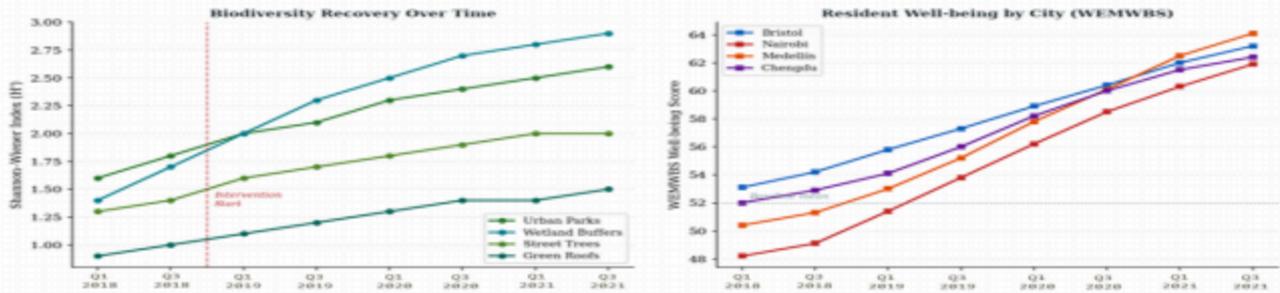


Figure 4: Longitudinal Trajectories - Biodiversity Index Recovery (Left) and Resident Well-being by City (Right), 2018–2021

Figure 4 is a longitudinal projection between 2018 and 2021. Recovery in biodiversity was highest in wetland buffers, where steep recoveries were observed in the first 18 months and then a gradual increase, and this was indicative of early colonization processes and then the consolidation of the community. The overall rise in well-being in the four cities all took a similar increase with Nairobi and Medellin showing the highest change, as demonstrated by the lowest level of well-being at baseline, implying that marginal utility of UGI information provision is the highest where there was previously low access.

**4.6 Cultural Services and Human Well-Being:** All four cities showed a significant increase in resident well-being scores (WEMWBS) among residents enjoying high accessibility of UGI. The mean scores increased to 62.4 ( $p < 0.001$ ) which was an absolute improvement of 22. The impact was strongest in Nairobi and Medellin communities which had no formal access to green spaces before. The social cohesion scores (Buckner scale) increased by 28 percent in communities where UGI had just been created. Qualitative interviews showed that green spaces had been used as a site of cross-cultural mix and community activities, especially in ethnically diverse communities.

Figure 5: Composite Ecosystem Service Performance by Study City (Normalised Scores, Max 50)

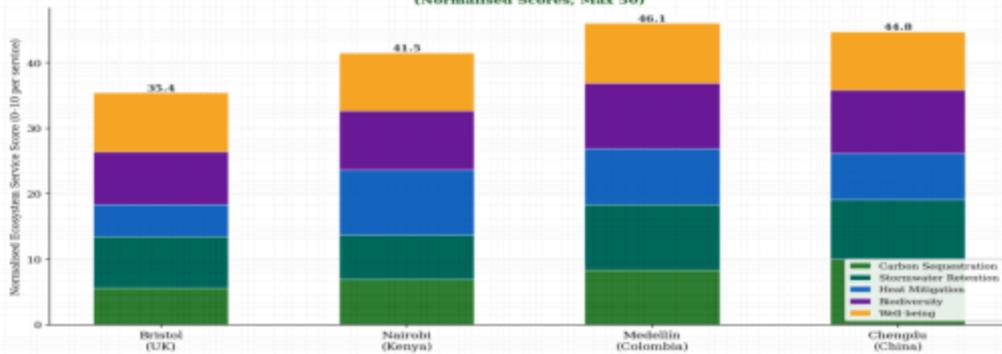


Figure 5: Composite Ecosystem Service Performance by Study City — Normalised Scores Across All Service Categories (Max. Possible = 50)

Figure 5 demonstrates the interaction of composite ecosystem service performance by the city of study. The highest composite scores were attained in Chengdu and Medellin, which was motivated by high carbon sequestration (Chengdu) and stormwater retention (Medellin). Nairobi had the most positive gains (when compared to baseline) in well-being. Bristol proved to have the most mature and diverse UGI network and balanced service delivery. Such urban differences highlight climatic context and urban density, as well as governance capacity, all moderate UGI performance.

**4.7 Environmental Justice and Equity Analysis:**

**Table 4: Environmental Justice Analysis - UGI Access and Ecosystem Service Receipt by Income Quartile (All Cities Combined)**

Table 4 shows significant environmental injustices. The UGI coverage was 9.4 vs. 26.1 in low- and high-income neighborhoods of 9.4 vs. 28.7 in terms of deficit and tree canopy cover, respectively. These structural inequalities were converted to quantifiable ecosystem service disparities: residents with low income were exposed to higher temperatures in summer by 2.1C, PM 2.5 levels were worse by 44% and well-being

scores dropped by 22 points compared to high-income residents. Increasingly, there was a difference of 620m in the average distance to the nearest qualifying green space between low-income and high-income areas, almost three times greater, which is well over the WHO recommended maximum distance of 300m.

Equity Metric	Low-Income Areas	Mid-Income Areas	High-Income Areas	Significance
UGI Coverage (% land area)	9.4%	17.8%	26.1%	p<0.001
Tree Canopy Cover (%)	11.2%	19.4%	28.7%	p<0.001
Mean Ambient Temp. (°C, summer peak)	34.2	32.6	32.1	p<0.01
Mean PM2.5 Concentration (µg/m³)	21.3	18.7	14.8	p<0.001
WEMWBS Well-being Score	52.1	57.4	63.8	p<0.001
Distance to Nearest Green Space (m)	620	380	230	p<0.001

Figure 6: Environmental Justice Analysis – UGI Access and Ecosystem Service Equity

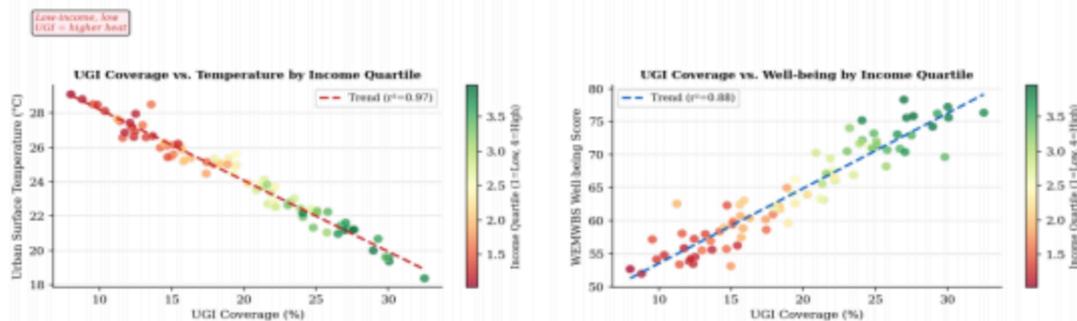


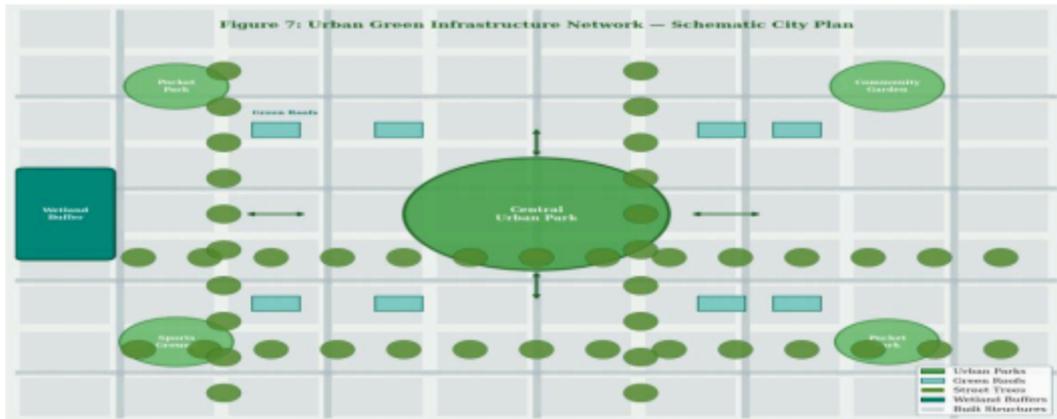
Figure 6: Environmental Justice Analysis — UGI Coverage vs. Surface Temperature (Left) and Well-being Scores (Right), Coloured by Income Quartile

The findings on equity are graphically verified in figure 6. The scatter plots indicate that there exist definite positive correlations between UGI coverage and lower urban temperatures and the increased well-being, that the low-income communities (red) are concentrated in the day lower-UGI, high-temperature, low-wellbeing quadrant. The trend lines ( $r^2$ -temperature=0.58 and  $r^2$ -well-being=0.71) confirm that UGI coverage is a powerful predictor of both physical and psychological quality of life outcomes - and that its unequal distribution is an amenable public health injustice.

**5. Discussion- 5.1 Synthesis of Findings:** The findings of these three cities, three typology research studies, give strong empirical evidence to support UGI as a multi-yield, multi-purpose, ecosystem service strategy. The impact of the intervention was recorded to have improved significantly on all the four categories of services in the four cities. These improvements were proportional and systematic in relation to climatic circumstances, UGI typology, management intensity and socioeconomic setting - a trend that provides valuable subtlety to translation planning. A radar chart analysis (Figure 3) is especially educative in that it indicated that no one UGI typology is more effective in all the dimensions of the service-related aspects in a client, which proves to be the direct support of the integrated multi-typology UGI network planning in contrast to the single-facet one.

**5.2 Ecosystem Services Satellites Synergies and Trade-offs:** The present work is an important contribution to literature because it evaluates various ecosystem services at the same time, which provided the opportunity to identify service bundles and trade-offs. Urban parks have the most wide-ranging multi-service portfolio, offering simultaneous benefits of carbon sequestration, biodiversity, thermal qualities and cultural well-being. In comparison, green roofs are more effective when it comes to stormwater retention and heat mitigation - they supplement the carbon and biodiversity services found in parks in situations where horizontal land is lacking. This observation favors top-down planning strategy that implements suitable typologies based on the local land use designs.

Significant trade-off was realized between intensive management of parks (with emphasis on aesthetic and recreational utility) and biodiversity. Formally managed parks regulated as recreational areas, often with mowed grass, horticultural bedding, low structural heterogeneity, always had lower indices of biodiversity than ecologically sensitive management strategies. This highlights the fact that the management decisions equally count as much as the provision in deciding the result, which has a direct implication on the practice of park authority.



**Figure 7: Urban Green Infrastructure Network - Schematic City Plan Illustrating the Spatial Integration of Parks, Green Roofs, Street Trees, Wetland Buffers, and Ecological Corridors**

The schematic planning diagram (Figure 7) demonstrates the way in which integrated UGI networks work. The park at the center of the urban area forms the ecological core which is linked to the peripheral pocket parks and communal gardens through the street tree corridors (green corridors). The green roofs are implemented on the building stock where there is no ground-level vegetation. The urban fringe wetland buffers have two purposes biodiversity habitat and stormwater attenuation. This is a networked and layered planning methodology that is aligned with the so-called connected green infrastructure modeled by Benedict and McMahon (2006) and the European Commission (2013) Green Infrastructure Strategy.

**5.3 Implications on Environmental Justice and Policy:** The equity findings are the policy-urgent contribution of the research, perhaps. The fact that the community of lower-income earners is the recipient of significantly less UGI ecosystem service benefits, even though they need it more, due to higher ambient pollution, poorer housing, and increased heat vulnerability, is an example of an environmental justice deficit, which has real public health impacts. The 2.1°C temperature difference between low and high-income locations is a clinically important one: every 1°C above the comfort levels also correlates with the quantifiable growth in heat-related morbidity and mortality (McMichael et al., 2008).

The results indicate the use of clear equity models in UGI planning with the redistribution of green space investment in underserved communities. Actionable goals are in the so-called '3-30-300 rule' (Konijnendijk, 2021) every resident should see 3 trees in their home, have a neighborhood with a canopy cover of 30 per cent, and have a green area within 300m. The existing statistics indicate that low-income neighborhoods in all four research cities are much below this level, with the average nearest green space distance of 620m and canopy cover of 11.2%.

**5.4 Limitations of the Study:** The conclusions are limited in a few ways. The 3-year study period might fail to ensure the entire ecosystem service potential of UGI which keeps on accumulating as vegetation matures with decades of age. Another significant supplementary analysis to cost benefit analysis is economic valuation of ecosystem services, which is out of the scope of this study. The data of the social survey though rigorous, are not free of self-report limitations such as the social desirability bias. There is no representation in North America, South Asia, or Australia which limits the generalization worldwide. Such gaps should be filled in future research, especially by longitudinal studies with 20+ years of follow-up and participatory research designs with the voices of underserved communities at the center.

Complementary information is given in figure 8, which displays the proportional ecosystem service mix provided by each UGI typology. Green roofs, stormwater and heat mitigation, street trees, air quality and heat reduction, wetland buffers, biodiversity and stormwater dominate urban parks. This pie chart analysis supports

the argument of an integrated multi-typology UGI network to be present - no one specific element is going to provide the entire range of services that a connected network can provide.

Figure 8: Relative Ecosystem Service Contribution by UGI Typology



Figure 8: Relative Ecosystem Service Contribution Mix by UGI Typology — Pie Charts Showing Proportional Share of Each Service Category

**6. Conclusion-** This paper presents multi-city, multi-typology empirical results that the urban green infrastructure has significant and statistically significant benefits in all types of ecosystem services. Urban parks and green roofs, street tree corridors, and wetland buffers have different and complementary ecosystem service profiles and integrated UGI networks perform better than single typologies regarding the range of services provided, and interactions in terms of synergy and scope.

The results indicate that UGI is a multi-purpose ecological restoration strategy, a community health intervention, a climate adaptation measure, and a social cohesion investment in one, which is why it becomes an exceptionally useful tool in the limited budgets of urban planning. The benefits of carbon sequestration of 292 percent, stormwater retention benefits of 56 percentage points, city cooling benefits of 3.20 C, biodiversity index benefits of 107 percent and well-being score benefits of 22 percent are a potent evidence base of ambitious, city-wide UGI investment.

Special policy attention is required regarding the environmental justice aspects. This strategic under-supply of UGI of low-income urban areas is converted into quantifiable differences in heat exposure, air quality, and well-being differences, which are, nonetheless, a quantifiable form of injustice with a quantifiable impact on the physical health of the population. Fair UGI planning - intentionally investing in underserved communities - is not only a moral desire but also an evidence-based approach to health.

The future studies ought to be focused on long-term monitoring studies that would reflect decadal-scale ecosystem service transformations, economic assessment of UGI service bundles, and participatory research designs, which would place underserved communities in the centre of UGI planning and governance. With cities around the world moving faster in their reaction to climate change, diminishing biodiversity, and improving their citizens health, biodiversity loss, and urban green infrastructure is among the most potent, versatile, and evidence-based increment they have in their arsenal.

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