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# Access to cultural ecosystem services and how urban green spaces marginalize underprivileged groups



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Rapid urbanization in cities has diminished urban green spaces (UGS), limiting access to recreational opportunities, and affecting social cohesion and mental well-being. We assess the influence of spatially-referenced socioeconomic factors of land value on green space access in Jakarta, Indonesia, to understand environmental justice issues in cultural ecosystem services (CES). Isochrones, gravity model principles, and a participatory spatial mapping survey ($n$ = 638) were used to identify culturally significant UGS and assess their accessibility based on respondents' residential land value information. Our analysis reveals a stark disparity in access to high-quality CES, with only visitors from high-land-value areas reaching these services within a 60-min pedestrian travel time. Consistent inequality patterns in lower socioeconomic groups reflect structural barriers that limit their access to the cultural benefits of UGS. Our discussion highlights contributions to the field and suggests critical planning directions to improve the quality, quantity, and accessibility of CES.

Urban green space (UGS) is understood as all vegetated urban land, such as private and public parks, including small water bodies like ponds, lakes, or streams[1]. The concept has emerged as a critical ecosystem in cities that plays a vital role in enhancing people's quality of life through the provision of cultural ecosystem services (CES). UGS generates a range of cultural services that people obtain through recreation, cognitive development, spiritual enrichment, and esthetic experiences[2]. However, these services are often undervalued, given their intangible natures[3,4], and are neglected in ecosystem service governance[5]. The extensive growth of built-up city areas also jeopardizes such benefits by often prioritizing residential, commercial, and industrial development at the expense of reduced access to UGS[6]. This is common in rapidly urbanizing cities, where urban planning models often fail to adapt to the expanding population and do not adequately consider which groups are at risk due to their lack of access to UGS[7,8]. The increasing share of the population residing in cities exacerbates these issues, as intensive energy use and natural resource extraction in urban areas have placed significant pressure on the environment. Cities are responsible for releasing 75–80% of total greenhouse gas emissions from human activities such as transportation, industrial production, and consumption, contributing to declining air quality and increased vulnerabilities in urban settings[9]. Consequently, cities with accelerated urbanization are increasingly more susceptible to climate hazards and confront heightened inequalities in green space exposure and accessibility[10]. These result in an imbalanced distribution of green spaces and CES benefits across the city, affecting the urban poor who are often culturally marginalized and are the most vulnerable in these situations[5,11].

Given the significant interests at stake, a large body of literature has increasingly focused on examining green space accessibility through various lenses. Most available studies apply provision-based assessments, which consider the distribution and per capita availability in relation to urban planning standards[12,13]. These studies provide valuable baseline data on whether cities meet minimum UGS standards. However, proximity-based metrics alone may overlook critical aspects of accessibility, such as usability and the capacity of UGS to meet the needs of a diverse population. To address these shortcomings, another stream of literature applies the environmental justice framework to broaden accessibility discussions by stressing the equity principle in analyzing access across different social groups. Evaluations in this domain highlight accessibility as a spatial equity issue, a broader concept than distance for examining which population groups experience better access to green space and who may be left underserved[14]. Studies have shown that environmental injustice in cities often results in a similar pattern of inequality in green space access, where neighborhoods and populations with higher socioeconomic status have better connections to parks than those living in disadvantaged communities[12,15,16]. Efforts to address these disparities often lead to gentrification[14,17], similar to Immergluck and Balan's[18] findings, which showed that the construction of

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environmental amenities in low-income areas, including parks, increases the likelihood of marginalized community displacement due to rising land prices and property costs. While the available studies have centered their analyses on the supply side, they have yet to include users' diverse preferences and experiences across different green space locations.

Incorporating a demand-side perspective into the analysis, as embodied in CES, is essential as people tend to access and benefit from green spaces that they find valuable[19]. A review of existing literature reveals that this approach allows for the quantification of UGS quality by differentiating users' demands based on CES classifications[20]. This highlights diverse perceptions across different social groups[21] and estimates the travel distances people must cover to access these services[22]. Integrating CES into accessibility assessments shifts the focus from measuring proximity to parks and green areas to enabling the development of accessibility metrics that capture both physical access and the quality of the user experience. Our study contributes to the ongoing debate between proximity and accessibility metrics[23] by incorporating CES as a critical quality factor in assessing the distribution of access to culturally significant green spaces among diverse population groups. Few studies have explored this, with notable examples including case studies in Rome[20] and Beijing's core area[24], which examined accessibility to culturally significant green spaces using socio-demographic variables. While these aspects are relevant, socioeconomic factors are more directly linked to equity issues in UGS access[12,25], exerting a more substantial impact on people's ability to access and benefit from them[26]. To this end, we use land value as a proxy for socioeconomic status[27] and household income levels[28,29]. Land value captures neighborhood-level economic conditions[30,31] and reveals spatial inequalities that other socioeconomic variables may overlook[32]. By applying this approach, our study contributes to the literature on green space accessibility and CES assessments in Jakarta, Indonesia, one of Southeast Asia's largest cities[33].

Designated as the capital of Indonesia, Jakarta covers an area of 661.23 $km^2$ and is home to 10.64 million residents as of 2022, making it one of the densest cities in Indonesia[34–36]. This significant demographic size underpins the city's economic role with a sustained 7% economic growth[37], the most significant contribution to the national GDP[38], and the highest per capita income nationwide[39]. However, these advancements have exacerbated income and well-being inequalities as the benefits from economic development are unequally distributed across the population. This has been evident in Jakarta, where the extensive urban expansion with sprawling infrastructure coexists alongside informal settlements, widening disparities and social segregation across the city[40]. The challenge is further compounded by congested road transport and long commute times, with many residents enduring up to 2 h and 9 min of travel to and from work per day[41]. This prolonged commute contributes to significant physical and mental health deterioration, particularly among lower-income commuters, with 27.13% reporting daily physical ailments such as headaches and sore pain, and 24.18% experiencing mental health issues[42]. With land-use policies continuing to favor sectors with potential economic gains, these circumstances have significantly reduced the city's environmental carrying capacity, mainly through the loss of UGS[43].

Jakarta has experienced a critical shortfall of green spaces. Founded in 1527, it served as a crucial harbor and trading hub under Dutch colonial rule (1619–1945) as Batavia, later renamed Jakarta, with green space development influenced by Dutch town planning practice focusing on agricultural lands[33,44]. By 1965, green areas covered about 35% of Jakarta, but rapid urbanization and market-driven land-use changes since the late 1980s have led to substantial conversion into built-up areas[44,45]. Given the important role of UGS in cities, the central government has aimed to achieve 30% of UGS provision in Indonesian cities, with 20% managed by the city governments and 10% privately owned[46]. However, a weak policy commitment, evident in the progressive reduction of green space allocation in the city's spatial plans[47], has significantly reduced Jakarta's green space, which has declined by 31% from 148 $km^2$ in 2000 to 106 $km^2$ in 2020[44]. Today, government-managed UGS spans only 33.54 $km^2$, representing 5.2% of the city's total land area[48]. Compared to a city's population size, this translates to a severe deficiency in green space per capita, falling short of the World Health Organization's (WHO) recommended standards for urban environments[49], such as in Europe, where citizens are suggested to have access to 0.5–1 ha UGS within 300 m of their homes[50]. This was further compromised by a green city development program that primarily utilized government-owned land for UGS provision to avoid land conversion[43]. The initiative failed to address local-specific context and needs for ecosystem services that vary across locations. Instead, it reinforced the existing spatial segregation that disproportionately benefits the wealthier segment of society[43,51]. Consequently, the development of Jakarta's UGS has lagged[27] and remains sparse across the city. This may also explain the limited exploration of ecosystem services provided by UGS in Jakarta, with the only existing study focused on site-specific[52] rather than city-wide contexts.

Zain et al.[43] identified a research gap in how spatial planning laws and greening policies in Jakarta prioritize achieving provision targets without adequately considering the city's socioeconomic and cultural contexts. Our study aims to address this gap by employing a participatory mapping approach, similar to previous studies[22,53,54], to identify and map culturally significant green spaces in Jakarta based on local knowledge and perceptions. We use participatory mapping to facilitate UGS planning that better accounts for how residents experience, use, and access green spaces they value, ensuring these spaces are recognized in policy and planning decisions. This approach aligns well with citizen-based principles that prioritize evaluating green spaces based on the residents' perceived qualities, uses, and accessibility[55]. The scope of UGS considered in this study was focused on public parks and green areas managed by the government. The paper investigates the spatial distribution of local CES demand in green spaces through a participatory mapping survey and examines how socioeconomic disparities shape accessibility to these spaces, utilizing land value as a spatial indicator. The survey also includes green space visitation patterns, such as frequency, timing, and duration of visits, to provide insights into how residents use UGS, offering context for addressing the following questions:

1. What are the spatial distribution patterns of high-quality CES in Jakarta's UGS, and how do they vary across different CES types?
2. How do socioeconomic factors, as measured by land value, shape disparities in access to high-quality CES within Jakarta's UGS?

A variety of methods have been developed in the literature to evaluate accessibility. Broadly, accessibility measurement can be categorized into methods that define practical reachability (e.g., isochrones), methods that account for gradual distance decay (e.g., cumulative opportunities and gravity models), and those focused on individual utility and preferences (e.g., utility-based models)[56–58]. This study adopts a hybrid approach that combines isochrone-based accessibility boundaries with gravity model principles to address two central research questions. In the first question, we identify the spatial distribution of UGS locations that received high experience ratings through an online survey, examining how residents' preferences and motivations shape the perceived value of these spaces. In this study, high experience ratings—measured using a predefined rating scale—reflect respondents' subjective yet collectively shared perceptions of UGS as places where CES are actively experienced and highly valued throughout the city, aligning with the conceptual rationale by Van Herzele and Wiedemann[55] and Tyrväinen; Mäkinen; and Schipperijn[59]. While these studies do not explicitly discuss CES, their emphasis on citizen-based principles, social valuation, and collective user experiences provides relevant context for our definition of high quality in this study. While the identified UGS served as the destination points for accessibility evaluation, the survey also collected respondents' residential postal codes, which were used as a proxy to determine the origins of travel. This approach allows us to calculate the distance and travel time between respondents' residences and their preferred green spaces.

In addressing the second question, we assess the accessibility of these green spaces across socioeconomic groups, focusing on disparities informed by respondents' residential land value levels. To achieve this, we use postal code data obtained from the survey to match each respondent's representative residential ward with corresponding land value information. Isochrones delineate practical travel boundaries, capturing the spatial reach of green spaces with a defined travel time. We refine the analysis by integrating gravity model principles of distance decay and destination attraction. We examine these concepts by analyzing the relationship between respondents' travel times to green spaces and their residential land value levels. This allows us to capture how accessibility to culturally attractive green spaces decreases with increasing travel time and examine whether this pattern varies across land values, which serve as a proxy for respondents' socioeconomic statuses. From this result, we analyze the distribution of access to culturally appreciated green spaces on inter- and intra-group variations based on the residential land value levels using the Lorenz curve and Gini coefficient estimations, methods which are commonly used in green space equity assessment studies[12,16]. The Lorenz curve visually represents the cumulative distribution of access, illustrating disparities among socioeconomic groups, while the Gini coefficient provides a quantitative measure of inequality.

## Results

### Demand for cultural ecosystem services from urban green spaces

A total of 554 sites were identified as green space locations with high cultural importance. These locations were weighted based on respondents' overall experience ratings on cultural ecosystem services, generating a heatmap of Jakarta's most highly valued green spaces. Notably, 65% of the marked coordinates corresponded to just 14 locations (Fig. 1a). In the heatmap, highly appreciated green spaces were centrally located, making them primary hotspots in the city for all eight types of CES (Fig. 1b–i). While the heat intensity and spread slightly vary between each service type, the consistent hotspots implied that these green spaces were multifunctional for providing a wide range of CES and perceived to have diverse uses and meanings, particularly for the 65% of respondents who identified them as culturally significant. The remaining 35% of identified locations, which were located in the peripheral areas, indicated green spaces that were less maintained and less attractive to residents, leading to lower perceived quality ratings.

Two primary hotspots, marked by the high number of responses and intense shading on the heatmap, were GBK Sports Complex and Tebet Eco Park. These green spaces were the most frequently visited and the most valued areas for high-quality CES. The high intensity of these hotspots appeared consistent across CES types, indicating that these green spaces attract users from outside the immediate vicinity. These patterns showed city-wide appeal and culturally diverse offerings, making them key destinations for residents seeking recreation, social interaction, and cultural enrichment. The parks are situated in different surrounding environments. GBK Sports Complex, located in Central Jakarta, is adjacent to one of Jakarta's business districts, while Tebet Eco Park is circled by residential housing in South Jakarta. In addition, cross-referencing the locations of these green spaces with land value data revealed that they were predominantly situated in high-value wards, indicating an alignment between high-quality green spaces and affluent neighborhoods. This observation underscores the need for further analysis to explore potential disparities in access and distribution across socioeconomic groups.

### Inequality of access to high-quality cultural ecosystem services

Given the diverse socioeconomic backgrounds of the respondents, we examined their accessibility to UGS using the indicated postal code of residence with control of residential land value information. In this study, we used pedestrian travel time to ensure comparable accessibility assessment between respondents, considering Jakarta's varied traffic conditions. We specified our analysis to two mostly visited and highly appreciated green spaces by the respondents: GBK Sports Complex (Fig. 2a) and Tebet Eco Park (Fig. 2b).

The maps showed concentric isochrones surrounding the green spaces, representing walking travel times from 20 to 120 min and the spatial distribution of respondents' residences. The rate of respondents covered within 60 min of walking was distinctive between green spaces, with GBK Sports Complex at 9% and Tebet Eco Park at 38%. Meanwhile, Tebet Eco Park was the only green space reachable on foot in less than 20 min, with 20% of respondents covered. Within a 2-hour walk, the maximum respondent coverage was 37% for GBK Sports Complex and 71% for Tebet Eco Park. While the walking travel time was used for comparative estimations, our isochrone analyses revealed that accessibility to these UGS locations remains spatially distant for most respondents.

From a social equity perspective, travel times to GBK Sports Complex (Fig. 2c) and Tebet Eco Park (Fig. 2d) were inversely related to residential land value, indicating that individuals living in higher-value areas have better access to high-quality CES provided by the green spaces, as reflected in their shorter travel times. In contrast, respondents residing in lower-value areas experienced more varied travel times, reflecting the broader and uneven distribution of affordable land across different parts of the city. Meanwhile, medium-land-value residents experienced accessibility levels that fall between these two groups—they faced neither the prolonged travel times of those in very low-land-value areas nor did they enjoy the shortest access times available to high-land-value residents. This result revealed significant inequalities in access to CES from urban green spaces across socioeconomic groups in Jakarta.

Recognizing the significance of the observed disparities, we used Lorenz curves to clarify whether the unequal access is disproportionately and systematically biased against certain socioeconomic groups. We analyzed 260 out of 386 responses usable for accessibility analysis, representing respondents who visited the top 14 previously identified green space locations, including GBK Sports Complex and Tebet Eco Park. The distribution of data used for the analysis is shown in Supplementary Fig. 1. Analysis of the Lorenz curves (Fig. 3) revealed that lower socioeconomic groups experience the least inequity among all groups, clustering closely along the equity line. This alignment indicated a uniform distribution of long commute times within these groups. Conversely, the distribution of travel times varied widely among residents from high-land value areas. This group exhibited the highest Gini Coefficient (GC), representing a pronounced inequality where some residents enjoy exceptionally convenient access while others face long travel times. The GC values for middle-land-value residents were between the high and lower groups. While their access was less restricted than that of lower-land-value residents, they still lacked the accessibility advantages gained by high-land-value residents.

From the location-specific perspective, GBK Sports Complex emerged as the green space with the most equitable access. The GC values and Lorenz curves for GBK Sports Complex consistently aligned closer to the equity line than those for Tebet Eco Park and other city-wide green spaces offering high-quality CES. Despite the pattern suggesting fewer disparities in commute times within each socioeconomic group, this did not imply better access. Travel time within each group remained consistent, with lower-income groups still facing the longest commutes. By contrast, Tebet Eco Park and the top 14 green spaces showed a more significant deviation from the equity line, with the most considerable disparity observed among high-land-value residents visiting Tebet Eco Park. The disparities observed in both categories revealed a recurring pattern of Lorenz curves, each with different magnitudes of GC values. This indicated that travel time inequalities were inherent and reflected broader accessibility trends. While the GC values for the top 14 green spaces provided a general measure of disparity across all respondents accessing high-quality CES, they obscured the more distinct access inequities unique to specific locations, as observed for GBK Sports Complex.

## Discussion

This study adds empirical evidence to the discussion on environmental inequality by integrating a quality-based assessment of UGS with an accessibility evaluation through the lens of CES. By linking UGS quality to

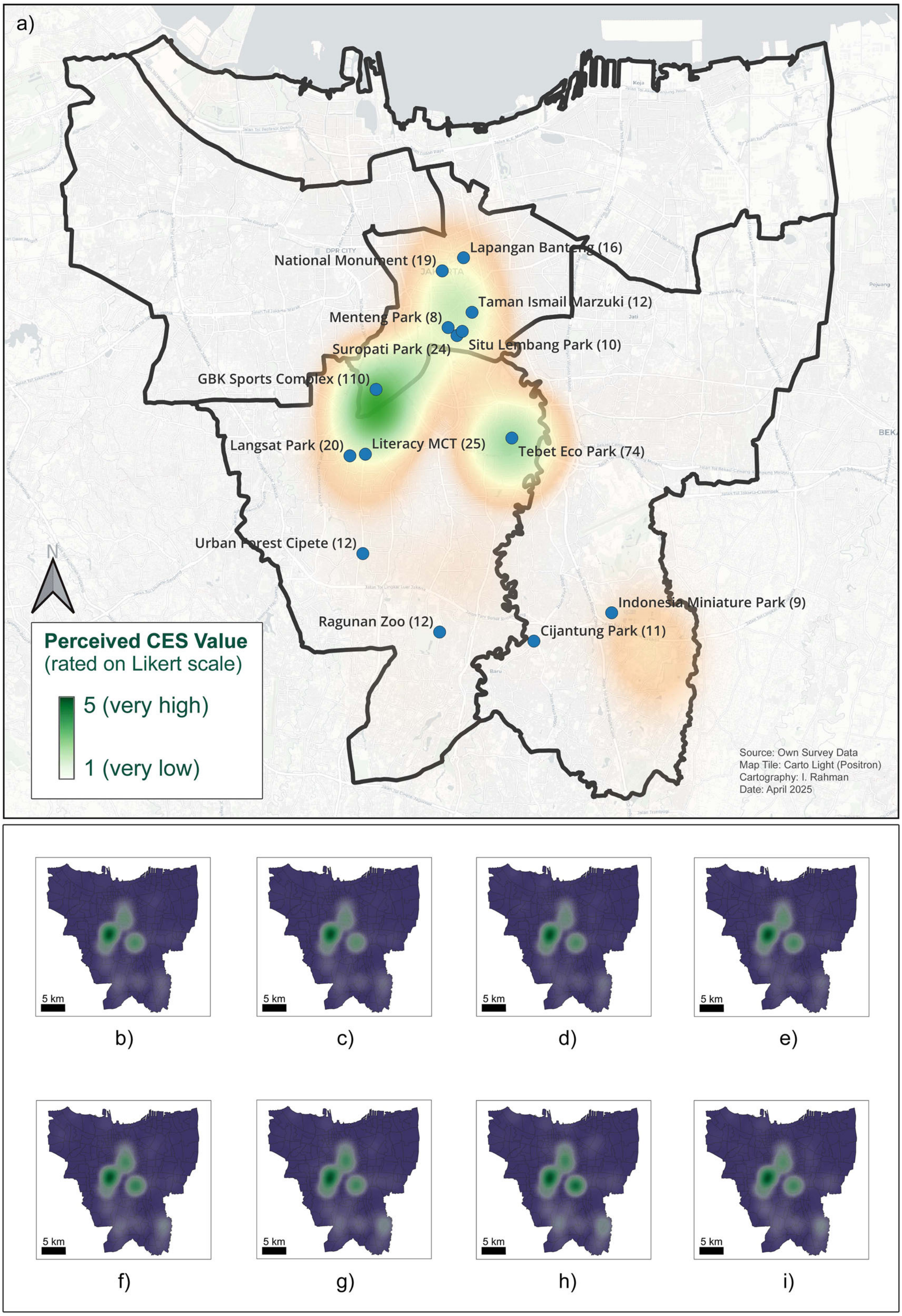


**Fig. 1 | UGS demand heatmaps for cultural ecosystem services (CES).** The main heatmap (**a**) displays blue dots representing the top 14 UGS locations across Jakarta's five municipalities (outlined in black), identified based on overall perceptions rated using a five-point Likert scale (1 = very low, 5 = very high). The number of respondents associated with each location is shown in brackets. These top 14 locations were derived from 362 coordinates marked by respondents out of 554 total indicated green space locations from the survey. Subfigures (**b**-**i**) display heatmaps for individual CES type: recreational (**b**), social relations (**c**), source of inspirations (**d**), esthetic value (**e**), sense of place (**f**), cultural heritage (**g**), educational value (**h**), and spiritual value (**i**). Areas with more intense green shading indicate UGS locations with higher perceived CES values, while lighter zones reflect lower-rated perceptions.

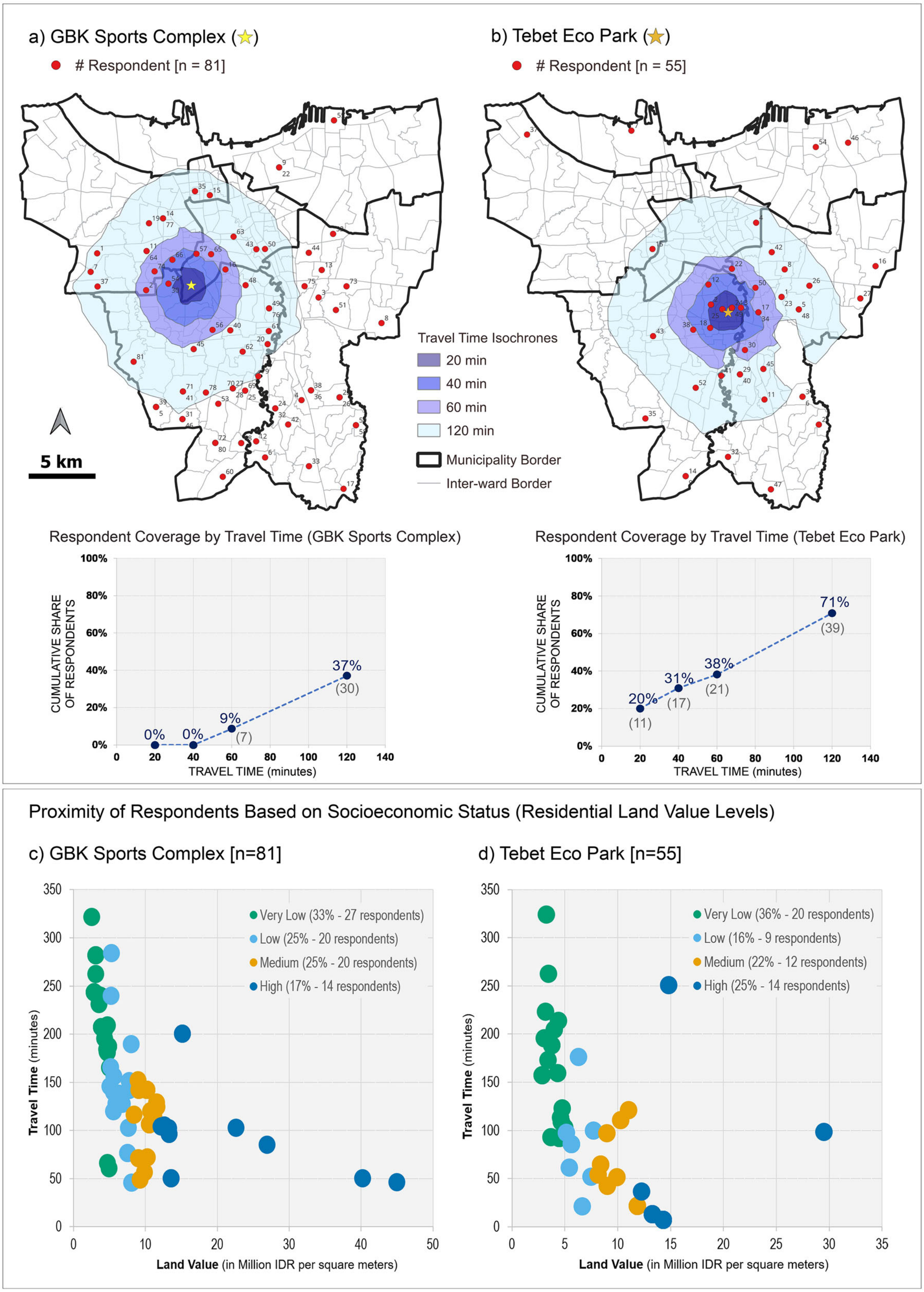


**Fig. 2 | Accessibility and proximity to high-quality cultural ecosystem services.** Maps (**a**, **b**) show pedestrian travel time isochrones to GBK Sports Complex (**a**) and Tebet Eco Park (**b**), the two highest-rated UGS locations. The charts below each map display the cumulative share of respondents residing within each travel time boundary. **c**, **d** show scatterplots of individual respondents' travel times against residential land values (used as a socioeconomic proxy), highlighting how proximity to these UGS varies across four socioeconomic groups: very low, low, medium, and high.

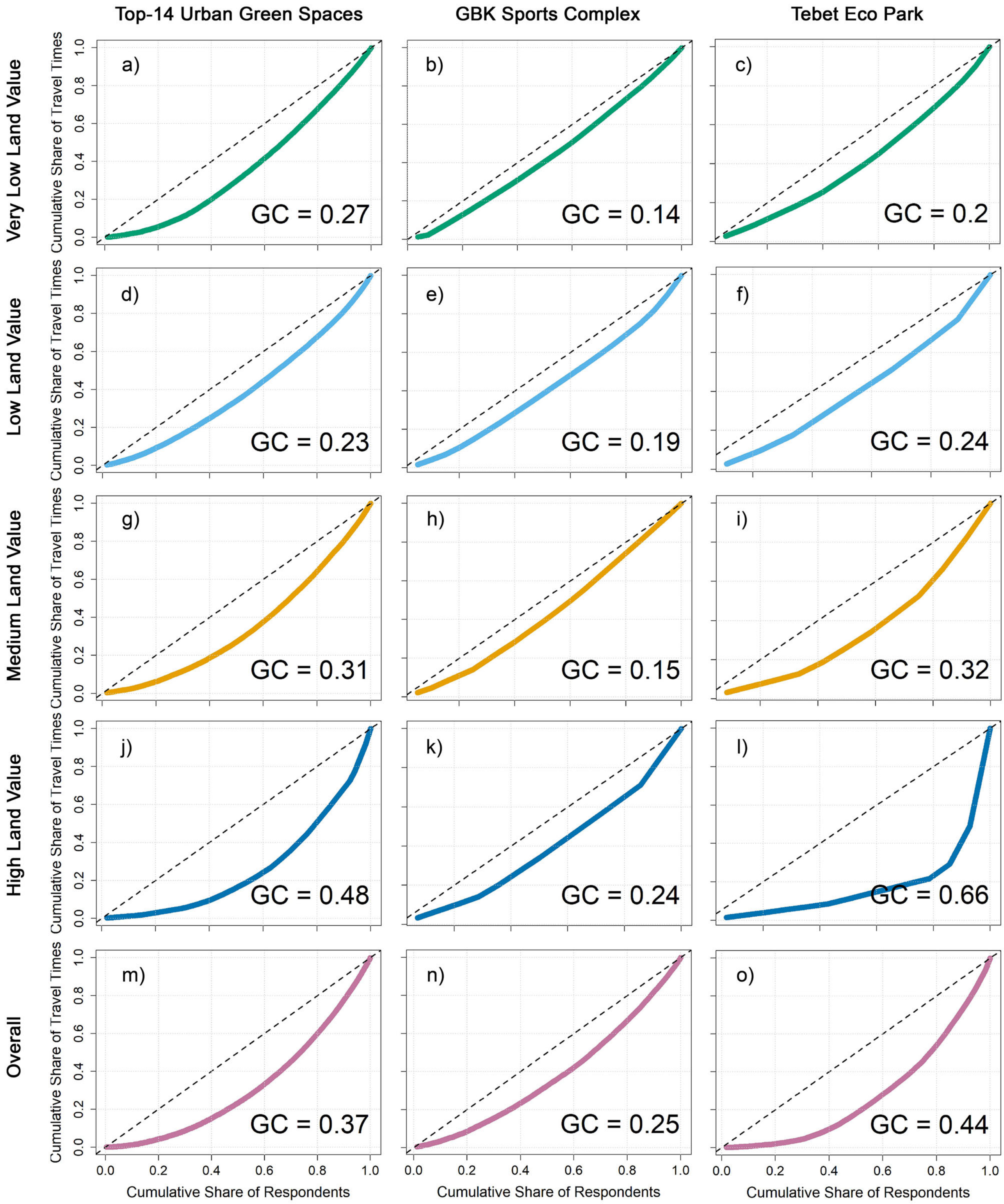


**Fig. 3 | Comparison of travel time inequality by socioeconomic group.** Panels visualize disparities in travel time access to UGS providing high-quality CES using Lorenz Curves, grouped by UGS category and socioeconomic level as follow: Top-14 UGS: Very Low (**a**), Low (**d**), Medium (**g**), High (**j**); GBK Sports Complex: Very Low (**b**), Low (**e**), Medium (**h**), High (**k**); Tebet Eco Park: Very Low (**c**), Low (**f**), Medium (**i**), High (**l**); The bottom panels (**m**–**o**) show overall travel time inequality aggregated by UGS category: Top-14 UGS (**m**), GBK Sports Complex (**n**), Tebet Eco Park (**o**). Gini Coefficients (GC) quantify inequality levels, with values closer to 1 indicating a greater disparity in travel time distribution.

socioeconomic disparities in access, the study integrates a methodological approach that applies land value as a spatially explicit socioeconomic proxy, complementing existing methods in the literature. The findings thus offer a dual contribution: they provide empirical insights into spatial inequalities in CES access while introducing methodological refinements in UGS assessment.

Methodologically, this study leverages land value as a critical socio-economic indicator, providing a robust spatial measure for assessing city-wide inequalities in access to UGS. Unlike a previous study[27] that established a broad linear correlation between land value and vegetation coverage, our approach used land value as a more spatially grounded measure of economic disparity, which is often applied in accessibility assessments to various urban services[30,31]. Linked to physical locations, this indicator captures structural economic conditions that other socioeconomic measures, such as income, age, or education, may overlook. Factors such as policy, housing markets, and investment patterns collectively shape access to quality amenities, including green spaces[60]. These dynamics are especially pertinent in a rapidly urbanizing Global South city like Jakarta, where accelerated growth over a short development period has contributed to widening income disparity, land scarcity, and segregation[43,44,52].

Furthermore, our analytical approach demonstrated methodological efficiency. While many studies on green space accessibility rely on larger datasets, our survey-based method efficiently captures broad accessibility patterns and detailed, respondent-level insights. Our analytical approach and sequence effectively revealed disparities in green space access across socioeconomic lines, even with a limited survey dataset and within a data-poor urban context[27]. This framework offers potential for replication in cities with limited data resources, providing valuable tools to gain actionable insights for policies that address proximity and quality in underserved areas. Nevertheless, this approach may be sensitive to sampling size and geographic specificity. Thus, adaptations could enhance accuracy by integrating additional measures to capture complex urban inequalities.

Next, our research marked the importance of an accessibility-focused approach over a provision-focused perspective in both CES valuation and green space accessibility studies. While the provision-based approach offers valuable insights into the spatial distribution and availability of green spaces[20], it falls short of ensuring equitable access when physical and socioeconomic barriers are present. By calculating pedestrian travel times of respondents across socioeconomic spectrums, this study captured a clearer view of actual physical accessibility to quality UGS and revealed spatial socioeconomic inequalities that provision data may overlook. This issue was evident in the Tebet Eco Park case, where even residents in high-land-value areas still encountered significant travel time inequalities when accessing high-quality green space.

Lastly on the methodological front, our hybrid approach enhanced the accessibility analysis by integrating spatially explicit data on qualitative preferences and isochrone principles. Introducing land value as a socioeconomic proxy complements existing methodological approaches in the literature, offering deeper empirical insights into inequalities in access to high-quality CES. Integrating the Lorenz curve and Gini coefficient estimations provided robust quantitative metrics for assessing inter- and intra-group variations, making it adaptable and practical for addressing equity concerns in diverse urban contexts.

Our findings highlight the importance of incorporating user-centered perspectives in planning decisions. By integrating the perceived quality aspects of UGS, our study acknowledges the importance of their social value, which is essential for developing green spaces that align with residents' needs and expectations. While most studies differentiate between the evaluation of green space accessibility and the appraisal of cultural ecosystem services, our study integrated both assessments by employing CES as a quality framework for respondents to identify culturally significant green spaces across an entire city. By incorporating CES as a quality layer, we emphasize that not all physically available green spaces hold equal value and benefits to the residents. Our study refined these areas based on respondents' preferences, narrowing it down to just 14 out of 5989 UGS sites[48], with only two locations perceived as providing high-quality CES: GBK Sports Complex and Tebet Eco Park.

As these two green spaces exhibited distinct patterns of inequality, these findings are useful for informing targeted policy interventions. For instance, maintaining good access and high-quality cultural amenities in the GBK Sports Complex is essential, as its accessibility is relatively unaffected by proximity, as indicated by the low disparity across land value groups. Since visitors reach this green space under fairly similar conditions, its attractiveness may be more closely tied to its diverse cultural offerings, which likely justifies its high appreciation in the survey and consistent heatmap patterns across eight types of cultural ecosystem services. In a broader view, the central concentration of hotspots indicated that high-quality green spaces were difficult for most people to access, as none of the respondents could reach GBK Sports Complex within 20 min of walking, whereas Tebet Eco Park remained the only green space accessible within this time frame, covering 20% of respondents. Considering the long commutes and the city's vast area, this may explain why respondents reported low visitation frequency on the UGS visitation pattern shown in Supplementary Fig. 2, with 80% of respondents choosing to visit green spaces primarily on weekends and public holidays. Recognizing the importance of the health benefits these spaces offer[61], our findings indicate that socioeconomically disadvantaged residents may not fully experience them, often having access only to lower-quality CES or less functional green spaces within their neighborhoods, which is consistent with previous research[11,14,15].

Reflecting on these contributions, our study suggests two critical areas for feedback on planning and design, along with one policy recommendation. First, our findings highlight structural barriers embedded within Jakarta's city planning. This was evident in the spatial disparities revealed by the isochrones and scatter plot analyses, which were not random but concentrated in specific zones, illustrating how location and travel time highlight critical access barriers. Lorenz curve analyses further clarified these inequality patterns, showing that marginalized groups are systematically restricted from benefiting from the green spaces with quality cultural amenities across the city. The consistent pattern of long commute times among lower socioeconomic groups highlights a twofold inequity: quality and access. These disparities jeopardize the potential health outcomes and restorative benefits that UGS could offer to city residents.

Second, despite perceptions that high-land-value residents uniformly enjoy better access, significant variability in access within wealthier neighborhoods indicates more profound underlying inequalities. The Lorenz curves for the top 14 green spaces and Tebet Eco Park revealed that while some residents in these affluent areas had immediate proximity to highly valued green spaces, others faced significantly longer travel times. This highlights a critical issue: the supply of publicly accessible green spaces often falls short of meeting the demand, leading to disparities in access even in wealthier neighborhoods. These disparities are likely driven by the uneven distribution and overall scarcity of UGS with high cultural importance across the city.

While these findings contribute to understanding spatial inequalities in CES accessibility, our study also offers critical recommendations for improving planning mechanisms to reduce unequal access. Drawing on Ostrom's work on Common-Pool Resources[62] and Colding and Barthel's institutional diversity framework of Urban Green Commons[63], we propose a shift toward a more community-inclusive approach to UGS planning, recognizing green spaces as collectively shared resources rather than solely government-managed amenities. In practical terms, strengthening community involvement—through participatory mapping, local monitoring, and co-management arrangements—can help ensure that UGS better reflects local needs, improves long-term maintenance, and supports more equitable access to culturally significant green spaces. While the effectiveness of these community-based strategies may vary according to local socioeconomic capacities as indicated by land value, targeted policy support and capacity-building investments mobilized by the city government can help bridge these differences to ensure inclusive participation and sustained outcomes.

A planning structure that empowers communities in UGS management could benefit the city in three ways. First, recognizing the differential value of green spaces to residents enables planners and policymakers to design interventions that improve physical accessibility and the meaningful benefits these spaces provide to diverse communities. Second, strengthening local engagement fosters greater flexibility in planning[55], helping the city to adapt to shifting demographics and evolving CES demand while mitigating further inequities. Lastly, a more participatory approach could support the national 30% UGS provision target by rebalancing responsibilities, with community-managed UGS expanding to 20% and government-managed UGS reducing to 10%. This initiative ensures a more inclusive and equitable approach to green space development and benefit distribution, as evident in Shanghai[13]. By incorporating bottom-up perspectives into the planning, this strategy promotes environmentally sustainable and socially inclusive development, ensuring urban growth that aligns with broader health and social equity goals. This is particularly relevant to Jakarta's greening plans and policies, which remain primarily top-down and are often hindered by complex governance structures and competing intersectoral interests, as Zain[43] argued.

We note that our analysis relies on online survey data, which may be subject to certain limitations, including potential self-reporting bias from respondents. Due to sample size variability across questionnaire and mapping sections, our findings may primarily reflect the perspective of active and engaged respondents with a particular interest in the topic. This potentially overlooks reasons why non-users avoid visiting green spaces altogether. We also note that the results obtained from the sociodemographic profile (shown in Supplementary Fig. 3) should be interpreted with caution due to the limited participation of individuals aged 40 and above. This underrepresentation likely stemmed from the intensive and varied questions, as well as the spatial mapping elements included in the survey.

Although we anticipated a skewed demographic by integrating land value data into our analysis, this study remained limited by its cross-sectional design, as data was collected at a single point in time. Consequently, the study may not capture temporal variations, infrastructure changes, or socio-economic shifts that influence green space accessibility and usage patterns over time. Our results further indicate that the ongoing lack of systematic integration of local knowledge and participatory approaches contributes to the undervaluation and neglect of UGS that provide high-quality CES value, reinforcing deeply embedded spatial inequalities. Future research should, therefore, examine the institutional and structural barriers that sustain these disparities from a systems-level perspective. Addressing these systemic dimensions is crucial for understanding why green space inequalities persist despite ongoing interventions and ensuring policies do not inadvertently reinforce accessibility barriers. From an environmental justice perspective, future research should further explore the health and well-being impacts of varying access to green spaces, particularly given the pressing need for CES in increasingly constrained urban spaces. For instance, longitudinal studies could provide deeper insights into the long-term effects of improved or diminished access to CES, particularly for vulnerable populations. Incorporating multimodal transportation networks into these analyses could help clarify how different mobility patterns influence UGS accessibility and its associated health and social benefits over time.

In conclusion, our research employs a mixed-methods approach to identify UGS locations that offer high-quality CES and to assess disparities in accessibility based on land value as a socioeconomic indicator. The findings provide valuable evidence-based insights for planners and policymakers, highlighting the need for city and UGS planning paradigms that address socioeconomically stratified access disparities to health-promoting spaces. By integrating participatory approaches and community co-management into green space planning, decision-makers can foster greater adaptability to demographic shifts along with evolving CES needs and tailor interventions to better serve diverse community needs. These efforts support broader sustainability goals, particularly in promoting healthier, more equitable, and more sustainable urban environments. City-wide and case-specific insights allow planners to identify underserved areas where improvements in green space quality, quantity, and accessibility are most needed. Addressing these disparities through inclusive planning structures can facilitate effective interventions in segregated areas, ensuring socioeconomically disadvantaged communities are prioritized and equitable access for all residents is enhanced. Despite its inherent limitations, this study bridges the gap identified in the existing research[43] and highlights critical areas for further exploration, particularly the governance challenges that drive and sustain green space inequalities.

## Methods

### Survey development and distribution

The questionnaire was developed using a map-based online survey platform called Maptionnaire (https://maptionnaire.com) that combined various question types with geo-referenced responses. A total of 26 questions were developed in Bahasa Indonesia and English and were organized into four sections:

(1) UGS visiting behavior (e.g., frequency, duration, timing, distance to nearest park) – 4 questions;
(2) Residential district, postal code, and pin-point mapping of one UGS location – 10 questions;
(3) Perceived physical and mental health benefits after visiting UGS – 7 questions; and
(4) Demographic data (e.g., gender, age, educational level, occupation, income level) – 5 questions

We adapted these four sections from a previous study by Zwierzchowska et al.[22] with an additional section on assessing perceived physical and mental health benefits after visiting UGS adapted from the WHO's guidelines[50]. The survey incorporated various question types, including multiple-choice questions with both single and multiple-answer options, fill-in-the-blank prompts, and rating questions using a 5-point Likert scale[64] with a slider bar to assess respondents' preferences or the importance of certain factors, ranging from "extremely unimportant" to "extremely important," as commonly applied in CES valuation studies[54,65]. 34 detailed survey questions are provided in Supplementary Note 1. Three experts from urban planning, sociology, and forestry reviewed the questionnaire. One expert from a landscape architecture background also provided feedback on terms used for green space definitions based on applied legal standings in Jakarta and Indonesia. With two rounds of pre-tests, the questionnaire's length was reduced after the first round to simplify the respondents' tasks, and the completion time per person was improved from 11–13 min to 9–10 min.

The survey was conducted online and distributed through physical and digital platforms to capture a broad outreach and a representative sample of participants from various demographic backgrounds. A leaflet was given to green space visitors and nearby pedestrians, which contained a short, inviting message and a QR code leading to the survey webpage. Survey posters were also placed at the entrances to major green space locations in Jakarta, on information boards within universities, and in some residential community halls. The digital version was also channeled through social media with support from local green communities to draw relevant interest and engage more participation. Lastly, following a similar method to Rall et al.[53] in Berlin, through randomly selected student and academic staff communities across various departments at the Universitas Indonesia in Jakarta, encouraging referral invitations to family and their relatives in the city. The survey ran online for two months and three weeks, from July 26th to October 19th, 2023.

### Scope of green space and cultural ecosystem service values

This study focused on government-managed parks and green areas[48], with the typologies classified according to Article 5 of the Minister's Regulation number 14/2022 by the Indonesian Ministry of Agrarian Affairs and Spatial Planning[46]. In a decentralized governance system, national regulations provide the legal foundation for developing subnational law. Thus, the Provincial Government of Jakarta also adopts the same UGS definitions developed at the national level. This information was provided in the survey before the questions to establish a shared understanding with the participants regarding which areas are considered UGS and which are not.

The selection of CES values included in this study was based on classifications and descriptions developed by the Millennium Ecosystem Assessment[2], as summarized in Supplementary Table 1. These classifications were also translated into the local language to enhance the participants' understanding. In addition, cultural diversity and knowledge systems values were excluded as these values are pertinent only when comparing service use across different cultural contexts[53], which was beyond the scope of this study.

### Data collection and pretreatment

The Maptionnaire platform recorded the responses online and provided downloadable results in a Microsoft Excel spreadsheet format. The responses were organized in a table format, with each column representing a question, resulting in 41 columns in the survey results. Geo-referenced responses from the mapping section were written in longitude and latitude. Land value information was obtained from the Jakarta Provincial City Government[66]. The information contains city-wide street-level land values for 2021, covering 194,555 street segments across five municipalities. The land value information was aggregated at the ward level to align with respondents' residential postal codes from the survey, linking each response to the unit land price per square kilometer within the corresponding postal code or ward. Incomplete answers, locations indicated outside the city border, and responses from non-residents were not used for analysis. Twelve responses from residents under 18 were also excluded due to legal restrictions.

### Data analysis

The survey recorded 638 valid responses for sections 1, 3, and 4, with 554 UGS locations and 541 residential postal codes recorded from the mapping part (section 2). From 541 indicated postal codes and 554 UGS locations, only 386 responses completed both parts usable for accessibility analysis. Supplementary Fig. 4 shows the analytical framework of this study. It highlights the connection between the methods applied and the study's objectives, encapsulating the scope of the survey, methodological approach, and sequence used in the analysis. The survey data analysis was mainly performed using Microsoft Excel and RStudio 2023.12.1, with QGIS 3.38.3 for spatial analysis and the Open Route Service (ORS) Tools plugin for generating distance matrix and isochrones[67].

Data analysis was conducted in six steps:

- **Survey data analysis** the completed responses were cross-tabulated and interpreted using descriptive statistics in Microsoft Excel, as these methods are frequently employed in questionnaire data analysis[68] and CES evaluation[22]. This first step provided an in-depth and general look at the data to understand respondents' usage patterns across various demographic profiles. In this stage, we excluded responses from section three, as it primarily revealed respondents' agreements and disagreements regarding perceived health advantages gained from UGS visits. Linkages between health benefits obtained were not explored in this study and require further investigation.
- **Origin-destination analysis** Geo-referenced information (e.g., UGS coordinate locations and residential postal codes) was analyzed and visualized using QGIS version 3.28.3. Using the Kernel density function, a heatmap was generated indicating respondents' preferred UGS locations, with respondents' Likert ratings weighted. The heatmap highlights city-wide green space hotspots that respondents highly valued for cultural ecosystem services. With UGS locations as destination points, we used the centroids of wards corresponding to residential postal codes as the respondents' originating points. A spatial distribution of respondents' residential origins is presented in Supplementary Figure 5.
- **Travel time** was calculated using the ORS Distance Matrix tool in QGIS, which provided network-based estimations between origin and destination points. There were 146 origin points with two destinations, representing 81 respondents visiting GBK Sports Complex and 55 visiting Tebet Eco Park. The program calculated travel time based on a combination of the road network data for different road types and pedestrian speed profiles using the following formula:

$$Travel\ Time_{i,j} = Travel\ Time\ from\ Origin_i\ to\ Destination_j$$

where $i$ represents each origin point (from 1 to 81 for GBK Sports Complex and 1 to 55 for Tebet Eco Park and $j$ represents the destinations, either GBK Sports Complex or Tebet Eco Park. The calculation output was presented in a table detailing each respondent's distance and travel time to their respective green space locations.

- **Spatial accessibility analysis** was visualized also using the ORS Isochrone tool. Isochrones were used to visualize the spatial accessibility of the respondents to two highly appreciated green spaces (GBK Sports Complex and Tebet Eco Park) by outlining multiple zones around each UGS location and representing various time intervals. We used pedestrian travel time to ensure comparable accessibility assessment between respondents. The plugin generated multiple isochrones, illustrating accessibility within 20, 40, 60, and 120 min of walking to surrounding areas. The maps were cross-referenced with the centroids of the residential postal codes, visualizing UGS accessibility for respondents within and beyond the outermost isochrone.
- **Travel time disparities by land value** were examined by analyzing the relationship between respondents' residential land values and travel times to both green spaces. Before the analysis, we used a percentile-based threshold to categorize residential land values into four segments: Very Low (below the 25th percentile), Low (25th to 50th percentile), Medium (50th to 75th percentile), and High (above the 75th percentile). This approach allowed us to assess respondents' spatial proximity to their preferred UGS with high cultural significance and established a foundation for evaluating the distributional equity of UGS access.
- **Access equity analysis** was conducted using the Lorenz curve and Gini coefficient to assess disparities across different locations and land value groups, providing insights into how green space access is distributed among various socioeconomic segments equitably.

## Data availability

The data for this study is available at https://doi.org/10.6084/m9.figshare.28023422. The land value data are publicly available for download[66].

## Code availability

The source code for plotting the Lorenz curves and calculating the Gini Coefficient is available from https://doi.org/10.6084/m9.figshare.28023425.

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## Author contributions

I.R. conceptualized the study, developed the questionnaire, analyzed the data, and wrote the manuscript. A.G. provided inputs during study conceptualization. S.S. evaluated and provided inputs in preparing the questionnaire and the manuscript. I.R. wrote and revised the original manuscript. A.G. and S.S. read the manuscript, provided feedback, and approved the final version. A.G. and S.S. supervised I.R., and this manuscript is expected to be part of I.R.'s Ph.D. dissertation.

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The authors declare no competing interests.

## Additional information

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