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PERCEIVED EFFECTIVENESS OF GREEN OPEN SPACES IN URBAN POLLUTION MITIGATION: A COMPARATIVE STUDY OF MELAKA AND PADANG

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Abstract:

Green open spaces (GOS) are widely examined as ecological infrastructure, yet less attention has been given to how regular users perceive their pollution-mitigation functions across contrasting spatial and governance contexts in Southeast Asia. This qualitative comparative study examines perceived effectiveness and limitations of GOS in relation to air pollution, traffic and urban noise, and water pollution in Melaka, Malaysia, and Padang, Indonesia. Semi-structured interviews were conducted with 10 purposively selected park users-five per city-across two parks in each city. Participants were selected for their long-term residency, regular park use and awareness of local green-city initiatives, providing focused experiential evidence for cross-city comparison. Interview data were analysed thematically using NVivo; two researchers independently coded the transcripts, coding decisions were compared and reviewed, member checking and literature triangulation were undertaken, and COREQ guided reporting. Participants in both cities most consistently perceived air-related benefits, particularly in relation to vehicle emissions and carbon-dioxide regulation, while perceptions of noise buffering, haze-related air-quality protection and water-pollution mitigation were more variable. Participants in Melaka more consistently perceived benefits across the three pollution domains, whereas participants in Padang more frequently highlighted constraints associated with smaller park areas, limited vegetation coverage, proximity to major roads and fragmented

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management arrangements. The findings represent perceived rather than objectively measured environmental effectiveness. They extend Ecosystem Services Theory by showing that perceived regulating services are shaped by the interaction of ecological design, urban exposure and governance capacity.

Keyword:

Ecosystem Services; Green Open Spaces; Melaka; Padang; Park Users; Perceived Effectiveness; Urban Pollution Mitigation

Introduction

Rapid urbanisation, industrial expansion and increasing traffic intensity have intensified environmental pressures in cities, particularly air, noise and water pollution. These challenges are especially significant in rapidly developing urban areas where ecological infrastructure has not expanded at the same pace as the built environment. In response, many governments have incorporated green open spaces (GOS) into sustainable urban-development and green-city agendas. GOS are increasingly regarded not only as recreational amenities, but also as ecological infrastructure capable of supporting environmental regulation, public well-being and urban resilience. Through vegetation, soil and water-related features, GOS may contribute to air purification, carbon absorption, noise buffering, surface-runoff regulation and water filtration (Costanza et al., 1997; Sandhu et al., 2014; Ostojic et al., 2013).

Malaysia and Indonesia have both incorporated GOS into their urban sustainability agendas. Malaysia has emphasised sustainable and low-carbon urban development, while Indonesia has promoted green infrastructure through the Green City Development Program and related sustainable-city initiatives (Janice et al., 2013; Mahesa et al., 2019; Zain et al., 2022). Yet formal recognition of GOS does not necessarily mean that environmental benefits are realised in practice. Limited land, unsuitable vegetation, competing land uses, uneven maintenance and fragmented responsibilities can all affect how well these spaces function.

Despite the substantial literature on the environmental role of GOS, the perspective of regular park users has received less attention in comparative Southeast Asian research. Three issues remain particularly relevant. Studies seldom examine users' views of several pollution-related functions together; direct comparison between Malaysian and Indonesian parks is still limited; and the relationship between perceived benefits and local conditions such as park size, vegetation, road exposure, water features and management is not yet well developed. Because regular users encounter these spaces repeatedly, their accounts can reveal practical benefits and limitations that may not appear in policy documents or technical indicators alone.

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Melaka and Padang provide a useful basis for comparison. Both cities have adopted green-development principles, but their physical settings, environmental pressures and institutional arrangements differ. The study covers Bukit Serindit Recreational Park and Bunga Merdeka Park in Melaka, and RTH Imam Bonjol and Nanggalo Park in Padang. These parks are exposed, in different ways, to traffic, development pressure and varying levels of green-space provision. The research question is therefore: How do park users perceive the effectiveness and limitations of GOS in mitigating air, noise and water pollution in Melaka and Padang?

The study compares park users' accounts of GOS-related pollution mitigation and examines the ecological, spatial and institutional conditions associated with those accounts. Its contribution is threefold: a user-based cross-country comparison, consideration of several pollution domains within one qualitative framework, and a context-sensitive application of Ecosystem Services Theory. Rather than assuming that green space produces the same benefits everywhere, the analysis considers how park characteristics, urban exposure and governance arrangements shape perceived service provision.

Literature Review and Theoretical Foundation

Green Open Spaces and Ecosystem Services Theory

Green open spaces form part of the ecological infrastructure of cities and support environmental quality as well as human well-being. Frequently discussed functions include air purification, carbon regulation, noise buffering, water filtration, climate moderation and biodiversity protection. Ecosystem Services Theory provides the conceptual basis for this study because it explains how natural systems generate benefits, including regulating services such as pollution control, water regulation and climate regulation (Costanza et al., 1997). In urban settings, however, those services are unlikely to be experienced in the same way everywhere. The present study therefore uses the theory to interpret both perceived benefits and the local conditions that may strengthen or constrain them.

Green Open Spaces and Air-Pollution Mitigation

Air pollution is one of the most significant environmental challenges in rapidly urbanising cities. Urban transport, industrial activity, construction and energy consumption release pollutants such as particulate matter, carbon dioxide and nitrogen oxides into the atmosphere. GOS may contribute to air-pollution mitigation through pollutant interception, absorption, deposition and carbon sequestration. Studies have shown that vegetation can reduce particulate-matter concentrations and improve surrounding air quality. Ai et al. (2023) found that greenspace contributes to lower air-pollution exposure, while Junior et al. (2022) demonstrated that urban green areas can reduce particulate-matter concentrations.

Urban parks may also reduce pollutants associated with motor vehicles. Parks located near heavily trafficked roads can function as green buffers between emission sources and nearby communities (Aly et al., 2020). However, their effectiveness depends on the density, width and continuity of vegetation. A small park with sparse planting may provide only limited protection where traffic intensity is high (Aly et al., 2020). Carbon dioxide represents another important subdimension of air-pollution regulation. Fan et al. (2023) emphasised the relationship between planting design and urban carbon sequestration, while Kusuma et al. (2023) demonstrated the

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potential of green open spaces to absorb carbon emissions from residential and industrial sources.

The role of GOS in haze mitigation is more complex. Haze may originate from local emissions or regional events such as forest and land fires. Zhang et al. (2020) found that the haze-absorption function of green spaces depends on vegetation quality and spatial characteristics. This suggests that GOS may reduce exposure to haze at the local scale, but their effectiveness may be limited when pollutant concentrations are severe or when green coverage is inadequate. Similarly, Su et al. (2022) showed that air-quality improvements associated with urban parks depend on park configuration and vegetation characteristics.

Green Open Spaces and Noise-Pollution Mitigation

GOS may mitigate noise by functioning as physical and perceptual barriers between noise sources and urban users. Vegetation can reduce noise through sound absorption, reflection, scattering and psychological masking. Trees, shrubs, ground cover and earth formations can interrupt the direct transmission of sound, especially when green barriers are sufficiently wide and dense. Ahmad et al. (2023) reported that integrated green noise barriers can reduce road-traffic noise, while Liu et al. (2023) demonstrated that increased green-space coverage can improve the ecosystem service of traffic-noise reduction.

Nevertheless, the effectiveness of GOS in reducing noise depends on more than the presence of trees. Park size, vegetation density, barrier width, tree arrangement and distance from the noise source are important. A park situated immediately beside a major road may continue to experience substantial traffic noise, even when vegetation is present. Conversely, a larger park with multiple layers of vegetation may provide a stronger transition between roads and residential areas.

Green Open Spaces and Water-Pollution Mitigation

GOS may contribute to water regulation by intercepting runoff, increasing infiltration, filtering pollutants and supporting soil–vegetation processes (Canteiro et al., 2023). Meuleman et al. (2004) demonstrated that aquatic vegetation can contribute to pollution control in treatment wetlands. Yang et al. (2015) further showed that urban green spaces provide water-related ecosystem services, including runoff regulation and water-quality improvement.

Plant and soil characteristics also matter for water-purification processes. Maktoof and Al-Enazi (2020), for example, found that selected plant species removed pollutants from wastewater in constructed wetlands. This finding is relevant because the performance of GOS depends not only on how much vegetation is present, but also on the kind of vegetation and the design of water-sensitive features. These services can be difficult for park users to observe directly. People may instead recognise them through visible signs such as lakes, drainage, surface runoff or routine monitoring.

Contextual Factors Shaping GOS Effectiveness

Previous studies suggest that GOS performance is shaped by a combination of ecological, spatial and institutional conditions. Five are especially relevant here: park size and spatial coverage; vegetation type, maturity and density; proximity to pollution sources; water and

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hydrological features; and governance and management. The last factor affects planting, maintenance, monitoring and longer-term development. Dahayu and Rindrasih (2024) show how fragmented responsibilities can constrain implementation, while work on Indonesia and Southeast Asia points to the importance of adaptive policy, institutional capacity and coordination (Faisal et al., 2022; Zain et al., 2022; Ostojic et al., 2013; Sandhu et al., 2014).

Synthesis of Literature and Research Gap

Taken together, the literature establishes that GOS can contribute to air purification, carbon regulation, noise buffering and water filtration. Much of that evidence, however, comes from technical measurement, modelling, geospatial assessment or single-city research. Less is known about whether regular park users recognise these services in the same way across different pollution domains, how their accounts vary between Malaysian and Indonesian settings, and how they connect benefits or limitations to park size, vegetation, road exposure, water features and governance. This study addresses those gaps through a comparative analysis of Melaka and Padang, using Ecosystem Services Theory as an interpretive foundation rather than assuming that all green spaces deliver identical services.

Methodology

Research Design

This study adopted a qualitative comparative case-study design to examine how park users perceived the effectiveness and limitations of green open spaces (GOS) in relation to air, noise and water pollution in Melaka, Malaysia, and Padang, Indonesia. The comparative design enabled the study to identify shared patterns as well as context-specific differences between the two cities and across the four selected parks. The study was reported with reference to the Consolidated Criteria for Reporting Qualitative Research (COREQ) (Tong et al., 2007). COREQ was used as a reporting framework to enhance transparency in describing the research design, participant selection, data collection and analysis; it was not used as an analytical or validation method.

Comparative Study Context and Research Sites

Fieldwork was carried out in four urban GOS: Bukit Serindit Recreational Park and Bunga Merdeka Park in Melaka, and RTH Imam Bonjol and Nanggalo Park in Padang. During interpretation, attention was given to differences in park size, vegetation, road proximity, water-related features and management arrangements. Comparison took place at two levels: between the two parks within each city and, subsequently, between the broader patterns identified in Melaka and Padang.

Participant Recruitment and Selection

The analysis drew on 10 park users, five from Melaka and five from Padang. Purposive sampling was used because the study required participants who were familiar with the selected parks and their local urban context. Eligibility required awareness of government green-city initiatives, permanent residence in the relevant city for at least three years, and regular use of the parks. Melaka participants had lived in the city for between three and 32 years, while the Padang range was eight to 24 years. The sample was intended to provide focused, experience-

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based qualitative evidence rather than statistical representation. Participants were coded M1-M5 in Melaka and P1-P5 in Padang to protect confidentiality.

Table 1. Participant Profile by Study Location and Residency

Informant code	Study location	Residency duration
M1	Melaka	32 years
M2	Melaka	12 years
M3	Melaka	13 years
M4	Melaka	3 years
M5	Melaka	12 years
P1	Padang	8 years
P2	Padang	24 years
P3	Padang	13 years
P4	Padang	10 years
P5	Padang	8 years
Total	**Melaka and Padang**	**10 informants**

Source: Researcher's Analysis Based on Fieldwork Data (2023-2024)

Data Collection

Primary data were collected through face-to-face semi-structured interviews conducted in June and July 2023. The interviews examined participants' perceptions of the functions and limitations of GOS in relation to air, noise and water pollution. Each interview lasted approximately 45-60 minutes. With participants' consent, the interviews were audio-recorded and supported by written field notes. The interviews were conducted in the language most suitable for each participant. Relevant excerpts were translated into English for comparative presentation in the manuscript, and the translated excerpts were checked against the original statements to preserve their intended meaning.

Data Preparation and Thematic Analysis

The interview data were analysed using thematic analysis based on Braun and Clarke (2006). The analytical process comprised six stages: (1) familiarisation with the interview transcripts; (2) generation of initial codes; (3) identification of potential themes; (4) review of themes against the coded material; (5) definition and naming of themes; and (6) comparative interpretation and reporting. NVivo was used to organise the transcripts, manage coding and facilitate systematic retrieval of the qualitative evidence. The data from Melaka and Padang were initially reviewed separately to identify patterns within each city. The two sets of findings were then compared to identify convergences, differences and context-specific explanations.

Interpretive Classification of Participant Responses

To facilitate the comparison of qualitative response patterns, participant statements were organised into five interpretive categories:

1. strong agreement, indicating clear confidence in the perceived environmental benefit;
2. moderate agreement, indicating recognition of a benefit accompanied by limitations;
3. uncertainty, indicating tentative or inconclusive perceptions;

4. disagreement, indicating rejection of the perceived function; and
5. non-mention, indicating that the issue was not discussed by the participant.

These categories were used as an interpretive organisational tool rather than as a quantitative measurement scale. They did not represent numerical scores, statistical measurements or fixed psychometric categories. Their purpose was to make the qualitative comparison across participants and cities more transparent.

Cross-Case Comparative Analysis

Following thematic coding, a cross-case analysis was conducted to compare the perceived environmental performance of GOS in Melaka and Padang. The analysis examined both the reported functions of GOS and the contextual explanations associated with those perceptions. Five explanatory factors were considered: (1) park size and spatial coverage; (2) vegetation type, maturity and density; (3) location and proximity to pollution sources; (4) the presence of water-related and hydrological features; and (5) governance and institutional-management arrangements.

Trustworthiness and Analytical Rigour

Several procedures were used to strengthen analytical credibility. Two researchers coded the interview material independently and then compared their coding decisions, noting areas of convergence and difference. Member checking was used to confirm transcript accuracy and the intended meaning of participants' statements. The interview findings were also cross-referenced with relevant empirical literature as a form of triangulation (Zain et al., 2022). NVivo supported the organisation and retrieval of coded material. COREQ informed the reporting of these procedures; it was not treated as a validation technique.

Ethical Considerations

Ethical approval for the original doctoral study was granted by the Universiti Teknologi MARA Research Ethics Committee on 7 February 2023 under reference REC/02/2023 (PG/MR/39). The approval covered the research sites and data-collection activities used in this manuscript. Participation was voluntary, informed consent was obtained, and anonymised informant codes were used throughout the study.

Methodological Scope and Boundary of Interpretation

This study concerns perceived effectiveness rather than direct environmental measurement. The findings reflect what park users observed, experienced and understood about GOS functions; they are not measurements of pollutant concentrations, particulate matter, acoustic levels, water quality, carbon sequestration or other biophysical indicators. With five participants in each city, the comparison is exploratory and interpretive and is not intended to represent all park users statistically or to rank the four parks objectively.

Findings

Participants' accounts were organised around three broad pollution domains: air-related environmental quality, noise pollution and water pollution. Within the air-related domain, they

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discussed general air quality, vehicle emissions, haze-related conditions and carbon-dioxide regulation. The analysis then compared these accounts within each city, between parks and against the contextual conditions described by participants.

Overall, Cross-City Pattern

Air-related benefits were the most consistently perceived across Melaka and Padang. Nine of the 10 informants strongly associated GOS with general air-quality improvement, while participants in both cities also frequently associated vegetation with carbon-dioxide regulation. Perceptions of noise buffering, haze-related air-quality protection and water-pollution mitigation were less uniform. The cross-city pattern reveals three important differences. First, participants in Melaka more consistently perceived benefits across the three pollution domains, particularly water regulation, carbon regulation and noise buffering. Second, Padang participants gave more explicit attention to vehicle emissions because both selected parks were experienced within busy urban-traffic environments. Third, participants in Padang more frequently highlighted constraints related to spatial coverage, exposure to major roads and the amount of vegetation available relative to perceived pollution intensity.

Table 2. Cross-City Thematic Patterns of Perceived GOS Effectiveness

Theme or subtheme	Melaka response pattern	Padang response pattern	Main cross-city interpretation
General air-quality improvement	Four strongly agreed; one did not mention	All five strongly agreed	Strongly perceived in both cities and especially explicit in Padang
Haze-related air quality	Two strongly agreed; two moderately agreed; one did not mention	One strongly agreed; three moderately agreed; one was unsure	Perceived local buffering existed, but confidence declined when haze intensity was viewed as exceeding vegetation capacity
Vehicle emissions	One strongly agreed; four did not mention	All five strongly agreed	More salient in Padang because of the parks' exposure to urban traffic
Carbon-dioxide regulation	All five strongly agreed	Four strongly agreed; one did not mention	Strongly associated by participants with vegetation and oxygen production in both cities
Noise buffering	Three strongly agreed; one was unsure; one did not mention	One strongly agreed; three moderately agreed; one was unsure	Perceptions were stronger in Melaka; Padang responses reflected differences in park size and road exposure
Water-pollution mitigation	Four strongly agreed; one was unsure	Two strongly agreed; three did not mention	More visible and consistently perceived in Melaka

Source: Researcher's Analysis Based on Fieldwork Data (2023-2024)

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Perceived Air-Quality Benefits

Within-City Patterns in Melaka

Melaka informants generally connected air-pollution mitigation with mature trees, carbon reduction and the role of vegetation within a densely developed urban environment. Four informants strongly agreed that the selected GOS contributed to cleaner air, while one informant did not discuss general air pollution directly. A distinctive feature of the Melaka evidence was the emphasis on mature vegetation. One informant referred to trees in Bunga Merdeka Park that were reportedly more than 50 years old and described them as contributing indirectly to the reduction of environmental pollution. This suggests that users associated long-established vegetation with stronger environmental performance rather than treating all green coverage as functionally equivalent.

Within-City Patterns in Padang

All five Padang informants strongly perceived that GOS contributed to reducing general air pollution. The Padang responses were particularly detailed in relation to vehicle emissions and the parks' urban locations. P1 connected the presence of trees directly with reductions in city pollution: "If it's a green open space, it already reduces pollution…surely, because green open spaces have trees growing, which helps to reduce pollution" [P1]. However, the Padang informants also distinguished between reduction and elimination. P2 explained that the trees and park reduced pollution, but the effect was not fully maximised because the volume of pollution remained high. This represents an important limitation: GOS were perceived as mitigating urban pollution, but not as independently removing the source of the problem.

Within-Park Contrast: Imam Bonjol and Nanggalo

The two Padang parks were experienced differently. Imam Bonjol was associated with a larger area and a calmer internal setting, whereas Nanggalo was repeatedly discussed in relation to heavy peak-hour traffic. That exposure made Nanggalo's air-quality role more noticeable to users, while at the same time increasing the pressure placed on the park. P3, for example, described intense traffic around Nanggalo and associated the park with the conversion or absorption of carbon dioxide.

Haze-Related Air-Quality Perceptions

Melaka Pattern

M1 described the park as a comparatively safer place to remain during haze because of its large, shady trees: "This place has become a safe haven for the public to stay as it's filled with large, shady trees" [M1]. M2 also noted that Bukit Serindit was affected by haze because of its position near a main road but believed that the abundance of trees reduced the effect on visibility. These accounts indicate fairly strong confidence in local haze-related buffering, although that view was not shared equally by all Melaka participants.

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Padang Pattern

P1 perceived that the two parks provided some protection during a previous haze episode. P3 provided the clearest limitation: "The amount of haze generated compared to the number of trees and the available area is not yet proportional" [P3]. This response connects perceived haze-related buffering with two contextual factors: (1) the number of available trees; and (2) the spatial area of the park. Participant confidence declined when the scale of haze was perceived as larger than the ecological capacity of the parks.

Perceived Mitigation of Vehicle Emissions

In Padang, vehicle emissions were one of the clearest air-related subthemes. All five informants strongly perceived a role for GOS in areas affected by passing vehicles. P2 stated: "Since there are so many vehicles passing by, these green open spaces can help to minimise the pollution emitted by each vehicle" [P2]. The cross-city difference should therefore be interpreted as a difference in salience rather than objective park performance: vehicle-related pollution was more visible to Padang users because the selected parks were embedded in traffic-intensive urban locations.

Perceived Carbon-Dioxide Regulation

Carbon-dioxide regulation was one of the most frequently perceived air-related functions in both cities.

Melaka Pattern

All five Melaka informants explicitly associated GOS with carbon reduction or absorption.

Padang Pattern

Four Padang informants explicitly discussed carbon-dioxide regulation, while one did not mention it. Participants commonly described the process through carbon absorption and oxygen production. P1 associated tree-based photosynthesis with carbon absorption and oxygen release, while P4 described trees as absorbing pollutants and carbon dioxide generated by vehicles and combustion. These statements are reported as participants' perceptions and are not treated as measured carbon-sequestration outcomes.

Perceived Noise Buffering

Melaka Within-City Pattern

Three Melaka participants strongly perceived the selected parks as buffering urban noise. They often described the green spaces as separating transport corridors from nearby urban or residential areas. One participant was unsure, while another did not mention noise. The overall pattern was positive, but the function was not equally apparent to everyone interviewed.

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Padang Within-City Pattern

Padang accounts were more qualified. P1 felt that noise was less disturbing inside the park because of its trees and larger area: "Even though it's next to the market, the park is fairly calm because of the many trees and its large area" [P1]. This account points to partial buffering rather than complete separation from surrounding noise.

Within-Park Contrast

The clearest within-city contrast concerned Imam Bonjol and Nanggalo. P2 regarded Imam Bonjol as better able to reduce noise because it was more spacious, while Nanggalo was seen as more constrained by its smaller area. P3 read the sites differently, suggesting that Nanggalo might work better as a barrier because it appeared to contain more trees. The contrasting accounts show that park size and vegetation density did not always point in the same direction.

Perceived Water-Pollution Mitigation

Melaka Pattern

Four Melaka participants strongly associated GOS with water-quality regulation, while one was unsure. M4 referred to an earlier pollution issue involving the lake at Bunga Merdeka Park and explained: "There was a slight issue with the lake water being polluted, but after that, it's been resolved, and we monitor it regularly" [M4]. M5 was less certain because the underlying water-related process was not readily visible from the user's perspective.

Padang Pattern

Only two Padang informants strongly discussed water-pollution mitigation, while three did not mention it. The limited number of comments indicates that water-related ecosystem services were less visible in participants' accounts. Unlike air quality or noise, water filtration may occur through processes that are not directly experienced during routine park use.

Functional Limitation

Relationship Between Themes and Contextual Factors

The cross-case findings indicate that the six environmental themes and subthemes were shaped by five recurring contextual factors.

Cross-Case Explanatory Synthesis

Four patterns emerged from the comparison. First, air-related functions were easier for participants to recognise because trees could be linked directly with cleaner air, shade, vehicle emissions and carbon regulation. Second, perceived noise buffering reflected both internal park characteristics and external exposure. Larger spaces and denser vegetation were generally associated with stronger buffering, while proximity to major roads remained an important limitation.

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Third, water-related functions were more often recognised when participants could point to visible park features or management practices. Melaka participants referred to runoff, lake conditions and monitoring, whereas most Padang participants did not identify this function as readily. Fourth, perceived limitations often appeared where ecological capacity seemed mismatched with urban pressure. Participants could value GOS while still judging the available space, vegetation or management arrangements as insufficient relative to traffic, haze or development intensity.

Discussion

Comparative Effectiveness of GOS in Melaka and Padang

Park users in both Melaka and Padang regarded GOS as contributing to pollution mitigation, but they did not describe every function with the same degree of confidence. Air-related benefits were the most consistently recognised. Noise and water-related functions generated more mixed accounts, suggesting that visibility matters: users more readily discussed services they could notice during ordinary park use, such as cleaner-feeling air, shade or some separation from vehicle emissions, than processes such as water filtration that are less directly observable. The cross-city comparison also requires caution. Melaka participants described benefits across the three pollution domains more consistently, while Padang participants gave particularly strong accounts of traffic-related emissions and general air quality but were more tentative about haze, noise and water. This does not establish that Melaka's parks are objectively more effective. Instead, it shows that perceived performance varied with site characteristics, surrounding pollution pressure and management conditions.

Perceived Air-Quality, Haze and Carbon-Regulation Functions

Air-related services were the most visible part of participants' accounts, a pattern broadly consistent with studies showing that urban vegetation can reduce particulate matter, absorb gaseous pollutants and improve local air quality (Ai et al., 2023; Junior et al., 2022; Su et al., 2022). Road proximity was experienced in two ways: it increased the perceived importance of green buffering, but it also increased the pollution pressure placed on the park. This interpretation is consistent with evidence that GOS near emission sources can be strategically valuable while still being environmentally pressured (Aly et al., 2020).

The Padang haze accounts show a similar tension. Participants recognised some local buffering but questioned whether the available vegetation and green area were sufficient during severe haze. Zhang et al. (2020) likewise found that haze absorption varies with vegetation quality and spatial characteristics. Participants also spoke explicitly about carbon-dioxide regulation, which is compatible with research on urban green-space carbon sequestration (Fan et al., 2023; Kusuma et al., 2023). These interview findings nevertheless remain evidence of perception and awareness, not quantitative confirmation of haze removal or carbon-sequestration rates.

Perceived Noise Buffering and Spatial Design

The noise findings are consistent with Ahmad et al. (2023) and Liu et al. (2023), who report relationships between green infrastructure and reduced traffic-noise exposure. The interviews add a user-based perspective on when that buffering is noticed. Participants referred to

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combinations of park size, vegetation density and arrangement, distance from the road and surrounding traffic intensity rather than to a single determining factor.

The findings should therefore be read as perceived moderation of noise exposure, not as measured acoustic reduction. The different accounts of Imam Bonjol and Nanggalo are useful because they show that parks within the same city can be experienced differently when size, vegetation and spatial configuration do not coincide.

Perceived Water-Pollution Mitigation and Visibility of Ecosystem Services

The water-related findings are consistent with studies of runoff regulation and water-quality improvement through soil, vegetation and hydrological processes (Canteiro et al., 2023; Meuleman et al., 2004; Yang et al., 2015). These functions depend on more than the presence of greenery; plant species, soil properties and water-sensitive infrastructure are also relevant. Maktoof and Al-Enazi (2020), for example, demonstrated pollutant removal by selected vegetation in constructed wetland systems.

What differed between Melaka and Padang was how visible these services were to users. Air and noise conditions can often be sensed during a park visit, whereas filtration may occur below the surface or through processes that are not immediately apparent. This may explain why participants were more likely to discuss water-related benefits when they could refer to visible features or activities such as lakes, drainage, runoff-management measures or regular monitoring.

Governance and Institutional Management

Governance also appeared in participants' explanations of GOS performance. In Padang, some accounts referred to parks managed by institutions outside the local environmental authorities, a situation participants associated with weaker attention to green infrastructure for haze and pollution control. Melaka participants, by contrast, referred to monitoring and maintenance, particularly around water conditions at Bunga Merdeka Park. These accounts suggest that confidence in ecosystem-service delivery is shaped not only by ecological features but also by how parks are maintained and institutionally supported.

The Padang case further suggests that fragmented authority may weaken the alignment between park management and environmental objectives (Dahayu & Rindrasih, 2024). Where the responsible institution does not have a specific environmental mandate, pollution-mitigation functions may receive less attention. The findings therefore indicate that ecological infrastructure is more likely to be perceived as effective when it is supported by coherent governance and management arrangements.

Theoretical Contribution

The findings support Ecosystem Services Theory by showing that park users recognise GOS as providing perceived regulating services related to air quality, carbon regulation, noise buffering and water regulation (Costanza et al., 1997). The study extends this application of the theory by demonstrating that the perception of regulating services is not uniform across green spaces. Instead, perceived effectiveness is shaped by the interaction of ecological design, urban pollution exposure and governance capacity, including park size, vegetation

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composition, location, hydrological features and institutional management. This context-sensitive interpretation helps connect ecosystem-service potential with how those services are experienced in specific urban settings.

Empirical and Practical Contribution

The user-based approach reveals that residents can identify both perceived benefits and practical limitations. Participants associated GOS with improved air quality, carbon regulation, noise buffering and water regulation, while also reporting constraints related to insufficient space, limited vegetation, traffic exposure and fragmented management.

Practically, the findings suggest that local governments should move beyond the objective of merely increasing the number of green spaces. Planning and management should prioritise: (1) adequate park size and spatial coverage; (2) mature, dense and pollution-responsive vegetation; (3) multilayered green buffers near roads; (4) water-sensitive landscape features; (5) systematic environmental monitoring; and (6) coordinated institutional management. The findings also caution against a one-size-fits-all approach. The design and management of each park should respond to the specific pollution sources, physical conditions and governance context of its location.

Conclusion

This study examined how park users perceived the effectiveness and limitations of GOS in relation to air, noise and water pollution in Melaka, Malaysia, and Padang, Indonesia. Participants in both cities most consistently perceived air-related benefits, including vehicle-emission buffering and carbon-dioxide regulation, while perceptions of noise buffering, haze-related air-quality protection and water-pollution mitigation were more variable. Participants in Melaka more consistently perceived benefits across the three pollution domains, whereas participants in Padang more frequently highlighted constraints associated with smaller park areas, limited vegetation, proximity to major roads and fragmented management arrangements. These patterns should not be interpreted as objective evidence that one city's parks perform better than the others. Rather, they show how perceived environmental effectiveness varies with local ecological, spatial and institutional conditions.

The study extends the application of Ecosystem Services Theory by showing that perceived regulating services are shaped by the interaction of ecological design, urban exposure and governance capacity rather than by the presence of green space alone. Practically, the findings suggest that GOS planning should consider adequate spatial coverage, mature and pollution-responsive vegetation, green buffers near roads, water-sensitive landscape features, environmental monitoring and coordinated institutional management. The study is limited by its focused sample of 10 park users and by its reliance on perceptions rather than direct environmental measurements. The findings are therefore exploratory and experiential, not technical confirmation of pollutant reduction. Future research should combine user-based evidence with direct measurements of air quality, noise, water quality, vegetation structure and spatial characteristics across a wider range of cities.

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