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Urban Nature Indexes: Methodology and Strategic Directions in Korea

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ABSTRACT

Cities are simultaneously vulnerable ecosystems exposed to risks such as heatwaves, floods, and air pollution, while also holding potential to drive biodiversity conservation and resilience. As cities play an increasingly critical role in achieving global biodiversity targets, the International Union for Conservation of Nature developed the Urban Nature Indexes (UNI) to assess urban ecological performance. This paper introduces the UNI methodology and discusses strategic directions for its application in Korea. The UNI is grounded in the Driving forces-Pressures-State-Impact-Response framework and the Urban Bioshed Impact Areas model, enabling assessment of ecological impacts within and beyond city boundaries. It comprises six themes and 30 indicator topics. For Korea, we highlight priorities including indicator localization, data infrastructure development, and policy integration. Applying the UNI in Korea is expected to strengthen national biodiversity strategies and position cities as active contributors to global sustainability agendas.

Keywords: Urban biodiversity, Ecological indicators, Sustainability assessment, Nature-based solutions, Ecosystem services, Urban resilience

Introduction

Biodiversity is the fundamental foundation that sustains human survival, health, and quality of life. The Convention on Biological Diversity (CBD), which institutionalized this internationally, has established conservation goals since its entry into force in 1993, but rapid urbanization threatens its achievements (Chan, 2024). Over half of the world's population now lives in cities, projected to reach 70% by 2050 (UNDESA, 2019). This population concentration and land-use transformation are altering urban ecosystem structures and intensifying complex environmental risks stemming from the combination of physical development and climate change (Bonthoux & Chollet, 2024; Miller, 2005). In particular, various climatic and non-climatic factors such as heatwaves, floods, and air pollution accelerate habitat fragmentation and species loss within cities (Faeth *et al*., 2011; Oke *et al*., 2021; Soga & Gaston, 2016). Despite these vulnerabilities, cities are dual-natured spaces with the potential to become crucial sites for biodiversity conservation and ecosystem restoration. Some endangered species inhabit and depend on cities for survival (Ives *et al*., 2016; Soanes & Lentini, 2019), while urban nature—such as parks, gardens, and green corridors—provides diverse ecosystem services including cooling, flood mitigation, air purification, food supply, and recreation (Dobbs *et al*., 2014; Elmqvist *et al*., 2015). These natural elements maintain human-nature connections, creating positive effects that enhance well-

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being and conservation, thereby supporting the necessity of urban ecosystem management.

As the importance of urban ecosystems and biodiversity is emphasized, research analyzing species richness, habitat connectivity, and ecosystem service functions is actively conducted in various cities (Kendal *et al*., 2020). However, these studies have primarily focused on large cities in developed countries and temperate regions, and have been centered on birds and plants, leaving data on other taxonomic groups and developing countries still limited (Faeth *et al*., 2011; Luederitz *et al*., 2015). To address these limitations and assess biodiversity management at the urban level, the Secretariat of the CBD and Singapore's National Parks Board jointly developed the City Biodiversity Index (CBI; Singapore Index) (Deslauriers *et al*., 2018). While the CBI is a useful indicator for assessing the state of biodiversity and management efforts within cities, it struggles to encompass ecological impacts extending beyond urban boundaries or social and policy responses. Consequently, there is a growing need for a more comprehensive indicator that can holistically evaluate not only species and habitats within cities but also ecosystem services, human well-being, and governance (Pierce *et al*., 2024).

The global biodiversity agenda (Post-2020 Global Biodiversity Framework, Sustainable Development Goals, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, etc.) is expanding beyond conservation to include restoration and the realization of Nature's Contributions to People (NCP) (Díaz *et al*., 2015; Xie & Bulkeley, 2020). The role of cities in achieving these goals is increasingly vital, suggesting that urban governance must adopt innovative strategies beyond simple land-use planning, such as experimental approaches, urban wilding, and nature-based solutions (Cohen-Shacham *et al*., 2016; Xie & Bulkeley, 2020). Cities are now required to act not as passive spaces managing vulnerability, but as active agents driving global transition.

The International Union for Conservation of Nature (IUCN) developed the Urban Nature Indexes (UNI) to comprehensively assess the ecological performance of cities within this context (Pierce *et al*., 2024). The UNI is designed to assess the ecological footprint extending beyond the city itself, based on the Driving forces-Pressures-State-Impact-Response (DPSIR) model and the concept of urban bioshed impact areas (Bradley & Yee, 2015; Patrício *et al*., 2016; Pierce, 2022). Furthermore, by comprehensively considering not only species and habitats but also ecosystem services, human well-being, and governance responses, it functions as a standardized assessment framework linking cities to global biodiversity goals. Therefore, this paper aims to evaluate the applicability and limitations of the index by examining UNI's conceptual foundation, indicator system, and methodological structure, and analyzing international application cases. Furthermore, based on the results of its pilot application in Korean cities, it aims to propose strategic management directions for localizing the UNI and enhancing the ecological performance of cities.

Materials and Methods

Conceptual framework and structural design of the UNI

Development rationale and conceptual foundations

The UNI is an international standard assessment system developed by the IUCN. It serves as a tool for quantitatively evaluating and monitoring the state and changes in natural capital and ecosystem services at the urban level. The development of the UNI stemmed from the recognition that while the existing CBI is useful for measuring the status of biodiversity within cities, its application is constrained by local conditions such as city size, socio-

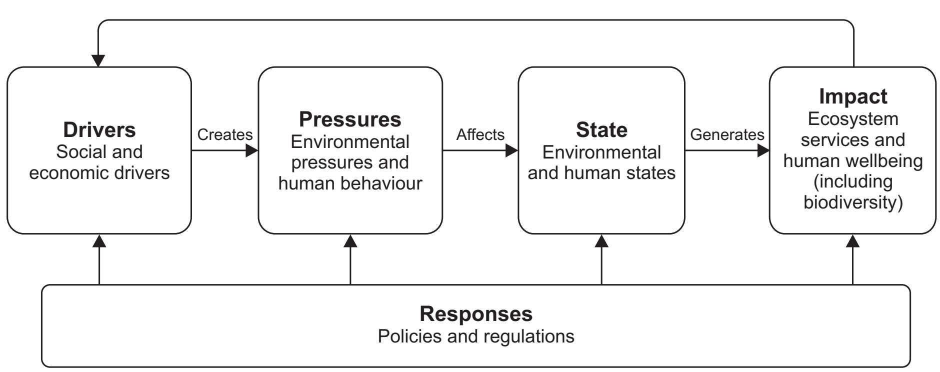

Fig. 1. Conceptual frameworks of the Urban Nature Indexes. Driving forces-Pressures-State-Impact-Response (DPSIR) model illustrating the feedback relationships between social drivers, environmental pressures, ecosystem states, impacts, and policy responses. Fig. 1 adapted from IUCN. The Urban Nature Indexes: Methodological Framework and Key Indicators; 2023, based on Bradley and Yee (2015).

economic context, and data availability. Consequently, the IUCN established an integrated indicator system to assess a city's ecological performance in a more systematic and standardized manner. UNI is designed based on two conceptual frameworks. First, it systematically reflects the complexity and causal structure of urban ecosystems by applying the DPSIR framework (Fig. 1) (IUCN, 2023). This model presents a five-stage causal structure: pressures originating from socio-economic drivers such as human health, safety, and welfare affect the state of the urban environment; the resulting impacts act upon ecosystem services and human well-being; and this leads to policy and institutional efforts to address these impacts. UNI's six themes (Drivers, Pressures, State, Impacts, Responses, Governance) were structured to reflect this causal flow. Second, it introduced the concept of urban bioshed impact areas, acknowledging that a city's ecological impacts extend beyond administrative boundaries to broader spatial scales (IUCN, 2023). Accordingly, UNI defines three spatial levels—① within the city (local scale), ② adjacent areas functionally connected to the city (bioregional scale), and ③ external areas linked to global supply chains and resource flows (global scale)—to establish the scope of influence for each indicator. This design enables UNI to simultaneously assess both a city's direct impacts and its linked impacts on distant regions. In summary, UNI integrates the causal structure of DPSIR with the spatial scale concept of the biosphere's sphere of influence. It serves as an integrated international standard assessment system capable of diagnosing a city's ecological performance across both time and space.

Structure and thematic composition

The UNI are composed of six themes and 30 detailed indicators based on the previously introduced DPSIR model to reflect the causal structure of urban ecosystems (Table 1). Each theme is designed to systematically diagnose the impacts of urban socio-economic activities on the natural environment, the resulting ecological responses, and societal countermeasures.

The first theme, 'Consumption Drivers,' assesses the fundamental drivers of social·economic activities—such as urban energy use and resource consumption—on ecosystems, specifically considering the indirect impacts these consumption patterns have on ecosystems outside the city. The second theme, 'Human Pressures,' evaluates direct pressures within cities, including various forms of environmental pollution and expansion, to identify the negative impacts of urbanization on ecosystem structure and function. The third theme, 'Habitat Status,' and the fourth theme, 'Species Status,' diagnose the physical habitat conditions and the state of biodiversity, respectively. This aims to evaluate the health of urban ecosystems through indicators such as habitat restoration, vegetation cover, green network connectivity, and changes in flora and fauna. The fifth theme, 'Nature's Contributions to People,' evaluates the ecosystem services provided by urban ecosystems. It measures social benefits such as citizen welfare, health, and quality of life, encompassing regulatory, provisioning, and cultural functions. Finally, 'Governance Responses' assesses urban governance capacity through policies, in-

Table 1. Structure of the Urban Nature Indexes framework

Theme	ID	Indicator topics
1. Consumption Drivers	1.1	Material consumption
	1.2	Harmful harvest & trade
	1.3	GHG emissions from energy
	1.4	Unsustainable diets
	1.5	Water withdrawal
2. Human Pressures	2.1	Sprawl
	2.2	Water pollution
	2.3	Noise pollution
	2.4	Light pollution
	2.5	Invasive species
3. Habitat Status	3.1	Land use/protection
	3.2	Ecosystem restoration
	3.3	Shorelines & riverbanks
	3.4	Vegetation cover
	3.5	Connectivity
4. Species Status	4.1	Animal species
	4.2	Plant species
	4.3	Functional diversity
	4.4	Microbiota
	4.5	Endemic species
5. Nature's Contributions to People	5.1	Exposure to nature
	5.2	Access to nature
	5.3	Human health
	5.4	Livelihoods
	5.5	Sacred nature sites
6. Governance Responses	6.1	Planning
	6.2	Laws & policy
	6.3	Education
	6.4	Management
	6.5	Incentives & participation

The Urban Nature Indexes are composed of six overarching themes—Consumption Drivers, Human Pressures, Habitat Status, Species Status, Nature's Contributions to People, and Governance Responses—each comprising five indicator topics (30 in total).
GHG, greenhouse gas.

stitutions, planning, and citizen participation, diagnosing the level of societal response to ecological issues identified in earlier stages. Thus, UNI perceives cities not merely as physical habitats but as socio-ecological systems where humans, nature, and policies interact. Consequently, each theme functions not as a list of individual indicators but as a component for analyzing a city's ecological performance in a causal and multi-layered manner.

Each detailed indicator follows a consistent format, comprising Aim, Definition, Guidance, Alternative Metrics, Resources, and Scoring Scheme. This structure enhances comparability between indicators and is designed for flexible application across cities with varying data availability. For example, the '1.1 Material consumption' indicator uses per capita solid waste generation as its primary metric, but may utilize per capita consumption-based ecological footprint as an alternative metric depending on city conditions. This standardized indicator design enables inter-city result comparisons and long-term monitoring, minimizing evaluator subjectivity while ensuring consistency in policy interpretation.

The UNI establishes a baseline for urban ecosystems through its initial assessment and identifies change trends using historical data or repeated assessments every three years. These trends can be categorized as no change, positive change, negative change, or insufficient data. The direction of change for each theme can be utilized to set priorities for urban policy and establish management strategies. Consequently, UNI's scoring system can track a city's ecological transition and scientifically present a development pathway toward becoming a sustainable and biodiversity-rich city.

Results

International applications and pilot implementation of the UNI

International applications: the Berlin case

The UNI is known to have been piloted in several cities, but the only officially validated assessment results currently available are those published by the IUCN for the Berlin case (IUCN, 2025). As Germany's capital, Berlin conducted a comprehensive assessment covering 23 detailed indicators across 6 themes, based on its extensive urban environment statistics and policy reports (Table 2) (IUCN, 2025). Data was collected from public databases such as Berlin's Senate Department for the Environment, Mobility, and Consumer Protection (SenUMVK) and the Federal Environment Agency (Umweltbundesamt). The evaluation results showed a trend toward sustainable transition in the 'Consumption Drivers' category, including efficient resource circulation management and a reduction in greenhouse gas emissions from energy use by approximately 17% in 2020 compared to 2019. In the 'Human Pressures' category, a baseline was established for environmental pressures such as urban expansion and noise/light pollution. The spread of the invasive species, the tree of heaven (*Ailanthus altissima*), was specifically identified as an ecological risk factor. The 'Habitat & Species Status' category confirmed high biodiversity, with the city maintaining a high urban green space ratio of approximately 59% and recording over 3,000 animal species and more than 1,200 plant species. However, results for some specific indicators (two habitat-related and one species-related) were not disclosed. In the 'Nature's Contributions to People' category, citizens' access to nature was favorable (approximately 40% of residents can access green space within 300 meters), and park usage rates were also high. However, indicators related to air quality remained at an intermediate level. In the 'Governance Responses' category, city-level green infrastructure and biodiversity management plans (e.g., GRaBS, Action Program for Urban Green Space) and citizen participation programs were well-established. However, evaluation results for the policy and legal/institutional sectors were absent, meaning the systematic foundation for governance as a whole was only partially assessed.

Overall, the Berlin case demonstrates that UNI is a practical tool capable of quantitatively diagnosing the multi-layered performance of urban ecosystems. In advanced cities with high data accessibility, the full set of UNI indicators could be effectively applied, enabling integrated evaluation across policy, planning, and educational programs. The absence of evaluation results for some indicators (e.g., 3.3, 4.4, 5.5, 6.1, 6.2) may stem from data gaps, but it is also possible they were excluded from assessment based on the city's capacity level.

Pilot evaluation in Seoul

To conduct a pilot assessment of the natural and ecological status among cities in the Republic of Korea, cities with well-established data and high data availability were reviewed. As a result, the UNI was calculated for Seoul Special City, the capital, using the methodology at (Table 3; SMG, 2025a, 2025b). Following the UNI's phased application principle, ten detailed indicators encompassing various sectors such as environment, climate, and green spaces were selected, considering the city's data availability and accessibility to administrative statistics. The data used for the indicators was extracted and compiled from sources including the Seoul Open Data Plaza (SMG, 2025a) and the Water Cycle Information Disclosure System (SMG, 2025b).

Evaluation results: under 'Consumption Drivers,' per capita solid waste generation (1.1) showed a decreasing trend from 0.014 kg/person/day in 2020 to 0.011 kg/person/day in 2023, while greenhouse gas emissions from

Table 2. Summary of Urban Nature Indexes indicator results for Berlin

Theme	ID	Indicator topics	Score
Consumption Drivers	1.1	Material consumption	Baseline measured
	1.3	GHG emissions from energy	Decreasing trend observed
	1.4	Unsustainable diets	Baseline measured
	1.5	Water withdrawal	Decreasing trend observed
Human Pressures	2.1	Sprawl	Baseline measured
	2.2	Water pollution	Baseline measured
	2.3	Noise pollution	Baseline measured
	2.4	Light pollution	Baseline measured
	2.5	Invasive species	Baseline measured
Habitat Status	3.1	Land use/protection	Baseline measured
	3.4	Vegetation cover	Baseline measured
Species Status	4.1	Animal species	Baseline measured
	4.2	Plant speceis	Baseline measured
	4.3	Functional diversity	Baseline measured
	4.5	Endemic species	Baseline measured
Nature's Contributions to People	5.1	Exposure to nature	Unchanged trend
	5.2	Access to nature	Baseline measured
	5.3	Human health	Baseline measured
	5.4	Llivelihoods	Baseline measured
	5.5	Sacred nature sites	Baseline measured
Governance Responses	6.3	Education	Baseline measured
	6.4	Management	Baseline measured
	6.5	Incentives & participation	Baseline measured

Data were obtained from the International Union for Conservation of Nature (IUCN) Urban Nature Indexes database and official materials provided by IUCN (IUCN, 2025).
GHG, greenhouse gas.

energy use (1.3) established a baseline of 3.16 t CO_2 in 2023, establishing a baseline. Under 'Human Pressures,' urban sprawl showed a mitigating trend, decreasing from 251 people/ha to 241 people/ha, while the noise indicator remained at a relatively high level of 54.4-56.6 db. In 'Habitat Status,' the protected area coefficient within the urban area decreased slightly from 0.558 in 2020 to 0.548 in 2024, while the green space ratio increased somewhat from 26.1% to 26.3%. This is judged to reflect the results of policies focused on qualitative management of existing green spaces and the creation of small-scale green spaces within living areas, rather than the expansion of new green areas. In the 'Nature's Contributions to People' category, citizens' access to nature (5.1) decreased to approximately 47 million people in 2022 but increased to about 6 million people in 2023, indicating that ecological accessibility within living areas was assessed as favorable.

Overall, the results of Seoul's pilot application reflect the characteristics of a large city with stable data accessibility and administrative statistics systems. While most of UNI's key indicators could be practically evaluated, some items could not be assessed due to limitations in data disclosure scope or format inconsistencies. However, these items are not deemed to be entirely absent; rather, they are considered difficult to use directly due to constraints in administrative procedures or access pathways.

Discussion

The UNI is an indicator system developed to comprehensively assess the structure, functions, and services of urban ecosystems. Its significance lies in its design to quantitatively evaluate natural assets and the contributions of nature—elements that have been relatively undervalued in existing environmental statistics and sustainability indicators. However, given the complex intertwining of urban ecological, social, and economic systems, various limiting factors are expected to arise during UNI applica-

Table 3. Results of the pilot application of the Urban Nature Indexes indicators in Seoul

<table>
<tr><th>ID</th><th>Indicator</th><th>Method</th><th>Result</th><th>Source</th><th>Score</th></tr>
<tr><td>1.1</td><td>Material consumption</td><td>Total waste volume (industrial, construction, municipal, designated waste)÷total urban population</td><td><table><tr><th colspan="4">Average daily solid waste generation per capita (kg)</th></tr><tr><td>2020</td><td>2021</td><td>2022</td><td>2023</td></tr><tr><td>0.014</td><td>0.014</td><td>0.012</td><td>0.011</td></tr></table></td><td>Seoul Open Data Plaza</td><td>+
Decreasing trend observed</td></tr>
<tr><td>1.3</td><td>GHG emissions from energy</td><td>Energy consumption by source (electricity, gas, district heating)×emission factor÷total urban population</td><td><table><tr><th>Per capita emissions (2023; t CO_2)</th></tr><tr><td>3.16</td></tr></table></td><td>Seoul Metropolitan City's energy consumption</td><td>•
Baseline measured</td></tr>
<tr><td>1.5</td><td>Water withdrawal</td><td>Water supply volume÷total urban population</td><td><table><tr><th colspan="5">Daily water supply per person (L)</th></tr><tr><td>2020</td><td>2021</td><td>2022</td><td>2023</td><td>2024</td></tr><tr><td>300</td><td>303</td><td>303</td><td>302</td><td>290</td></tr></table></td><td>Seoul Open Data Plaza</td><td>+
Decreasing trend observed</td></tr>
<tr><td>2.1</td><td>Sprawl</td><td>Total population÷developed land area (Biotop map: roads, urbanized areas, etc.)</td><td><table><tr><th colspan="2">Average density (persons/ha)</th></tr><tr><td>2020</td><td>2025</td></tr><tr><td>251</td><td>241</td></tr></table></td><td>Seoul Open Data Plaza</td><td>+
Decreasing trend observed</td></tr>
<tr><td>2.2</td><td>Water pollution</td><td>Calculate the difference in total nitrogen values measured at the upper and lower reaches of the river</td><td><table><tr><th rowspan="2">Stream</th><th colspan="4">Total N (mg/L)</th></tr><tr><td>2021</td><td>2022</td><td>2023</td><td>2024</td></tr><tr><td>Cheonggye</td><td>0.53</td><td>0.36</td><td>0.57</td><td>0.11</td></tr><tr><td>Jungnang</td><td>−0.92</td><td>−1.75</td><td>−0.01</td><td>1.26</td></tr></table></td><td>Seoul Water Cycle Information Disclosure System</td><td>=
Unchanged trend</td></tr>
<tr><td>2.3</td><td>Noise pollution</td><td>Arithmetic mean of four daily noise measurements in green areas</td><td><table><tr><th>Year</th><th>Sites</th><th>Noise (dB)</th></tr><tr><td rowspan="3">2023</td><td>Olympic Velodrome</td><td>54.9</td></tr><tr><td>Pool</td><td>57.4</td></tr><tr><td>Musical fountain</td><td>57.5</td></tr><tr><td rowspan="3">2024</td><td>Olympic Velodrome</td><td>53.7</td></tr><tr><td>Swimming pool</td><td>55.2</td></tr><tr><td>Musical fountain</td><td>54.3</td></tr></table></td><td>Seoul website</td><td>+
Decreasing trend observed</td></tr>
<tr><td>3.1</td><td>Land use/ protection</td><td>Calculating the Protected Land Factor by assigning weights according to protection levels</td><td><table><tr><th colspan="2">Protected land factor</th></tr><tr><td>2020</td><td>2025</td></tr><tr><td>0.558</td><td>0.548</td></tr></table></td><td>Seoul Open Data Plaza</td><td>-
Negative trend observed</td></tr>
<tr><td>3.4</td><td>Vegetation cover</td><td>Tree and shrub area÷total urban area (Biotop map: vegetation)</td><td><table><tr><th colspan="2">Vegetation cover (%)</th></tr><tr><td>2020</td><td>2025</td></tr><tr><td>26.1</td><td>26.3</td></tr></table></td><td>Seoul Open Data Plaza</td><td>+
Positive trend observed</td></tr>
<tr><td>5.1</td><td>Exposure to nature</td><td>Estimate the total annual number of visitors to Hangang Parks</td><td><table><tr><th colspan="4">Total annual number of site visitors (×1,000 persons)</th></tr><tr><td>2020</td><td>2021</td><td>2022</td><td>2023</td></tr><tr><td>56,328</td><td>57,629</td><td>47,424</td><td>60,488</td></tr></table></td><td>Seoul Hangang Park Headquarters</td><td>+
Positive trend observed</td></tr>
<tr><td>5.3</td><td>Human health</td><td>Measure air quality (PM2.5) within the region</td><td><table><tr><th colspan="4">Average PM2.5 concentration (μg/m^3)</th></tr><tr><td>2020</td><td>2021</td><td>2022</td><td>2023</td></tr><tr><td>20.67</td><td>19.78</td><td>18.35</td><td>19.66</td></tr></table></td><td>Seoul Open Data Plaza</td><td>=
Unchanged trend</td></tr>
</table>

Source: SMG (2025a; 2025b).
GHG, greenhouse gas.

tion, including data availability, mismatches between administrative units and ecological spaces, and differences in social contexts (McPhearson *et al.*, 2016). Particularly, the level of data infrastructure—a prerequisite for indicator calculation—varies significantly between countries and cities, potentially negatively impacting the comparability and reliability of the indicators.

The pilot evaluation results for Seoul analyzed in this study clearly demonstrate these structural characteristics. In large cities where data accessibility and administrative statistical systems are relatively well-established, UNI's key indicators could be practically evaluated. However, evaluation was limited for some items due to inconsistencies in the scope or format of data disclosure. This appears to stem more from constraints in administrative procedures or access pathways than from data absence. It is judged that most indicator calculations would be feasible if consultation procedures were followed with the agencies directly managing the data. Conversely, when examining the availability of the same indicators for small and medium-sized cities at the city and county levels (e.g., Suncheon, Seocheon), the proportion of data directly obtainable was only about 50%. This indicates that the presence of environmental measurements and data infrastructure conditions vary significantly depending on the size and budget level of the local government. Therefore, a supplementary process is necessary to flexibly adjust the indicator calculation method, considering the data gap between local governments, to enable evaluation even in environments with insufficient data. This goes beyond simply developing specialized indicators for each city; it involves establishing an alternative evaluation system tailored to the administrative and technical capacity levels of each local government.

Meanwhile, UNI is based on the premise that a city's ecological impact extends beyond administrative boundaries to adjacent ecological units. This spatial expansiveness signifies that cities do not exist as isolated units but are closely interconnected with water resources, air quality, land use, and other aspects of neighboring areas (Seto *et al*., 2012). Therefore, fundamental environmental improvement is difficult to achieve through internal management systems alone. Furthermore, while time-series measurable indicators such as water intake volume, energy consumption, noise pollution, and water quality pollution clearly demonstrate changes in the urban environment, structural constraints exist before these results translate into tangible improvements. While the current UNI is effective in diagnosing a city's environmental performance, the system for linking these results to policy implementation or citizen participation is relatively inadequate. To overcome these limitations, it is necessary to evolve into an action-oriented evaluation system that promotes policy realization and citizen participation. This requires concurrent efforts in interconnected management beyond city boundaries, changes in citizen behavior, and the establishment of collaborative governance among diverse stakeholders.

Based on this discussion, the following strategic approaches are required to apply UNI more effectively within the Korean context. First, since UNI is designed to allow indicator selection based on city size and data capabilities, Korean local governments should establish a differentiated indicator selection strategy reflecting each city's size, administrative capacity, and data infrastructure level, rather than uniformly applying all indicators. Second, to ensure reliability in inter-city comparisons, management must be based on a common data template with a consistent format and structure. Third, for UNI to be utilized in actual policy decision-making, it is essential to directly link the indicator results to existing policy frameworks like Korea Nature-based Solutions (K-NbS) and the National Biodiversity Strategy, converting them into actionable implementation and investment strategies. Finally, since most indicators are difficult to improve through policy measures alone, the practice foundation must be strengthened by linking evaluation results to citizen-participatory monitoring or community-based environmental management programs, ensuring they lead to positive change. These strategic considerations will form a crucial foundation for UNI to transcend being a mere evaluation tool and establish itself as a sustainable ecological management system for Korean cities.

Conclusion

This study systematized the conceptual foundation and structure of the UNI and examined its applicability and limitations at the urban level through case studies of Berlin and Seoul. The UNI, an international standard indicator system integrating the DPSIR model and the concept of the biosphere sphere of influence, was confirmed to enable spatiotemporal diagnosis of urban ecosystem structure, function, and services, as well as quantitative assessment of ecological performance and sustainability. Case analysis revealed that while large cities could calculate indicators relatively stably, medium and small cities exhibited limitations in applying some indicators due to constraints in data infrastructure and administrative systems. Future research should verify the applicability of all 30 indicators domestically, beyond the 10 applied in Seoul, and systematically analyze the standardization potential for data requirements, substitute indicators, and calculation units per indicator. Additionally, research is needed to examine the feasibility of indicator calculation across 17 metropolitan governments and major basic local governments, leading to the creation of a nationwide data availability map. Furthermore, developing a spatial analysis framework to address the mismatch between administrative boundaries and ecological space units is also proposed as a future task. Furthermore, for UNI to transcend a one-time diagnosis and be utilized for tracking long-term changes and comparative analysis between cities, a monitoring infrastructure must be established.

This infrastructure should include regular data updates and a system for linking and managing evaluation results. Ultimately, UNI possesses the potential to evolve beyond a tool for measuring a city's ecological performance into an action-oriented indicator system that connects policy implementation with citizen participation. It can become a core foundation for sustainable urban transformation. From this perspective, when developing K-NbS indicators, it is necessary to leverage UNI's structural strengths while designing a customized evaluation system that reflects each city's data foundation, shifts in citizen behavior, and local governance characteristics.

Author Contributions

Conceptualization: YC, SRK. Funding acquisition: YC, SRK. Investigation: YC. Methodology: YC. Validation: YC, SRK. Writing – original draft: YC. Writing – review & editing: YC, SRK.

Conflict of Interest

The authors declare that they have no competing interests.

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