EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(4), 227–240
https://doi.org/10.12912/27197050/183790
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Received: 2024.01.25
Accepted: 2024.02.19
Published: 2024.02.25

Assessing the Ecological Function Effectiveness of Urban Parks in Surakarta City, Indonesia

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ABSTRACT

Urban parks are vital for ecological sustainability within city landscapes, offering services that range from biodiversity preservation to climate regulation. This study evaluates the ecological function effectiveness of urban parks in Surakarta City, providing a quantifiable assessment of their contribution to environmental health and urban biodiversity. Through a systematic analysis of various parks within the Jebres sub-district, ecological function indicators such as green open space ratios, oxygen production, microclimate regulation, air pollution absorption, and biodiversity were measured. The findings indicate that Lansia Park holds the highest effectiveness rate at 78.80%, signifying its exemplary management and ecological value. Contrarily, Gendon ISI Park and Tegalharjo Park presented lower effectiveness rates of 70.40% and 71.00%, respectively, suggesting areas for potential improvement. The average ecological function effectiveness rate across all studied parks stands at 74.03%, reflecting the overall positive impact of Surakarta's green spaces on urban ecology. This research underscores the imperative role of urban parks in enhancing ecosystem services and provides a framework for future urban planning and conservation strategies, emphasizing the enhancement of carbon sequestration capabilities within urban green spaces.

Keywords: urban parks, ecological function, biodiversity, green open space, ecological effectiveness.

INTRODUCTION

The escalating challenges posed by urbanization and climate change have galvanized a global emphasis on sustainable urban planning, with urban greening playing a pivotal role in this paradigm [Suryawan et al., 2024; Suryawan & Lee, 2023; Tiwari & Singh, 2023]. The rationale behind integrating green spaces into urban landscapes hinges on their multifaceted benefits, which include enhancing biodiversity, improving air quality, regulating urban microclimates, and augmenting psychological well-being among city dwellers. In the context of Surakarta City, the distribution and effectiveness of urban parks are crucial for the city's ecological and social vitality. Recent studies have underscored the significance of urban green spaces as critical infrastructures that contribute to the resilience of cities against climate impacts. Parks serve as urban oases that provide ecosystem services, such as carbon sequestration, which is vital in mitigating urban heat island effects and reducing atmospheric CO_2 levels [Elliott et al., 2020; Semeraro et al., 2021; Singh et al., 2020]. The strategic placement of parks can enhance connectivity between habitats, facilitating wildlife movement and promoting urban biodiversity [Apfelbeck et al., 2020; Hwang & Jain, 2021]. In Surakarta City, known for its cultural heritage and burgeoning urban growth, city parks play an instrumental role in maintaining ecological balance within its rapidly urbanizing landscape. The assessment of ecological function effectiveness rates of these parks becomes a cornerstone for evaluating the success of existing green infrastructure policies [Lin et al., 2021]. Such evaluations are aligned with global sustainable development goals that advocate for the creation of inclusive, safe, resilient, and sustainable cities [Pérez del Hoyo et al., 2021]. The concentration of CO_2 in urban areas, primarily due to transportation and industrial activities, heightens the need for effective carbon sinks. Urban parks in Surakarta, therefore, are not merely recreational spaces but also critical components in the city's climate action strategy. The varying effectiveness rates across Surakarta's parks reflect the heterogeneity of urban ecosystems and the potential for optimized land management to enhance ecological benefits.

Studies have largely concentrated on urban centers in developed countries, offering insights into the ecological functions of green spaces within these contexts [Reyes-Riveros et al., 2021; J. Zhang et al., 2020]. Yet, there is a dearth of detailed empirical research examining the relationship between park biodiversity, design, and ecological service provision in emerging urban areas, where different patterns of park usage and maintenance may lead to distinct outcomes for ecosystem services [Dade et al., 2020; Klaus & Kiehl, 2021]. Surakarta City, also known as Solo, presents a unique case study. Despite its rich cultural heritage and notable green spaces, the city's rapid development poses challenges to the maintenance and enhancement of its urban parks' ecological functions. The existing literature provides a baseline understanding of urban greening benefits [Dade et al., 2020; Klaus & Kiehl, 2021; Tibesigwa et al., 2020], but falls short in addressing the complexities of park management and ecological function within the specific socio-economic and cultural context of Indonesian cities. This research aims to delve into the nuances of urban park management in Surakarta, investigating the relationship between park design, biodiversity, and ecological services. By drawing comparisons with other urban studies, this research seeks to contribute to the global discourse on urban sustainability and to propose evidence-based recommendations for urban greening policies that are tailored to the needs and context of Surakarta City.

MATERIALS AND METHODS

Study location

Figure 1 displays a map illustrating the distribution of city parks within the Jebres sub-district of Surakarta City. The map shows a section of the city with its grid-like street layout and the surrounding geography. Each park is indicated by a colored dot, with the legend providing a key to identify the specific parks: Bengawan Solo Park, Cerdas Park, Gendon Humardani Park, Jayawijaya Park, Lansia Park, Sekartaji Park, Sunan Jogo Kali park, and Tegalharjo Park in the Jebres Subdistrict of Surakarta City. Sekartaji Park, known for its lush environs, is a notable green space within the district. Tegalmulyo Park, another significant area, offers a retreat amidst the urban landscape. The Cerdas Soekarno Hatta Park, dedicated to the first President of Indonesia, serves not only as a memorial but also as an ecological haven. Close by, Jayawijaya Park provides a serene atmosphere, contributing positively to the city's green infrastructure. Further enriching the city's green spaces, 1 Lansia Park is a dedicated area for the elderly, promoting well-being through its natural setting. Gendeng Park, associated with the Indonesian Institute of the Arts, adds an artistic dimension to its ecological contribution. Sunan Jogo Kali Park, possibly named after a historical figure or event, is another important ecological spot in the district. Lastly, Bengawan Solo Park, potentially named after the famous river, plays a crucial role in the ecological and cultural landscape of Jebres Subdistrict. Each of these parks is a testament to Surakarta's commitment to maintaining ecological balance and providing recreational spaces for its citizens.

Park effectiveness in Surakarta City analysis

The analysis of park effectiveness in Surakarta City employs a suite of ecological indices and survey methods to ascertain the ecological health and user satisfaction of urban green spaces. The methodological approach is multi-faceted, incorporating both biodiversity metrics and human dimension assessments.

Shannon-Wiener diversity index

The Shannon-Wiener diversity index, denoted as H′, is a mathematical formula used to

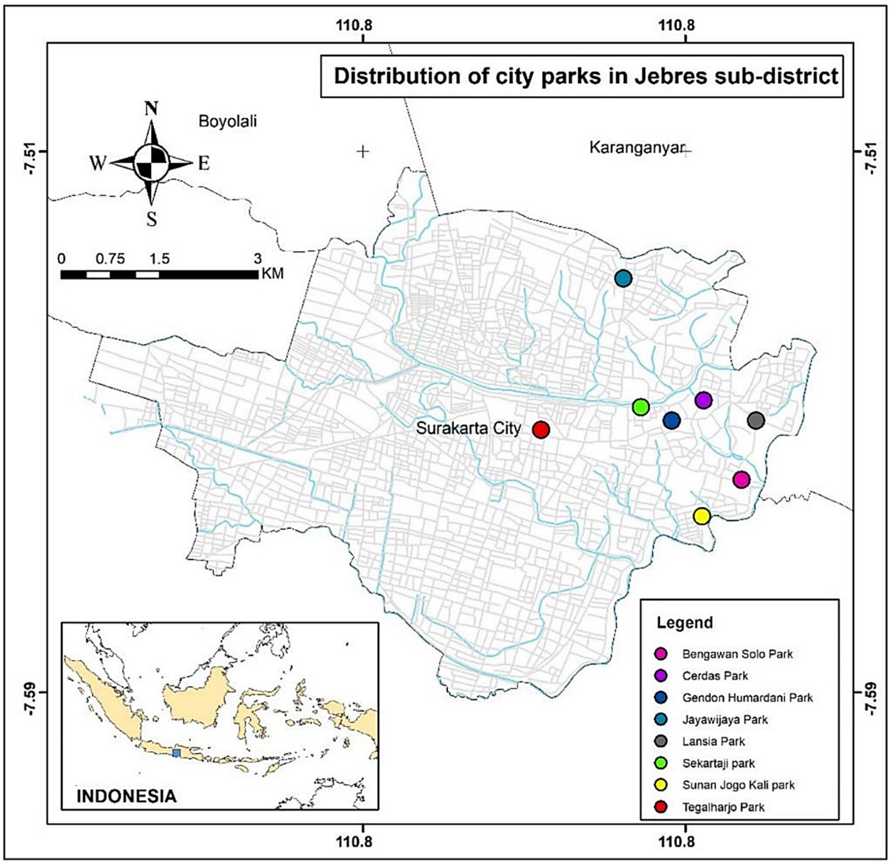

Fig. 1. Park location in Surakarta City

characterize species diversity in a community [Kwiatkowski, 1980; Zhou et al., 2021]. The index accounts for both abundance and evenness of the species present (Equation 1).

$$H' = \sum (p_i \cdot ln(p_i)) \quad (1)$$

where: H' – species diversity index, p_i – proportion of individuals of species i relative to the total number of individuals, calculated as Equation 2.

$$p_i = \frac{ni}{N} \quad (2)$$

where: n_i – number of individuals of species *i, N* – total number of individuals.

Evenness index

The evenness index, denoted by E, measures how evenly individuals are distributed across the different species present in the sample. The ratio of H′ to ln(S) gives the evenness index, which ranges from 0 to 1, with 1 indicating perfect evenness (Equation 3).

$$E = \frac{H\prime}{ln(S)} \quad (3)$$

where: E – species evenness index, S – total number of species, ln(S)– natural logarithm.

Margalef richness index

The Margalef richness index, denoted as R (equation 4), is used to estimate species richness, accounting for the number of species in a habitat relative to the logarithm of the total number of individuals.The formula takes the total number of species S, subtracts 1, and then divides by the natural logarithm of the total number of individuals N. This gives a value that increases with the number of species but is moderated by the sample size.

$$R = \frac{S-1}{ln(N)} \quad (4)$$

where: R – species richness index, S – total number of species in habitat, N – total number of individuals in habitat, ln(N) – natural logarithm.

Simpson's dominance index

Simpson's dominance index, denoted as C (Equation 5), measures the probability that two individuals randomly selected from a sample will belong to the same species. The squared number of individuals for each species is summed and then divided by the square of the total number of individuals. The result is a value between 0 and 1, with 0 representing infinite diversity and 1 representing no diversity.

$$C = \sum\left(\frac{n_i}{N}\right)^2 \quad (5)$$

where: C – dominance index, $\sum$ – summation symbol, indicating that you sum the squared number of individuals of each species across all species.

Likert method

The Likert method is used to calculate the effectiveness based on a Likert scale, which is a psychometric scale commonly involved in research that employs questionnaires (Equation 6).

$$Effectiveness\ (\%)\ \frac{Total\ score\ average}{Maximum\ score} \times 100 \quad (6)$$

RESULTS AND DISCUSSION

Park density in Surakarta City

Park density in Surakarta City, as illustrated by the comprehensive park e in Table 1 for Sekartaji and the tables for other parks, plays a crucial role in the urban ecosystem. These green spaces offer a refuge for biodiversity within the urban landscape, contributing to the ecological balance by supporting a variety of flora and fauna. Parks like Sekartaji, with its casuarinas and mango trees, serve as vital green lungs for the city, improving air quality, regulating the urban heat island effect, and enhancing the aesthetic value of the city. Each park in Surakarta City, as cataloged in the tables, offers a unique assemblage of plants, contributing to the overall green tapestry of the city. Parks like Bengawan Solo, with its high tree density, become critical habitats for urban wildlife, while parks like Jayawijaya and Tegalharjo, with their own distinct floral compositions, offer spaces for environmental education and community engagement. The diversity and density of plants in these parks are indicative of the city's commitment to preserving natural habitats in urban settings, enhancing the quality of life for its residents, and taking active steps towards sustainable urban development.

Table 2 presents the plant density in Sekartaji Park, detailing the diversity of flora within the area. For instance, there are 11 individuals of Casuarina with a density of 0.00180, and the Rain Tree has 5 individuals with a density of 0.00082. A significant number of Mango trees, 60 individuals, are present with a density of 0.00980. Table 2 also includes species with a single individual, such as the Jackfruit and the Breadfruit, showing densities of 0.00016 and 0.00033, respectively. Teak has the highest number of individuals at 131, with a density of 0.02141. The list continues with other species, providing a comprehensive overview of the plant population in Sekartaji Park, reflecting the area's ecological diversity.

Table 3, titled provides a detailed overview of the flora within Bengawan Solo Park. The table lists the common and Latin names of various

Table 1. Park function in Surakarta City

No	Park name	Function
1	Sekartaji Park	Possibly a well-located urban green space known for its rich diversity of plants, contributing to the city's oxygen supply and providing a cool, shaded area that helps mitigate urban heat islands.
2	Bengawan Solo Park	Likely situated in a strategic area where the convergence of natural and urban elements provides significant ecological benefits, such as air purification and recreational spaces.
3	Tegalharjo Park	Could be described as a park that enhances local biodiversity and offers educational opportunities on the importance of maintaining green spaces in urban settings.
4	Jayawijaya Park	Might be an urban oasis with dense vegetation that serves as a carbon sink and a hub for community engagement and environmental awareness.
5	Lansia Park	This park could cater to the elderly population, providing a tranquil environment that supports a variety of plant species and promotes wellbeing.
6	Gendon ISI Park	As a park linked to an educational institution, it might blend the functions of leisure, learning, and ecological sustainability, possibly featuring a diverse range of flora.
7	Cerdas Soekarno Hatta Park	This park may serve as a memorial and a green space, offering both historical significance and ecological benefits such as air quality improvement and urban cooling.
8	Sunan Jogo Kali Park	Perhaps a park with cultural or historical importance, maintaining a collection of native plants that contribute to the local ecosystem's health and resilience.

Table 2. Plant density in Sekartaji Park

Common name	Latin name	Number of Individuals	Density
Casuarina	*Casuarina Equisetifolia Linn*	11	0.00180
Rain tree	*Samanea Saman*	5	0.00082
Yellow bamboo	*Bambusa vulgaris var. striata*	10	0.00163
Jackfruit	*Artocarpus heterophyllus*	1	0.00016
Mango	*Mangifera indica*	60	0.00980
Phoenix palm	*Phoenix canariensis*	5	0.00082
Cabbage tree	*Cordyline Australis*	2	0.00033
Indian almond	*Terminalia catappa*	13	0.00212
Weeping fig	*Ficus Benjamina*	7	0.00114
Sea hibiscus	*Hibiscus tiliaceus*	5	0.00082
Pigeon berry	*Polyalhia longifolia*	18	0.00294
Red powderpuff	*Syzygium myrtifolium*	3	0.00049
Water apple	*Syzygium aqueum*	1	0.00016
Mahogany	*Swietenia Mahogany*	3	0.00049
Coconut	*Cocos nucifera L*	2	0.00033
Flame tree	*Delonix Regia*	19	0.00310
African oil palm	*Elaeis guineensis*	37	0.00605
Bamboo	*Bambusa vulgaris*	24	0.00393
Rosewood	*Dalbergia sissoo*	2	0.00033
Star apple	*Chrysophyllum cainito*	4	0.00065
Saga seed	*Abrus precatorius*	1	0.00016
Trumpet tree	*Tabebuia chrysotricha*	1	0.00016
Teak	*Tectona grandis*	131	0.02141
Quinine	*Cinchona*	1	0.00016
Lead tree	*Leucaena leucocephala*	1	0.00016
Breadfruit	*Artocarpus altilis*	2	0.00033
Giant bamboo	*Gigantochloa verticillata munro*	7	0.00114
Muntingia	*Muntingia calabura*	1	0.00016
Royal palm	*Roystonea regia*	9	0.00147
Cabbage palm	*Cordyline Australis*	3	0.00049

plant species, the number of individual plants of each species found within the park, and their respective densities. Pigeon Berry, with 34 individuals, has a notable presence with a density of 0.000938, suggesting it may be a commonly featured tree in the park. The Rain Tree, though fewer in number, still contributes to the park's canopy with one individual recorded. The Lead Tree and Angsana, with 6 and 3 individuals respectively, indicate a moderate presence, offering diversity with densities of 0.001736 and 0.000868. Casuarina and Guava, both with 2 individuals, add to the park's biodiversity.

Betel Nut Palm shows a higher density of individuals, numbering 10, which is significant for the park's ecological structure. The Red Powderpuff stands out with the highest number of individuals at 63, indicating its prominence in the park's ecosystem with a density of 0.018229. Noni and Kecapi, each with 2 and 6 individuals respectively, along with Sea Trumpet and Frangipani (White), each with one and two individuals, contribute to the park's ecological health and aesthetic value.

Tegalharjo Park boasts a modest variety of flora, including the Casuarina with its whispering needles and sturdy form, represented by three specimens that contribute to the park's serene atmosphere (Table 4). A single Matoa tree is noted for its exotic fruit, adding a touch of diversity. The Jelutong trees, numbering four, stand tall, offering dense canopies that are likely hubs for birdlife. Three Indian Almond trees, with their

Table 3. Plant density in Bengawan Solo Park

Common name	Latin name	Number of Individuals	Density
Pigeon berry	*Polyalhia longifolia*	34	0.009838
Rain tree	*Samanea Saman*	1	0.000289
Lead tree	*Leucaena leucocephala*	6	0.001736
Angsana	*Pterocarpus Indicus*	3	0.000868
Casuarina	*Casuarina Equisetifolia Linn*	2	0.000579
Guava	*Psidium guajava*	2	0.000579
Betel nut palm	*Calamus ciliaris*	10	0.002894
Red powderpuff	*Syzygium myrtifolium*	63	0.018229
Noni	*Morinda citrifolia*	2	0.000579
Kecapi	*Sandoricum koetjape*	6	0.001736
Sea trumpet	*Thespesia populnea*	1	0.000289
Frangipani (White)	*Plumeria pudica*	2	0.000579

Table 4. Plant density in Tegalharjo Park

Common name	Latin name	Number of Individuals	Density
Casuarina	*Casuarina Equisetifolia Linn*	3	0.022901
Matoa	*Pometia pinnata*	1	0.007634
Jelutong	*Larpotea*	4	0.030534
Indian almond	*Terminalia mantaly*	3	0.022901
Red powderpuff	*Syzygium myrtifolium*	3	0.022901

broad, spreading branches, provide ample shade, while an equal number of Red Powderpuff trees brighten up the landscape with their vivid flowers. Each species enriches the park with its unique characteristics, enhancing the green fabric of Tegalharjo Park and offering ecological and aesthetic value to the urban environment.

Table 5 provides an inventory of the plant life within Jayawijaya Park. The park is home to a diverse array of trees and plants, each contributing to the park's lush environment. Indian Almond trees with their widespread shade, alongside the elegant Rosewood trees, and the ornamental Trumpet Trees enhance the park's beauty and biodiversity. The park also features the robust Sala Tree and the vibrant Red Powderpuff, adding splashes of color against the green backdrop. Several Weeping Fig trees intersperse the park, creating cool spots for visitors, while the Malabar Ebony adds a touch of the tropics with its presence. Fruit-bearing trees like the Mango and Breadfruit offer both shade and sustenance, and the singular Durian tree stands as a unique feature. The Lead Tree and the flamboyant Peacock Flower diversify the botanical range, and a solitary Hibiscus bloom adds a tropical flair. Sawo trees and Muntingia, with their sweet offerings, are joined by the Pule tree, known for its traditional uses. Paw-Paw trees, with their distinctive fruits, stand alongside the tangy Tamarind, and the Bisbul tree adds to the park's ecological richness. Visitors can also find the Kaki Persimmon and Guava trees, as well as the White Champaca, with its fragrant blossoms. The grand White Teak and the stately Flame Tree are notable landmarks within the park, while the Pigeon Berry trees and Angsana add further greenery. The park's Teak trees stand tall, symbolizing strength and endurance, and the Ebony trees, with their impressive density, are integral to the park's character. Each plant species plays a role in creating a harmonious ecosystem, making Jayawijaya Park a verdant haven in the urban landscape.

Table 6 details the variety of plant life populating Lansia Park. The park is graced with a single Lead Tree, known for its resilience in urban environments. Dominating the landscape is the Red Powderpuff, with its 270 individuals boasting vibrant blooms that contribute significantly to the park's aesthetic and density. The Persian Silk Tree adds a touch of elegance with eight

Table 5. Plant density in Jayawijaya Park

Common name	Latin name	Number of individuals	Density
Indian almond	*Terminalia catappa*	3	0.00048
Rosewood	*Terminalia mantaly*	22	0.00352
Trumpet tree	*Tabebuia chrysotricha*	13	0.00208
Sala tree	*Shorea robusta*	2	0.00032
Red powderpuff	*Syzygium myrtifolium*	13	0.00208
Weeping fig	*Ficus longisland*	12	0.00192
Malabar ebony	*Diospyros malabarica*	7	0.00112
Mango	*Mangifera indica*	8	0.00128
Breadfruit	*Artocarpus altilis*	2	0.00032
Durian	*Durio zibethinus*	1	0.00016
Lead tree	*Leucaena leucocephala*	1	0.00016
Peacock flower	*Caesalpinia pulcherrima*	11	0.00176
Hibiscus	*Hibiscus rosa-sinensis*	1	0.00016
Sawo	*Manilkara zapota*	3	0.00048
Muntingia	*Muntingia calabura*	6	0.00096
Pule	*Alstonia scholaris*	2	0.00032
Paw-paw	*Asimina triloba*	13	0.00208
Tamarind	*Tamarindus indica*	4	0.00064
Bisbul	*Diospyros blancoi*	1	0.00016
Kaki persimmon	*Diospyros kaki*	3	0.00048
Guava	*Psidium guajava*	1	0.00016
White champaca	*Magnolia × alba*	1	0.00016
Wuni	*Antidesma bunius*	1	0.00016
Flame tree	*Delonix regia*	1	0.00016
Pigeon berry	*Polyalhia longifolia*	9	0.00144
Angsana	*Pterocarpus Indicus*	5	0.0008
Teak	*Tectona grandis*	2	0.00032
Ebony	*Diospyros celebica*	15	0.0024

specimens, while the stately Mahogany is well represented with 73 trees, providing a substantial canopy and contributing to the park's green infrastructure. The Bintaro and Guava trees, with three and two individuals respectively, offer fruit and shade. The Namnam and Angsana/Padauk, each with a single tree and three trees respectively, enhance the park's biodiversity. An Indian Almond tree stands alone, and a couple of Weeping Fig trees add to the mix with their distinctive appearance. A lone Black Wattle, a Teak with nine strong individuals, and a Sea Hibiscus contribute to the park's tropical feel. The Mango tree, the Barbados Nut, and two types of Earleaf Acacia, each represented by a single specimen, diversify the botanical collection of Lansia Park. These species together create a microhabitat for urban wildlife and a peaceful retreat for the park's visitors, reflecting the importance of plant diversity in urban green spaces.

Gendon ISI Park is adorned with a selection of plants that enhance its tranquil ambiance (Table 7). The Weeping Fig makes its presence felt with three individuals, contributing to the park's shaded areas with a notable density. The fragrant Frangipani, with its five blooming individuals, adds a tropical allure to the park's landscape. Sturdy Teak trees, numbering four, stand as testaments to the park's commitment to long-term greenery, while six Bottle Palms lend an exotic touch with their distinctive silhouettes. The park also features seven Royal Palms, which are prominent features that likely line pathways or frame vistas within the park.

Table 8 presents a rich tapestry of plant life within the park. The park is distinguished by the

Table 6. Plant density in Lansia Park

Common name	Latin name	Number of individuals	Density
Lead tree	*River tamarind*	1	0.000260
Red powderpuff	*Syzygium myrtifolium*	270	0.007029
Persian silk tree	*Prunus persica*	8	0.002083
Mahogany	*Swietenia mahagoni*	73	0.001901
Bintaro	*Cerbera manghas*	3	0.000781
Guava	*Common guava*	2	0.000260
Namnam	*Cynometra cauliflora*	1	0.000260
Angsana/padauk	*Pterocarpus indicus*	3	0.000781
Indian almond	*Terminalia catappa*	1	0.000260
Weeping fig	*Ficus benjamina*	2	0.000521
Black wattle	*Acacia mearnsii*	1	0.000260
Teak	*Tectona grandis*	9	0.002341
Sea hibiscus	*Hibiscus tiliaceus*	1	0.000260
Mango	*Mangifera indica*	1	0.000260
Barbados nut	*Jatropha curcas*	1	0.000260
Earleaf acacia	*Acacia retinodes*	1	0.000260
Earleaf acacia	*Acacia auriculiformis*	1	0.000260

Table 7. Plant density in Gendon ISI Park

Common name	Latin name	Number of individuals	Density
Weeping fig	*Ficus benjamina*	3	0.001353
Frangipani	*Plumeria acuminata*	5	0.000225
Teak	*Tectona grandis*	4	0.001803
Bottle palm	*Hyophorbe lagenicaulis*	6	0.002705
Royal palm	*Roystonea regia*	7	0.003156
Red powderpuff	*Syzygium myrtifolium*	3	0.001353

presence of Indian and Tropical Almond trees, each species numbering thirteen and creating a lush canopy with their collective density. Mango trees, equally numbered, add to the park's fruity abundance. A solitary Weeping Fig offers a quiet corner of respite, while the Longan trees, with four individuals, and the Rambutan trees, with three, introduce a subtropical element to the mix. The single Mistletoe Fig and two Mulberry trees contribute to the botanical diversity, as do a pair of Hong Kong Orchid Trees with their striking flowers. The Broadleaf Lady Palm and a lone Sapodilla stand as unique elements, each enhancing the park's landscape. Two Lead Trees provide shade and structure, while the singular Golden Shower Tree and Persian Silk Tree add bursts of color. A Matoa tree and nine Pigeon Berry trees infuse the park with their distinct characteristics, and a Casuarina tree rounds out the park's varied plant community. Mango trees take the lead with 35 individuals, creating a vibrant and lush setting with their dense foliage in Sunan Jogo Kali Park (Table 9). The park also cherishes a single Indian Almond tree, and a considerable number of Sapodilla trees, amounting to 16, which might be contributing to the park's diversity with their sweet fruit.

The Sweet Orange trees, with 13 individuals, dot the park with their citrus fragrance, while a couple of Cajeput trees lend their medicinal properties to the mix. The Soursop trees, five in number, add to the park's tropical feel. The Matoa trees, significantly represented by 17 individuals, are likely to be a highlight in the park with their unique presence. A single Sandbox Tree stands out with its distinctive features, and the Hong Kong Orchid Trees, numbering two, embellish the park with their ornamental flowers. A lone Coconut tree adds to the tropical atmosphere, indicative of the park's varied ecological habitat. The lower part of the table, though partially obscured, seems to list

Table 8. Plant density in Cerdas Soekarno-Hatta Park

Common name	Latin name	Number of individuals	Density
Indian almond	*Terminalia mantaly*	13	0.002845
Tropical almond	*Terminalia catappa*	13	0.002845
Mango	*Mangifera indica*	13	0.002845
Weeping fig	*Ficus benjamina*	1	0.000218
Longan	*Dimocarpus longan*	4	0.000875
Rambutan	*Nephelium lappaceum*	3	0.000655
Mistletoe fig	*Ficus deltoidea*	1	0.000218
Mulberry	*Morus alba*	2	0.000436
Hong kong orchid tree	*Bauhinia blakeana*	2	0.000436
Broadleaf lady palm	*Rhapis excelsa*	1	0.000218
Sapodilla	*Manilkara zapota*	1	0.000218
Lead tree	*Leucaena leucocephala*	2	0.000436
Golden shower tree	*Dysoxylum lutescens*	1	0.000218
Persian silk tree	*Prunus persica*	1	0.000218
Matoa	*Pometia pinnata*	2	0.000436
Pigeon berry	*Polyalhia longifolia*	9	0.001964
Casuarina	*Casuarina Equisetifolia Linn*	1	0.000218

Table 9. Plant density in Sunan Jogo Kali Park

Common name	Latin name	Number of individuals	Density
Mango	*Mangifera indica*	35	0.007778
Indian almond	*Terminalia mantaly*	1	0.000222
Sapodilla	*Manilkara zapota*	16	0.003556
Sweet orange	*Citrus aurantium*	13	0.002889
Cajeput	*Melaleuca cajuputi Powell*	2	0.000444
Soursop	*Annona muricata*	5	0.001111
Matoa	*Pometia pinnata*	17	0.003778
Sandbox tree	*Hura crepitans*	1	0.000222
Hong Kong orchid tree	*Bauhinia blakeana*	2	0.000444
Coconut	*Cocos nucifera*	1	0.000222
Guava	*Psidium guajava*	1	0.000222
Weeping fig	*Ficus benjamina*	1	0.000222

two additional plants – a Guava tree and a Weeping Fig, each with a single individual, suggesting that these species might be playing their part in enhancing the park's biodiversity. This botanical assortment in Sunan Jogo Kali Park not only contributes to the aesthetic and ecological value of the urban landscape but also offers educational and recreational opportunities for visitors.

Park effectiveness in Surakarta City

Sekartaji Park stands out with the highest Shannon-Wiener Diversity Index (H') at 2.42, indicating a high variety of species. Its Species Richness (R) is moderate at 4.86, suggesting a good number of different species, while the Evenness (E) score of 0.71 and low Dominance (D) value of 0.16 reveal that species are relatively evenly distributed, with no single species dominating the ecosystem. Bengawan Solo Park has a lower H' value at 1.82 but boasts the highest R value at 41.84, suggesting that while there may be fewer species overall, there is a high representation of individual species. Tegalharjo Park shows more modest biodiversity with an H' of 1.54 and the second-highest R value at 10.99, indicating a park with fewer species but a reasonable spread among them (Table 10). Jayawijaya Park has the second-highest H' value at 2.97, paired with a high evenness of 0.87, suggesting a diverse and well-balanced ecosystem. Its low D score reinforces this, implying minimal dominance by any single species. Lansia Park presents the lowest H' value at 1, indicating less diversity. Its R score of 4.88 is like Sekartaji Park, but a higher D score suggests a more uneven distribution of species. Gendon ISI Park, with an H' of 1.5 and a very high R of 26.4, might have fewer species but a significant number of certain species, as indicated by its higher dominance index. Cerdas Soekarno Hatta Park shows respectable diversity with an H' of 2.33 and a moderate R value of 6.83, suggesting a balanced ecological setting. Finally, Sunan Jogo Kali Park, with an H' of 1.77, has a moderate level of diversity and an R value of 6.38, which points to a reasonably rich variety of species within the park.

The diversity indices of various parks in Surakarta City, as depicted in Table 10, provide insightful data for ecological and conservation discussions. Sekartaji Park's high Shannon-Wiener Diversity Index (H') reflects a successful implementation of biodiversity conservation strategies, possibly due to the variety of habitats within the park that support different species. Its moderate Species Richness (R) and high Evenness (E) suggest that the park's management practices might be focusing not just on the quantity but also the quality of species diversity, ensuring that no single species dominates the ecosystem.Comparatively, Bengawan Solo Park, despite its lower H' value, showcases an incredibly high R value, which might be due to specific ecological niches or the presence of a particular species that thrives in its environment. This characteristic is somewhat reminiscent of findings in other urban ecological studies, such as the study by Fuller and Gaston (2009), which found that some urban parks, due to their size or historic planting schemes, can harbor a large number of individuals from a smaller pool of species [Fournier et al., 2020].Tegalharjo Park's biodiversity is more modest, with an H' of 1.54 and the second-highest R value at 10.99. This park may benefit from habitat enhancements or management interventions aimed at increasing species variety. Jayawijaya Park, on the other hand, exhibits a rich biodiversity like that found in larger or less-disturbed parks in urban landscapes, as reported by Nielsen et al. (2014), where higher plant diversity has been linked to larger park areas and naturalistic park management practices [Aronson et al., 2017; Chang et al., 2021].

Lansia Park, with the lowest H' value, may face challenges in species diversity, which could be due to its specific use or design, limiting habitat variety. This contrasts with Gendon ISI Park, which, despite its lower diversity index, shows a high R value, suggesting that certain species have been given the conditions to thrive, a phenomenon also observed in specialized habitats within urban environments [Callaghan et al., 2020; Chang et al., 2021; Kotze et al., 2022]. Cerdas Soekarno Hatta Park shows a respectable diversity, with its H' and R values suggesting a well-maintained balance between species richness and evenness, highlighting the potential for urban parks to maintain biodiversity amidst development, as noted by [Ayeni et al., 2023; Chen & Li, 2021]. Sunan Jogo Kali Park's moderate diversity index aligns with the trend observed in smaller urban parks or those with a high degree of human intervention, where a moderate number of species are well represented but without a high level of overall diversity.

Table 11 examines the performance of various parks in Surakarta City across several ecological

Table 10. Values of diversity indices, species richness, evenness, and dominance

Park name	H'	E	D	R
Sekartaji Park	2.42	0.71	0.16	4.86
Bengawan Solo Park	1.82	0.54	0.3	41.84
Tegalharjo Park	1.54	0.45	0.16	10.99
Jayawijaya Park	2.97	0.87	0.06	5.65
Lansia Park	1	0.29	0.54	4.88
Gendon ISI Park	1.5	0.44	0.15	26.4
Cerdas Soekarno Hatta Park	2.33	0.69	0.12	6.83
Sunan Jogo Kali Park	1.77	0.52	0.22	6.38

function indicators. The Table 11 evaluates each park based on its green open space ratio, oxygen production, microclimate regulation including dust and noise absorption, air pollution absorption, water habitat and fauna diversity (biodiversity), culminating in an average score that reflects overall ecological function effectiveness. Lansia Park excels in the green open space ratio, suggesting it may serve as a significant green buffer within urban and provincial areas, while also scoring highly in oxygen production and microclimate regulation, indicative of its well-maintained vegetation that contributes to air quality and climate moderation.

Jayawijaya Park, while having a lower green open space ratio, maintains a strong performance in oxygen production and shows a commitment to biodiversity conservation, potentially offering a variety of habitats within its confines. Cerdas Soekarno Hatta Park demonstrates notable effectiveness in oxygen production and air pollution absorption, pointing to robust plant growth that can sequester carbon and mitigate pollutants, contributing to a healthier urban environment. Gendon ISI Park, with slightly lower scores across the indicators, might focus on specific areas of improvement, particularly in enhancing its biodiversity to elevate its overall ecological contribution. Sekartaji Park shows exceptional oxygen production, possibly due to its rich plant diversity and density, which also contributes positively to its microclimate regulation and air pollution absorption. Bengawan Solo Park, maintaining a solid average in all indicators, might benefit from targeted conservation efforts to boost its lower water habitat and fauna diversity score. Tegalharjo Park, while showing more modest scores, still contributes to the city's ecological functions, especially in oxygen production and microclimate regulation, signaling potential for further ecological enhancements. Sunan Jogo Kali Park presents a high green open space ratio, indicating ample greenery, which is supported by its good scores in oxygen production and ecological function indicators, making it a vital component of the city's green infrastructure.

Figure 2 showcasing the distribution and effectiveness ratings of various city parks within the Jebres sub-district of Surakarta City. The map provides a visual guide to the location and ecological performance of each park, as indicated by colored dots scattered across the urban grid. The parks are evaluated based on their ecological function effectiveness, with percentages displayed to denote the success rate of each park in fulfilling its ecological role. For example, Sekartaji Park is noted for having a high effectiveness rate of 77.90%, while Jayawijaya Park is slightly higher at 78.80%. Cerdas Park has an effectiveness rate of 76.60%, indicating a robust contribution to the city's environmental health. Lansia Park stands out with the highest effectiveness at 78.80%, suggesting it may be particularly well-maintained or feature a diverse range of habitats. Bengawan Solo Park also shows a high effectiveness rate of 78.90%, potentially reflecting well-implemented conservation practices or a variety of recreational and natural areas that boost its

Table 11. Ecological function effectiveness rates

Park	Ecological function indicators					
	Green open space ratio (urban and provincial)	Oxygen	Microclimate regulation, dust, and noise absorption	Air pollution absorption	Water habitat and fauna diversity (biodiversity)	Average
Lansia Park	89.20%	81.20%	77.60%	77.60%	67.20%	78.56%
Jayawijaya Park	56.80%	79.60%	76.80%	68.00%	72.00%	70.64%
Cerdas Soekarno Hatta Park	83.20%	85.20%	68.00%	65.00%	70.00%	74.28%
Gendon ISI Park	75.20%	74.40%	65.20%	73.70%	66.80%	71.06%
Sekartaji Park	82.00%	87.60%	73.20%	77.20%	75.20%	79.04%
Bengawan Solo Park	75.60%	81.20%	77.20%	68.40%	61.20%	72.72%
Tegalharjo Park	65.00%	78.90%	68.40%	69.20%	71.60%	70.62%
Sunan Jogo Kali Park	81.65%	80.95%	71.95%	71.95%	69.90%	75.28%
Average score	76.08%	81.13%	72.29%	71.38%	69.24%	74.03%

ecological functions. Other parks, such as Tegalharjo Park and Gendon Humardani Park, have effectiveness rates of 71.00% and 70.40% respectively, which are still commendable and contribute to the overall green infrastructure of the city. Sunan Jogo Kali Park, with an effectiveness rate of 76.50%, adds to the network of green spaces providing ecological benefits to the urban area.

The high ecological effectiveness rates found in parks like Sekartaji and Jayawijaya suggest that current management practices are successful in maintaining biodiversity and providing ecological services. This implies that urban greening policies should continue to focus on diversity, not just in plant species but also in the types of habitats offered within urban parks. It is recommended that city planners and policymakers replicate these practices in less effective parks to enhance overall urban biodiversity. The effectiveness rates also highlight the importance of integrating green spaces into urban planning. Policies that prioritize the expansion of green spaces can lead to increased carbon sequestration, reduced urban heat island effects, and improved air quality. Cities should consider incentivizing the creation of private green spaces, such as green roofs and community gardens, as complementary strategies to public park enhancement.

For future research, the data points to the need for a comprehensive assessment of carbon stocks within these urban parks. Carbon stock research in urban environments can help quantify the role of city parks in mitigating climate change. This research should employ a multidisciplinary approach, combining remote sensing technology for biomass estimation with on-the-ground measurements of tree girth and species-specific growth rates [Krause et al., 2023; Vázquez-Alonso et al., 2022]. Further, the varying effectiveness rates across different parks suggest that the impact of park size, design, and location on carbon sequestration should be investigated. Research could explore how park features, such as water bodies, varied topography, and the presence of mature trees, contribute to carbon storage capacity. The role of park usage patterns in influencing carbon sequestration should also be examined, as human activities can affect the health and growth of vegetation [Feng et al., 2023; Suhardono, Septiariva, et al., 2024; Wang et al., 2021]. Lastly,

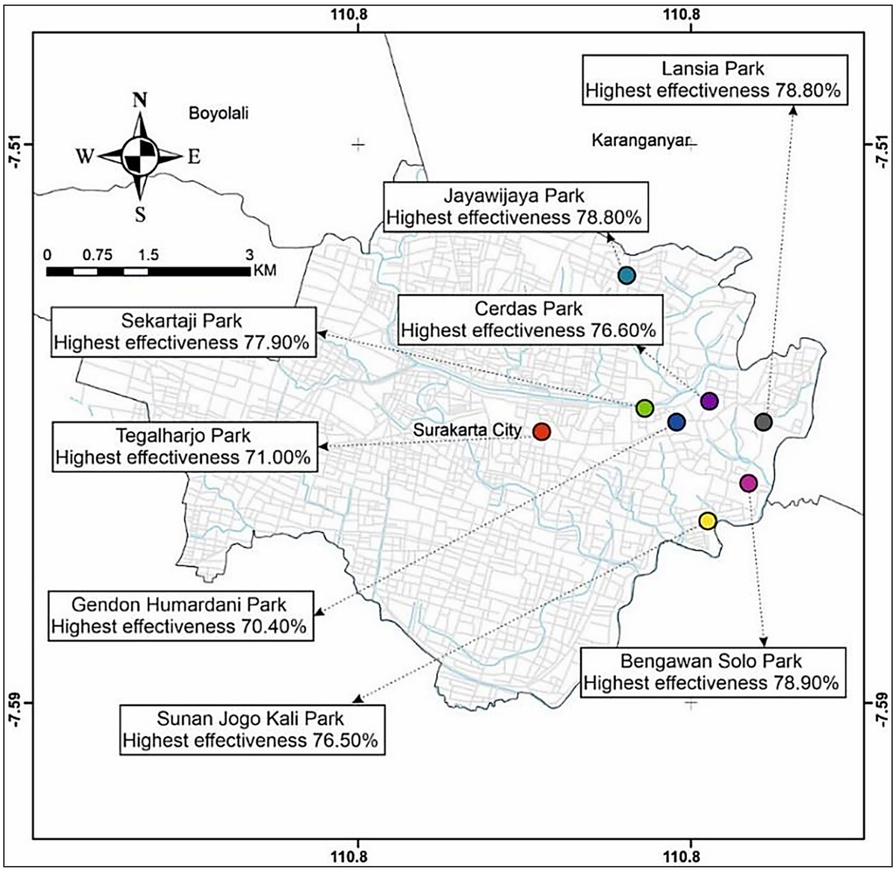

Fig. 2. Distribution and effectiveness ratings of various city parks within the Jebres sub-district of Surakarta City

this research should be integrated into broader urban sustainability studies, contributing to the development of green infrastructure as a key element of climate change mitigation strategies. The adoption of policies that promote the planting of native, carbon-rich tree species, and the maintenance of healthy soils in urban parks can enhance carbon sequestration and maximize the ecological benefits of urban green spaces [Mendez et al., 2023; Shin et al., 2022; Suhardono, Hermawan, et al., 2024]. The findings from Surakarta's city parks serve as a valuable benchmark for other urban areas and underline the importance of investing in green infrastructure as a critical component of sustainable urban development.

CONCLUSIONS

The study of urban park effectiveness in Surakarta City reveals a multifaceted insight into the ecological and recreational utility of these green spaces. The application of biodiversity indices such as the Shannon-Wiener Diversity Index (H'), Evenness Index (E), Margalef Richness Index (R), and Simpson's Dominance Index (C), alongside the Likert method for assessing public perception, has provided a comprehensive assessment of the parks' ecological functions.Key findings indicate that Lansia Park ranks highest in ecological function effectiveness, demonstrating successful management practices that enhance biodiversity and ecosystem services. Despite some parks exhibiting lower effectiveness rates, the overall average effectiveness rate for all parks studied stands at a commendable 74.03%. This indicates that, while there is room for improvement, Surakarta City's parks collectively contribute positively to the urban environment.

The variation in effectiveness rates underscores the need for tailored management strategies for each park, prioritizing biodiversity, user satisfaction, and ecological benefits. Future policies should focus on enhancing species richness and evenness, especially in parks with lower biodiversity indices, to foster a more balanced and resilient urban ecosystem. Furthermore, this study lays the groundwork for future research, particularly in the realm of carbon sequestration. Given the current global emphasis on climate action, the ability of urban parks to act as carbon sinks is of paramount importance. Subsequent research should delve deeper into the quantification of carbon stocks within these urban landscapes to better integrate green spaces into climate mitigation strategies.

REFERENCES

1. Apfelbeck B., Snep R.P.H., Hauck T.E., Ferguson J., Holy M., Jakoby C., Scott MacIvor J., Schär L., Taylor M., Weisser W.W. 2020. Designing wildlife-inclusive cities that support human-animal co-existence. Landscape and Urban Planning, 200, 103817.
2. Aronson M.F.J., Piana M.R., MacIvor J.S., Pregitzer C.C. 2017. Management of plant diversity in urban green spaces. Urban Biodiversity, 101–120.
3. Ayeni A.O., Aborisade A.G., Onuminya T.O., Soneye A.S.O., Ogundipe O.T. 2023. Urban Development in Africa and Impact on Biodiversity. Current Landscape Ecology Reports, 8(2), 73–89.
4. Callaghan C.T., Benedetti Y., Wilshire J.H., Morelli F. 2020. Avian trait specialization is negatively associated with urban tolerance. Oikos, 129(10), 1541–1551.
5. Chang C.-R., Chen M.-C., Su M.-H. 2021. Natural versus human drivers of plant diversity in urban parks and the anthropogenic species-area hypotheses. Landscape and Urban Planning, 208, 104023.
6. Chen W.Y., Li X. 2021. Urban forests' recreation and habitat potentials in China: A nationwide synthesis. Urban Forestry & Urban Greening, 66, 127376.
7. Dade M.C., Mitchell M.G.E., Brown G., Rhodes J.R. 2020. The effects of urban greenspace characteristics and socio-demographics vary among cultural ecosystem services. Urban Forestry & Urban Greening, 49, 126641.
8. Elliott H., Eon C., Breadsell J.K. 2020. Improving City Vitality through Urban Heat Reduction with Green Infrastructure and Design Solutions: A Systematic Literature Review. Buildings, 10(12).
9. Feng H., Kang P., Deng Z., Zhao W., Hua M., Zhu X., Wang Z. 2023. The impact of climate change and human activities to vegetation carbon sequestration variation in Sichuan and Chongqing. Environmental Research, 238, 117138.
10. Fournier B., Frey D., Moretti M. 2020. The origin of urban communities: From the regional species pool to community assemblages in city. Journal of Biogeography, 47(3), 615–629.
11. Hwang Y.H., Jain A. 2021. Landscape design approaches to enhance human–wildlife interactions in a compact tropical city. Journal of Urban Ecology, 7(1), juab007.
12. Klaus V.H., Kiehl K. 2021. A conceptual framework for urban ecological restoration and rehabilitation. Basic and Applied Ecology, 52, 82–94.
13. Kotze D.J., Lowe E.C., MacIvor J.S., Ossola A.,

Norton B.A., Hochuli D.F., Mata L., Moretti M., Gagné S.A., Handa I.T., Jones T.M., Threlfall C.G., Hahs A.K. 2022. Urban forest invertebrates: how they shape and respond to the urban environment. Urban Ecosystems, 25(6), 1589–1609.

14. Krause P., Forbes B., Barajas-Ritchie A., Clark M., Disney M., Wilkes P., Bentley L.P. 2023. Using terrestrial laser scanning to evaluate non-destructive aboveground biomass allometries in diverse Northern California forests. Frontiers in Remote Sensing, 4.
15. Kwiatkowski R.E. 1980. The use of the Shannon-Wiener diversity index to delineate the horizontal distribution of crustacean zooplankton communities in Lake Superior, 1973. Hydrobiologia, 68, 247–256.
16. Lin S.-H., Zhao X., Wu J., Liang F., Li J.-H., Lai R.-J., Hsieh J.-C., Tzeng G.-H. 2021. An evaluation framework for developing green infrastructure by using a new hybrid multiple attribute decision-making model for promoting environmental sustainability. Socio-Economic Planning Sciences, 75, 100909.
17. Mendez Q. R., Creutzig F., Fuss S., Lück S. 2023. Towards carbon-neutral cities: an assessment of urban CO2 removal and albedo management. Research Square.
18. Pérez del Hoyo R., Visvizi A., Mora H. 2021. Chapter 2 - Inclusiveness, safety, resilience, and sustainability in the smart city context (A. Visvizi & R. B. T.-S. C. and the un Sdg. Pérez del Hoyo (Eds.). Elsevier, 15–28.
19. Reyes-Riveros R., Altamirano A., De La Barrera F., Rozas-Vásquez D., Vieli L., Meli P. 2021. Linking public urban green spaces and human well-being: A systematic review. Urban Forestry & Urban Greening, 61, 127105.
20. Semeraro T., Scarano A., Buccolieri R., Santino A., Aarrevaara E. 2021. Planning of Urban Green Spaces: An Ecological Perspective on Human Benefits. Land 10(2).
21. Shin Y., Midgley G.F., Archer E.R.M., Arneth A., Barnes D.K.A., Chan L., Hashimoto S., Hoegh-Guldberg O., Insarov G., Leadley P. 2022. Actions to halt biodiversity loss generally benefit the climate. Global Change Biology, 28(9), 2846–2874.
22. Singh N., Singh S., Mall R. K. 2020. Chapter 17 - Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus (P. Verma, P. Singh, R. Singh, & A.S.B.T.-U.E. Raghubanshi (Eds.). Elsevier, 317–334.
23. Suhardono S., Hermawan B., Aulia A.N.A., Restanti A.D., Ramadhan A.W.W., Septiariva I.Y., Sari M. M., Suryawan I.W.K. 2024. Carbon Sequestration and Environmental Service Assessment in the Special Purpose Forest Area of Mount Bromo, Indonesia. Journal of Ecological Engineering, 25(4).
24. Suhardono S., Septiariva I.Y., Mulyana R., Sari M.M., Ulhasanah N., Prayogo W., Suryawan I.W.K. 2024. Human activities and forest fires in Indonesia : An analysis of the Bromo incident and implications for conservation tourism. Trees, Forests and People, 15.
25. Suryawan I.W.K., Lee C.-H. 2023. Community preferences in carbon reduction: Unveiling the importance of adaptive capacity for solid waste management. Ecological Indicators, 157, 111226.
26. Suryawan I.W.K., Mulyana R., Yenis Septiariva I., Prayogo W., Suhardono S., Sari M.M., Ulhasanah N. 2024. Smart urbanism, citizen-centric approaches and integrated environmental services in transit-oriented development in Jakarta, Indonesia. Research in Globalization, 8, 100181.
27. Tibesigwa B., Ntuli H., Lokina R. 2020. Valuing recreational ecosystem services in developing cities: The case of urban parks in Dar es Salaam, Tanzania. Cities, 106, 102853.
28. Tiwari D., Singh A. 2023. Exploring the Role of Municipalities in Promoting Sustainable Development with Special Reference to Green Bonds in India. International Journal of Environmental Sciences, 9(2).
29. Vázquez-Alonso M., Lentz D.L., Dunning N.P., Carr C., Anaya Hernández A., Reese-Taylor K. 2022. Lidar-Based Aboveground Biomass Estimations for the Maya Archaeological Site of Yaxnohcah, Campeche, Mexico. Remote Sensing, 14(14).
30. Wang Y., Chang Q., Li X. 2021. Promoting sustainable carbon sequestration of plants in urban greenspace by planting design: A case study in parks of Beijing. Urban Forestry & Urban Greening, 64, 127291.
31. Zhang A., Deng R. 2022. Spatial-temporal evolution and influencing factors of net carbon sink efficiency in Chinese cities under the background of carbon neutrality. Journal of Cleaner Production, 365, 132547.
32. Zhang J., Yu Z., Zhao B., Sun R., Vejre H. 2020. Links between green space and public health: a bibliometric review of global research trends and future prospects from 1901 to 2019. Environmental Research Letters, 15(6), 63001.
33. Zhou J., Gao Y., Wang Y., Zhao Y. J. 2021. The effect of different afforestation tree species on plant diversity after 50 years on mount TAI, CHINA. Applied Ecology & Environmental Research, 19(6).