Do persons with low socioeconomic status have less access to greenspace? Application of accessibility index to urban parks in Seoul, South Korea

Seulkee Heo, Amruta Nori-Sarma, Sera Kim, Jong-Tae Lee and Michelle L Bell

1 School of the Environment, Yale University, 195 Prospect Street, New Haven, CT 06511, United States of America
2 Environmental Health Department, School of Public Health, Boston University, Boston, MA 02118, United States of America
3 Interdisciplinary Program in Precision Public Health, Department of Public Health Sciences, Graduate School of Korea University, Seoul, Republic of Korea
4 Division of Health Policy and Management, College of Health Sciences, Korea University, Seoul, Republic of Korea

* Author to whom any correspondence should be addressed.
E-mail: seulkee.heo@yale.edu

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Abstract
Access to urban greenspace has many benefits such as improved health and social cohesion. If access differs by population, these benefits make access to greenspace an environmental justice issue, but little is known regarding accessibility of parks among different sub-groups in Seoul, South Korea. We explored potential socioeconomic inequities for access to parks in Seoul measuring two park provision metrics: total park area per capita (TPPC), and park accessibility index determined by size and proximity of parks. We assessed correlations between a deprivation index for the 25 Gus (administrative unit equivalent to the US borough) and each park provision metric. Regression analyses were applied for the associations between eight socioeconomic indicators of the 424 Dongs (equivalent to the US neighborhood) and each park provision metric. An interquartile range (IQR) increase in percent elderly (≥65 years) was significantly associated with larger TPPC. An IQR increase in percent elderly and divorce rates was associated with increased park accessibility and decreased park accessibility, respectively. An IQR increase in percent elderly and divorce rates was associated with increased park accessibility by 3571 km (95% CI: 1103, 6040) and decreased park accessibility by 1387 (95% CI: −2706, −67), respectively. An IQR increase in percent elderly and divorce rates was associated with increased park accessibility by 1568 (95% CI: 15, 3120). Results suggest higher park access for socioeconomically disadvantaged regions. Findings indicate that measures of detailed park access considering spatial proximity and park size may more accurately measure park inequity compared to more basic metrics (e.g. TPPC), which may bias estimation of park inequity by capturing only one characteristic of parks. Detailed park measures should be considered in urban planning and health studies of greenspace.

Abbreviation

| Abbreviation | Definition |
|--------------|------------|
| EVI          | Enhanced vegetation index |
| IQR          | Interquartile range |
| NDVI         | Normalized difference vegetation index |

1. Introduction

The world has experienced urban growth at an unprecedented pace, and more than two-thirds of the global population is expected to live in urban environments.
by 2050 (Un 2015). Spatial patterns showed that the key regions of urbanization have shifted from global north to global south (Kundu and Pandey 2020). South Korea is undergoing a remarkable transformation to a more urbanized society with a projection of population at 55.0 million by 2030 (Son 2013). Urbanization brings land use changes in addition to socioeconomic transformations and population growth. Emerging problems associated with urban living have been studied in social science, environmental sciences, ecology, environmental studies, and geography (Wang et al 2012). Suggested environmental problems of urbanization include increasing greenhouse gas emissions; deteriorated environmental conditions, such as increased air pollution; loss of biodiversity; and decreased greenspace per capita (Wang et al 2012, 2020b, Zhang et al 2020a). These changes in urban environments can further lead to health problems such as lifestyle-related diseases, mental health, and diseases related to air pollution (Wang et al 2020a, Lu et al 2021, Ventriglio et al 2021). In addition, significant health threats to urban populations are posed as climate change is anticipated to contribute to poor air quality, high ambient temperature, and extreme weather events (Wu et al 2008), and urban land use cover and energy change further accelerate climate change (Qiu et al 2020). One of the aims of urban spatial planning is to minimize the harmful impacts of urbanization on environment, ensure efficient resource distribution and accessibility, and keep balance within a city for sustainable development (Gerten et al 2019).

Greenspace is defined as vegetation such as grass, bush, plants or trees and the built environment such as urban green infrastructures (e.g. parks) and unstructured vegetated areas (Lachowycz and Jones 2013). Greenspace can contribute to better health and well-being of populations through ecosystem services such as improving air quality, decreasing heat (e.g. heat island effects) and noise, encouraging physical activities, and providing direct interactions between nature and humans (Choi et al 2012, Markevych et al 2017). Given the potential ecosystem services, recent epidemiologic studies have suggested effects of greenspace on reduced risks of mortality, adverse birth outcomes, obesity, mental disorders, and cardiovascular and respiratory health outcomes in urban populations across the world (Dadvand et al 2015, Grazuleviciene et al 2015, Sugiyama et al 2016, Kim and Kim 2017, Vienneau et al 2017, Laurent et al 2019, Li et al 2019, Seo et al 2019). Further, other studies suggested that greenspace can reduce mortality or morbidity risks associated with exposures to high temperature and air pollution (Gronlund et al 2015, Burkart et al 2016, Dang et al 2018, Heo and Bell 2019). Based on these potential benefits, management of sustainable greenspace, as a part of nature-based solutions, can be linked to long-term sustainable development for adapting to climate change (Aslan-Tutak and Adams 2015).

Access to greenspace can significantly improve the economic and social health of cities and is increasingly recognized as an environmental justice issue. Social equity has long been recognized as one of the key components of sustainable development in urban areas globally, particularly in high-income countries with income disparity in Europe, North America, and Australia (CEC 1990, Elkin et al 1991, Yiftachel and Hedgcock 1993). The environmental justice movement, both in the US and globally, focuses on the challenges such as environmental health burdens that are disproportionately experienced by certain persons or groups, such as those who are low-income or racial/ethnic minorities (Holifield 2001, Fong et al 2020). While study results differ, deprivation defined as the state of disadvantage of community or an individual in relation to social or material nature (Cabrera-Barona et al 2015) and sometimes referred to as ‘socioeconomic disadvantage’ (Kind and Buckingham 2018), has been related with park provision (Gilliland et al 2006, Kihal-Talantikite et al 2013, Hoffmann et al 2017, Mears et al 2019). In particular, reduced access to greenspace could be an important contributor to health disparities by income and race/ethnicity (Jennings et al 2012, Browning and Rigolon 2018). The scientific literature suggests that subgroups including the elderly, low-income residents, racial/ethnic minorities, and children from low-income communities and communities of color are vulnerable to health risks from high temperature and air pollution and also that some of these subpopulations may have a more limited access to urban parks (Landrigan et al 2010, Zhang et al 2011, Kabisch and van den Bosch 2017, Rigolon et al 2018). The health benefits from greenspace can be larger and more crucial for those with low socioeconomic status (SES) and those residing in more deprived neighborhoods as people with lower SES having relatively worse baseline health status, lower of mobility, and live in more polluted areas, so they may benefit more from interventions (Markevych et al 2017). Therefore, it is important to understand the ways in which access to urban greenspace can be quantified and how greenspace is provided to vulnerable subgroups within communities in examining the health impacts that can accrue from disparate access to greenspace.

Numerous studies on inequity related to parks have been conducted over the last 2 decades and have shown somewhat inconclusive findings for the relationships between SES and park provision (Tan and Samsudin 2017, Mears et al 2019). For example, studies conducted in the US indicate that urban planning prioritizes access to greenspace for neighborhoods that are disproportionately White and disproportionately high income, thereby raising the potential for environmental injustices (Jennings et al...
2012, 2016, Wolch et al 2014). Another study using park geographic information systems (GIS) data and US Census tract data in 2010 found that census tracts of higher poverty or larger percentages of Hispanics or African Americans had a lower percentage of park areas in the US (Wen et al 2013). In contrast, some studies found that African Americans had a higher proportion of service areas of parks but also that there was more congestions within parks and fewer facilities such as playgrounds (Boone et al 2009, Vaughan et al 2013). A review study reported that inequity of greenspace distribution has complex historical patterns noting that Whites once lived closer to parks but African Americans moved into those areas with closer access to parks after White middle-class flight during the 1960s–1970s in the US city of Baltimore, Maryland (Benton-Short et al 2019). Another recent review in China suggested that urban afforestation-related policies were successful in promoting the equal distribution of green space from in more than half of the Chinese cities from 2000 to 2015 (Xiao et al 2017, Wu and Kim 2021). These findings indicate that inequity of greenspace distribution would show contrasting patterns across cities or communities, especially with different policies of equitable urban greenspace planning. Also, research is still relatively scarce in global South cities and further evidence is required to aid local decision makers in this region.

The absence of consensus on GIS measurements of distribution of parks may contribute the inconsistent research findings. Park provisions can be measured by three general approaches including density of parks in a defined geographical unit and for population (e.g. park area per capita), spatial proximity based on travel costs (i.e. time, distance), and spatial accessibility conceptualized by combined effects of park size, spatial proximity of parks park safety, or park attractiveness (Zhang et al 2011, Vaughan et al 2013, Ekkel and de Vries 2017). In assessing inequity of park provision, previous studies primarily focused on the relationships between total area or proportion of area that is parks within an administrative region in relation to socioeconomic factors (Wen et al 2013, Sugiyama et al 2016). The total area of parks within a geographical unit is often calculated by a common method often called the container approach, which assumes that residents evenly prefer access to parks, including farther parks, within their residential boundary (e.g. ZIP code, city, or county) rather than other parks, including closer parks located outside of their residential unit. Spatial proximity analysis measures the accessibility by distances to parks using either Euclidean distance or street network distance (Fan et al 2017) and the choice of distance metric can affect ranking spatial proximity (Vaughan et al 2013, La Rosa 2014). Using the total area of parks per capita as the extent of park provision for a region can provide useful information, but is limited as it does not consider parks outside of the region boundary that are proximate or accessible for the residents living near the boundary (Miyake et al 2010). Further, this is a single-dimension metric for the distribution of urban parks and does not represent the dispersion of urban parks within a defined geographical unit, the spatial accessibility to parks as a function of the dispersion of parks, or the nature of the urban park and different park features. While both large and small parks can contribute to cooling effect, study results are inconclusive for the correlation between access to parks or size of parks and physical activities such as walking and running (Mowen et al 2007, Miyake et al 2010, Sugiyama et al 2015, Wang et al 2019, Zhang et al 2020b). With such uncertainties, these findings call for examination of the distribution of parks in relation to size and accessibility of parks in local regions rather than the more basic metric of total area of park per capita. Increase in size of a park is also associated with park facilities and recreational programs, which can promote likelihood of visits for physical activities and relaxation (Sister et al 2010). However, relatively little is known for inequity of park provision regarding type, size, and accessibility of parks, especially in Asian cities (Ye et al 2018).

In previous Korean studies examining the relationships between park provision and SES, park provisions were often measured by the total area of parks within a region or a defined boundary and distance to the nearest park (Seo and Jun 2011, Kim 2014). One study investigated environmental justice based on the accessibility of urban parks by measuring the number of parks and the total area of parks within administrative regions across South Korea and reported that amount of urban parks is positively associated with individual’s physical activities and social solidarity (Jeong and Jun 2019). Another study in Seoul (Kim 2014) reported that the total park area per capita (TPPC) in administrative regions in the city was correlated with community-level SES such as population density, percent of population ≥65 years, percentage of population who are beneficiaries of social low-income support program, and flood and air pollution vulnerability. A few Korean studies assessed the disparities in distance to parks by regional demographic and income status (Seo and Jun 2011) and the relationship between monetary house values and distance to parks (Park et al 2017). In these studies, the measurement of accessibility to parks from residential areas was not incorporated into analysis. TPPC has been a widely used metric for access to greenspace in Korea as studies mostly relied on the national health survey data or death certificate data that do not provide exact geographical locations (e.g. address) of each participant.

We investigated a potential environmental injustice issue related to access to parks by social class and deprivation in Seoul, South Korea. We analyzed how TPPC, distance to parks, and spatial accessibility of urban parks are associated with socioeconomic
variables in the 424 administrative districts of Seoul in 2015. This study aimed to apply methods for spatial accessibility of parks and provide insights for equity of park provision, which can assist decision makers for planning urban greenspace and parks for sustainable development and prevention of health effects in the present day and under a changing climate.

2. Methods

2.1. Study regions

Our analysis was conducted based on cross-sectional design. We studied the park provisions in Seoul, South Korea, in 2015. The population and population density were 10,022,181 persons and 16,364 person km$^{-2}$, respectively, in 2015 according to the Korean Statistical Information Service. The area around northern city border is composed of a mountain area that is connected to some northern districts in the city. A large river called Han River runs through the center of the city. The Korean Statistics Agency provides estimations of official statistics for a range of variables such as demographics, economy, and health, for the administrative unit of the Gu, which is equivalent to the US or European administrative unit ‘borough’. The city has 25 Gus, which vary in size and population. The average size of Seoul’s Gus is 24.21 km$^2$ with a minimum value of 9.96 km$^2$ and maximum of 46.98 km$^2$. There are 424 Dongs in Seoul; a Dong is a smaller administrative unit than the Gu. The administrative unit of a Dong is equivalent to the US neighborhood. We calculated the park accessibility index for the Dong level. The highest spatial resolution available for the deprivation index was Gu, however we investigated several socioeconomic variables at the Dong level related to the elderly population, SES, disability, and other features. Data availability for SES and park accessibility is further described in the next section.

2.2. Data

For each dataset we obtained the most recent data available. The 2015 population data for the 424 Dongs were obtained from the Korean Statistical Information Service (Statistics Korea 2020). We obtained the 2015 geographical data of parks in Seoul from the Seoul Metropolitan Government (Department of Smart City Policy). To verify the 2015 GIS park data, we compared them to the Nation Urban Park Standard Data in 2019 obtained from each municipality in Seoul. About 10% of the parks identified in the National Urban Park Standard Data was missing in the 2015 GIS park data. The 2015 GIS park data in Seoul enables examination of the spatial characteristics of parks such as size, types, and accessibility to parks from residential areas. The 2015 GIS park data included information of park type based on the Laws of City Parks and Greenspaces (Ministry of Land Infrastructure and Transport 2018). These laws use three main categories of parks: ‘natural park’, ‘residential park’, and ‘special use park’. Natural parks are those that are also considered a national park. Natural parks are built in forest and/or mountain areas to protect the natural environment and landscape and to provide city residents with a healthy leisure and relaxation space. Residential parks are legally built near residential areas (e.g. <1000 m) in urban regions. This includes small parks (i.e. pocket park), children parks (i.e. playground), and neighborhood parks. Special use parks are built with specific purposes of providing space for relaxation and education and are not subject to thresholds of legal distance to residential areas. They include cultural, riverside, historical, sports, ecological, and cemetery parks. The area of a special use park is usually larger than that of a residential park. In this study, we use the term ‘urban park’ to refer to residential parks and special use parks. We excluded natural parks from our analysis in order to provide information regarding inequity of park provisions that might be associated with the differences in local government’s capability to build and manage planned greenspace.

The 2015 land cover data were obtained from the Facility Planning Division of the Urban Planning Bureau of Seoul Metropolitan Government. The data included categorized land cover of residential, commercial, and industrial area, urban infrastructure, transportation, greenspace, river and streams, crop land, and forest. We identified residential land cover to calculate residents’ access to parks (i.e. park access) in Seoul. We also obtained the 2014 road connectivity data from the Seoul Metropolitan Government. These GIS data contain information of the name, location, and type (e.g. highway, main road, street) of roads in Seoul.

In this study, we used the deprivation index as a dependent variable in associations between socioeconomic disadvantage and park provision. Individual SES indicators were further assessed for their associations with park provision to better understand the underlying mechanisms or determinants of potential socioeconomic inequality of park provision. The sets of SES indicators we obtained from public data sources differed between the Gu level and the Dong level in Seoul (table 1). Due to privacy issues, most nationwide population-based survey data (e.g. Korean Community Health Survey) are primarily provided at the Gu level, which would substantially deidentify individuals. While we obtained data of 11 SES indicators, available at the Gu level, from a public open data source (Statistics Korea; KOSTAT), not all these SES indicators were available at the Dong level. Thus, we could only calculate the deprivation index, using indicators used in previous literature, for the 25 Gus in Seoul. For assessing the underlying individual SES indicator for the potential socioeconomic inequality of park provision, we obtained eight SES indicators, that were available at the Dong level in
Table 1. Spatial unit of the socioeconomic indicators used in analysis.

| Data used in analysis | Spatial unit of data |
|-----------------------|----------------------|
|                       | Gu       | Dong     |
| Socioeconomic indicators used to calculate privation index | O       | X        |
| % of households with more than 1.5 persons per room | O       | X        |
| % of households living in rented houses | O       | X        |
| % of households that do not own a house | O       | X        |
| % of households without a car | O       | X        |
| % of households living below the minimum housing standard | O       | X        |
| % of households with only one person | O       | O        |
| % of households with female head-of-household | O       | O        |
| % of households not living in an apartment | O       | O        |
| % of individuals >65 years | O       | O        |
| % of individuals (age 30–64 years) with high school education or below | O       | X        |
| % of individuals who are divorced or widowed | O   | X        |
| Indicators similar to those used for deprivation index | —     | —        |
| Divorce rate (person/1000 population) | X       | O        |
| % of individuals with disability | X       | O        |
| % of population who are beneficiaries of social low-income support program | X   | O        |
| Average number of cars per household (car/household) | X   | O        |
| Notes. 'X' indicates data are available; 'O' indicates data are not available. The administrative unit ‘Gu’ is equivalent to the US or European administrative unit ‘borough.’ The administrative unit ‘Dong’ refers to sub-division regions in a Gu. Dong is equivalent to the US neighborhood. Data for socioeconomic indicators used to calculate the Gu-level deprivation index were obtained from Statistics Korea (KOSTAT). The socioeconomic indicators available at the Dong level were obtained from the Seoul Yeollin Data Portal website of Seoul Metropolitan Government. |
We obtained publicly available socioeconomic indicators for each Dong from the Seoul Yeollin Data Portal website of Seoul Metropolitan Government (Seoul Metropolitan Government 2019): percentage of households with only one person, percentage of households with female head-of-household, percentage of households not living in an apartment, divorce cases/1000 population, percentage of individuals ≥65 years, percentage of individuals with disability, average number of cars per household (car/household), and percentage of persons who are beneficiaries of the government low-income support program. Except for the data for the percentage of female head-of-household for which the latest data were for 2010, all variables were obtained for the year 2015. The government low-income support program is often referred to as ‘the national basic livelihood security system’ and is government aid with cash and in-kind benefits for the households with income below a yearly-designated minimum income (about 3% of the population) (Jeon et al 2017).

2.3. Estimation of access to parks based on spatial characteristics of parks

We estimated spatial characteristics of the populations’ access to parks using three approaches, calculated separately for each Dong and Gu: (a) TPPC within an administrative boundary, (b) distance to the closest park, and (c) accessibility of park associated with both park size and distance. Total area of parks within an administrative boundary was calculated as the sum of park size of every urban park within each Dong and Gu. This was used to calculate TPPC, which was computed as the sum of total park areas (m²) divided by the total population in 2015 in each Dong (or Gu). To calculate the distance to the closest park and the accessibility index of parks from where people live, we created a GIS file of the 30 × 30 m resolution grid cells overlapping with the residential land cover, which was identified from the land cover data. We call these cells ‘residential grid cells’, which refers to grid cells with residential communities, not individual residences. The 30 × 30 m resolution has been widely used in previous studies to calculate park area per capita (Xing et al 2018). The distance to the closest park based on the Euclidean distance (i.e. straight-line distance) to the closest park was calculated for each 30 × 30 m grid cell on the residential land cover. The calculated distance to the closest park for every 30 × 30 m residential grid cell was aggregated at the Dong level and separately at the Gu level.

We calculated accessibility to parks using a spatial interaction model, also known as the gravity model, i.e. widely used in research of parks. This index defines the accessibility to a park as a combined measure of proximity and area of parks for a given region. Unlike a measure of TPPC within an administrative boundary, this method has the strength of including proximate parks from the target area in the analysis even though those parks are outside of the administrative boundary. The spatial interaction model can be flexibly modified, and we applied the method presented by Zhang et al (2011), which builds on the original version of this method, the gravity model proposed by Hansen (1959). The spatial accessibility (Aij) from a residential place (i) to a destination park (j) was calculated as:

\[ A_{ij} = \sum_j S_j^o / d_j^{\beta} \]  

(1)

where \( S_j \) is size of the destination park \( j \), \( d_j \) is the distance from a 30 × 30 m residential grid cell \( i \) to destination park \( j \), \( \alpha \) is the parameter that reflects the size effects of park \( j \) on its accessibility, and \( \beta \) is distance decay or friction parameter. As indicated by equation (1), the accessibility of park increases with higher park area and shorter distance to parks for a neighborhood. While the distance decay parameter can be different among different types of destinations (e.g. park, shopping center) and activities (i.e. purpose of visiting the destinations), we applied the same decay parameter effect for our study parks, which assumes that different recreational physical activity behaviors have the same attractiveness for local neighborhoods. We adopted 1.91, the empirical value for the distance decay parameter for public open place, and an empirical value of 0.85 for the parameter \( \alpha \) used in some US studies (Giles-Corti and Donovan 2002, Zhang et al 2011), as an empirical value of these parameters has not been developed for our study region. Although different values of the distance decay parameter were not available for residential and urban parks in this study, we addressed potential differences in attractiveness and accessibility of parks by stratifying the main analysis between residential and urban parks.

We calculated the \( A_{ij} \) for the 30 × 30 m grid cells overlapping with the data for residential land cover data and all parks located in or intersecting with a 1 km buffer from the centroid of a given grid cell. This approach of calculating the park access for grids dividing a study area into smaller areas is a commonly applied method in previous studies (Lee and Hong 2013). In our study, the \( d_j \) was calculated based on the shortest Euclidean distance between a residential grid cell's vertex and a neighboring park edge. The detailed calculation can be found from the GIS software website (ESRI 2020). After calculating the values of \( A_{ij} \) for every grid cell overlapping with the residential land cover, we calculated the average of \( A_{ij} \) for each Dong. To examine the correlations between the park accessibility, calculated at the Dong level, and the deprivation index, available only at the Gu level, we calculated the average \( A_{ij} \) for each Gu as well.

As sensitivity analysis, the distance to parks was measured as distance based on roads, hereafter referred to as ‘walking distance’, from a starting point
to target features (i.e. parks) using the ‘cost distance analysis’ (Smith et al 2018) in GIS software. Calculating walking distance is a different representation of proximity to parks than a Euclidean distance as this approach recognizes that people can reach a destination through walkable roads avoiding barriers such as buildings. Further, the approach of walking distance considers where parks are accessible for entry rather than the park’s boundaries. The cost distance analysis returns an accumulated cost surface raster based on least cost paths from a starting point to multiple regions. We first generated a cost raster with walkable roads and non-road areas being masked out and calculated accumulated cost distance from each 30 × 30 grid cell to neighboring parks within the grid cell’s 1 km buffer (i.e. within 1 km of the grid cell’s boundary). Among the pixel values in the cost raster of a 30 × 30 m grid cell intersecting with the polygon of a park, the minimum pixel value was considered as the shortest walking distance to the park from that residential grid cell. The average difference between the walking distance (based on the cost distance analysis) and the Euclidean distance was 199.7 m (Q1 = 86.0 m, Q3 = 206.8 m). Walking distance was about 2000 m larger than Euclidean distance when there were special use parks between the starting residential grid cell and the target park blocking access. An outlier difference larger than 9000 m was observed for a special use park alongside Han River’s stream due to relatively fewer entrances or accessible points into the park sporadically located through that park. On the contrary, walking distances on average 100 m shorter than Euclidean distances were observed when the Euclidean distance computed between a vertex of residential grid to the vertex of the closest segment composing a park polygon was longer than the distance between the two shorter points. In all these cases, the cost distance method is theoretically more realistic than the Euclidean distance method for the perspective of residents traveling to parks. The calculated walking distances were applied to A_{ji} for every grid cell of residential land cover.

2.4. Statistical analysis
We conducted a correlation analysis for the deprivation index with the TPPC and also with the park accessibility index at the Gu level to assess socioeconomic inequality of park provision in Seoul. As a next step, a generalized linear model with a maximum likelihood estimation was applied for the associations for individual socioeconomic indicators with the TPPC and the park accessibility index to identify underlying factors for such inequality of park provision. Single-indicator models included each of the socioeconomic indicators as an independent variable, whereas multiple regression analyses using generalized linear models with a maximum likelihood estimation included all socioeconomic indicators except percentage of individuals with disability, which was excluded to its high variance inflation factor (>5, James et al 2013). These two approaches were separately applied to the park area per capita and the park accessibility index included in the models as a dependent variable. We conducted single-variable regression analyses for the associations between each of the eight socioeconomic variables that were available for the 424 Dongs and the park provision metrics (i.e. TPPC, park accessibility index). The eight socioeconomic variables included percentage of households with only one person, percentage of households with female head-of-household, percentage of households not living in an apartment, divorce rate, percentage of individuals age ≥65 years, percentage of individuals with disability, percentage of persons who are beneficiaries of the social low-income support program, and average number of cars per household. We also conducted multiple regression analyses including seven socioeconomic variables and excluding the percentage of individuals with disability, which had high correlations with the other variables, as the main independent variables in relation to TPPC and park accessibility index. The associations were presented as regression coefficients for an interquartile range (IQR) increase in the independent variables; we used the IQR as a one-unit change in an independent variable would mean different units, scales, and meanings in comparison to meaning of the other included variables. The results of regression analyses and correlation analysis were compared between the TPPC and the park accessibility index.

The ArcGIS 10.7.1 GIS (ESRI, Redlands, CA) and statistical software R (version 3.5.3) were used to generate the map of the park provision metrics and the SES variables in the study regions. R was also used for statistical analyses.

3. Results
Table 2 shows descriptive statistics of the park data and the socioeconomic variables of the 424 Dongs used in our analysis. Among the 424 Dongs, the average number (SD) of residential parks in a Dong was 4.2 (2.9), while the average number of special use parks was 1.3 (0.6). The average (SD) of total area of urban park per capita (m²/person) was 4.3 (13.2) for residential parks and 11.1 (23.2) for special use parks. The average size of a special use park (189 732 m²) was 11 times larger than the average size of a residential park (16 603 m²). The average of TPPC in the study Dongs (6.5 m²/person, SD = 17.1) satisfied the standard park area per capita of the Laws of City Parks and Greenspaces, which is 6 m²/person (Jeong and Jun 2019).

Large-scale parks (appearing as large polygons rather than small dots in figure 1) were located near the center of the city, particularly along the river (figure 1(A)). Many large-scale residential parks
Table 2. Descriptive statistics of urban parks and socioeconomic variables in 424 neighborhoods (Dongs) for 2015.

| Variable | Mean (SD) | Min–Max | IQR |
|----------|-----------|---------|-----|
| Number of urban parks | — | — | — |
| Residential and special use park | 4.4 (3.0) | 1.0–31.0 | 4.0 |
| Residential park | 4.2 (2.9) | 1.0–29.0 | 4.0 |
| Special use park | 1.3 (0.6) | 1.0–4.0 | 0.0 |
| Total area of urban parks per capita (m²/person) | — | — | — |
| Residential and special use park | 6.5 (17.1) | 0.0–167.7 | 4.3 |
| Residential park | 4.3 (13.2) | 0.0–113.6 | 1.7 |
| Special use park | 11.1 (23.2) | 0.0–167.5 | 11.8 |
| Average size of urban parks (m²) | — | — | — |
| Residential and special use park | 27 030 (102 620) | 43.4–1613 | 364 |
| Residential park | 16 603 (52 115) | 43.4–598 603 | 5073.5 |
| Special use park | 189 732 (384 828) | 119.7–2275 329 | 204 858.5 |
| SES | — | — | — |
| % of households with only one person (%) | 29.4 (12.2) | 4.9–71.9 | 14.3 |
| % of households with female head-of-household (%) | 28.0 (6.0) | 11.6–50.5 | 7.2 |
| % of households not living in an apartment (%) | 47.2 (30.7) | 0.0–100.0 | 52.5 |
| Divorce rate (case/1000 population) | 2.1 (1.5) | 0.1–21 | 1.2 |
| % of individuals age ≥65 years (%) | 12.6 (2.5) | 2.5–5.5 | 3.2 |
| % of individuals with disability (%) | 3.9 (1.4) | 1.1–14.2 | 1.3 |
| % of population who are beneficiaries of social low-income support program (%) | 3.0 (2.3) | 0.0–19.6 | 2.2 |
| Average number of cars per household (car/household) | 0.8 (0.2) | 0.3–1.4 | 0.2 |

(appearing as large green polygons in figure 1) are located in the northern part of the city. Almost every park was located within the 500 m buffers of a residential area (as grid cells at 30 × 30 m resolution) (figure 1(B)).

Maps of TPPC, distance to parks in a 1 km buffer from the 30 × 30 m grid cells overlapping with the residential land cover, and accessibility index of parks aggregated into the 424 Dongs and into the 25 Gus are compared in figure 2. The comparisons between the Dong and Gu levels show that the level of park provision for each Gu was influenced by a few Dongs with high park provisions. In such Gs, some Dongs with relatively low park provisions were categorized as a region with higher park provisions indicating heterogeneity of park provision at the Gu level. The ranges of the three metrics at the Gu level were (0.9–19.6 m²/person for TPPC, 577.5–657.8 m for distance, and 59–38 653 km for park accessibility index), which were narrower than the ranges estimated for the Dong level. For example, the range of TPPC at the Gu level was 0.9–19.6 m²/person, while the range for the Dong level was 0.0–282.6 m²/person. The TPPC and the park accessibility index show slightly different spatial patterns for the study regions. Based on the TPPC, the central northern part of Seoul had the highest park provision at the Gu level. On the other hand, when the accessibility index of parks based on the Euclidean distance was considered, the central southern part of Seoul showed the highest park provision at the Gu level. The southeast part of Seoul showed a moderate level of park provision based on the TPPC but the level of park provision was low when the accessibility index was considered.

Figure 3 represents the top 10%, 25%, and 50% of Dongs based on their levels of TPPC and park accessibility index. This figure highlights variability of the two metrics among Dongs within a Gu, which is not noticeable from the maps at the Gu level in figure 2. There was a slight difference of the spatial patterns between TPPC and park accessibility index. This difference was stronger in the center and the southern east part of Seoul.

The correlation coefficient for the deprivation index and the park area per capita at the Gu level was 0.26. The correlation coefficient for the deprivation index and the park accessibility index at the Gu level was 0.10. Thus, low correlations were observed for socioeconomic disadvantage levels and park provision metrics.

Table 3 shows results from the regression analysis for Dong-level SES variables related to TPPC and park accessibility index. For TPPC, only percentage of individuals ≥65 years was significantly associated among the eight SES variables included in the fully adjusted model. An IQR increase in percentage of individuals ≥65 years (3.2%) was associated with an increase in TPPC by 5.0 m²/person (95% CI: 2.5, 7.6). On the other hand, percentage of individuals ≥65 years, percentage of individuals with disability, and percentage of persons who are beneficiaries of the social low-income support program were associated...
with park accessibility index in single variable models. In the fully adjusted model, an IQR increase in divorce rate (1.2 case/1000 population) was associated with decreased park accessibility by 1386.6 km (95% CI: -2705.9, -67.4) and an IQR increase in percentage of individuals \( \geq 65 \) years (3.2%) was associated with a 3571.4 km increase in park accessibility (95% CI: 1103.3, 5039.5).

The results of regression analysis conducted only for residential parks except special use parks are shown in table 4. Findings were robust for the included SES variables with TPPC compared to the analysis conducted for both residential and special use parks. Additional SES variables were significantly associated park accessibility index. In the fully adjusted model, an IQR increase in percentage of the population who are beneficiaries of the social low-income support program (2.2%) was associated with a 1567.6 km increase in park accessibility (95% CI: 15.0, 3120.2). An IQR increase in percentage of
households with only one person (14.3%) was associated with decreased park accessibility by $-2280.6$ km (95% CI: $-4860.7$, $299.4$) at a significance level of 0.1.

Results for the accessibility index based on the walking distance from the cost distance analysis (table 5) were different from the analysis of park accessibility based on the Euclidean distance. Percentage of the population who are elderly and the divorce rate were not associated with park accessibility. An IQR increase in percentage of households not living
Table 3. Regression coefficient (95% CI) of socioeconomic variables related to TPPC and park accessibility index \((n = 424)\).

| Variable                                                   | TPPC                  | Park accessibility index |
|-------------------------------------------------------------|-----------------------|--------------------------|
| % of households with only one person                        | 0.0 (−2.0, 2.0)       | −404.0 (−2298.9, 1490.9) |
| % of households with female head-of-household               | 0.2 (−1.8, 2.2)       | 688.6 (−1254.0, 2631.2)  |
| % of households not living in an apartment                  | 0.5 (−2.1, 3.2)       | 273.0 (−2482.2, 3027.7)  |
| Divorce rate (case/1000 population)                         | 0.1 (−1.2, 1.5)       | −1015.9 (−2311.4, 279.6) |
| % of individuals age ⩾65 years                               | 3.2 (1.1, 5.3)        | 3481.3 (1485.0, 5477.5)  |
| % of individuals with disability                            | 0.1 (−1.5, 1.6)       | 2174.9 (720.9, 3628.9)   |
| Average number of cars per household (car/household)        | 0.5 (−1.4, 2.3)       | −729.5 (−2511.8, 1052.8) |
| % of population who are beneficiaries of social low-income support program | 0.0 (−1.6, 1.6) | 1664.1 (130.2, 3198.0) |

Notes. * \(p\)-value < 0.05. Fully adjusted models included all variables listed in the table except percentage of individuals with disability, which was excluded due to its high variance inflation factor.

Table 4. Regression coefficient (95% CI) of socioeconomic variables related to TPPC and park accessibility index of residential parks \((n = 424)\).

| Variable                                                   | TPPC                  | Park accessibility index |
|-------------------------------------------------------------|-----------------------|--------------------------|
| % of households with only one person                        | 0.7 (−1.1, 2.4)       | −619.2 (−2196.3, 957.8)  |
| % of households with female head-of-household               | 1.1 (−0.7, 3.0)       | 592.5 (−1025.0, 2210.0)  |
| % of households not living in an apartment                  | 2.1 (−0.5, 4.7)       | 483.5 (−1810.2, 2776.7)  |
| Divorce rate (case/1000 population)                         | −0.4 (−1.6, 0.8)      | −663.2 (−1743.1, 416.7)  |
| % of individuals age ⩾65 years                               | 3.9 (1.7, 5.8)        | 3053.1 (1393.3, 4712.9)  |
| % of individuals with disability                            | 0.7 (−0.6, 2.1)       | 2552.3 (1353.7, 3750.8)  |
| Average number of cars per household (car/household)        | −0.4 (−2.1, 1.2)      | −543.6 (−2028.0, 940.7)  |
| % of population who are beneficiaries of social low-income support program | 0.5 (−1.0, 2.0) | 2180.2 (913.1, 3447.4) |

Notes. * \(p\)-value < 0.05, † \(p\)-value < 0.10. Fully adjusted models included all variables listed in the table except percentage of individuals with disability, which was excluded due to its high variance inflation factor.

in an apartment was (52.5%) significantly associated decreased park accessibility by 1363.4 km (95% CI: −2604.5, −121.8).

In summary, park accessibility tended to be higher in regions with higher percentage of the elderly population, individuals with disability, and beneficiaries of the social low-income support program, whereas it was lower in regions with higher divorce rate, percentage of households with only one person, and households not living in an apartment. Overall, there was no strong pattern that park provision was lower in socioeconomically deprived regions in Seoul.

4. Discussion

A few previous Korean studies examined inequity of park distribution by SES. In those studies, total area or proportion of parks within an administrative region was mainly measured in relation to park distributions...
by socioeconomic factors. To our best knowledge, our study is the first study for Korea that examined environmental justice of park provision by the size, type, and spatial accessibility of parks, using various park provision metrics. The park accessibility index used in this study provides more detailed information including the spatial distribution of urban parks in smaller-scale regions than the larger administrative unit of a Gu and the spatial interaction between urban parks and residents. Also, this study is the first to relate these in-depth spatial characteristics of urban parks to SES status at the neighborhood levels in Seoul.

By using spatial interaction modeling, we estimated the spatial accessibility of parks in addition to the distance to the nearest park and the sum of areas of parks per capita. Our results showed that the park accessibility index does not correspond to the total area of parks within the administrative units. Interestingly, park accessibility index was associated with more SES variables in the study Dongs than was TPPC. The statistical power of regression analysis was stronger in the analysis only for residential parks compared to that of both residential and special use parks. These results may imply that special use parks complement the provision of parks in regions where the provision of residential parks is relatively limited. The results may imply that the demand or necessity of the provision of residential parks might have been less recognized or less possible in regions where more special use parks had been built.

The two park provision metrics presented different insights for the environmental justice of park provision in Seoul when related with SES variables and the deprivation index at the Gu level. TPPC was distinctively high in one region while it was similar for the other regions in relation to the deprivation index and each socioeconomic variable incorporated in the deprivation index (supplementary figures S2 and S3 (available online at stacks.iop.org/ERL/16/084027/mmedia)). The park area per capita does not present sufficient information for the correlations with other variables or the deprivation index. For example, it is unclear if parks are more often located in Gus with a higher percentage of households not living in an apartment based with respect to an outlier value of total area per capita against the percent of households not living in an apartment. However, more consistently dispersed values were found for park accessibility index among the study regions. The park accessibility index shows a more normal distribution without outliers. Differences between the TPPC and park accessibility index were more distinctive for the percentage of households with female head-of households and the percentage of individuals \( \geq 65 \) years. In summary, park accessibility was higher in the Gus with medium values of deprivation index, whereas TPPC indicated that park accessibility was higher in socially more deprived regions.

Some researchers have suggested that inconsistent results for the relationship between urban park access and resident’s physical activity could be due to various measurements of accessibility of parks across studies (Zhang et al 2011). The potential misclassification caused by measuring TPPC within a region’s boundary is likely to affect analysis of the health effects of urban parks on health. While there are only a few studies about environmental inequity of urban parks in Korea, there are more studies for the health effects of urban parks such as physical activity, cardiovascular diseases, and mental health outcomes (e.g. depression, suicidal indicator) in general (Park et al 2013, Min et al 2017, Jeong and Jun 2019, Seo et al 2019).

### Table 5. Regression coefficient (95% CI) of socioeconomic variables related to park accessibility index based on walking distance (n = 424).

| Variable | Single variable model | Multiple regression model |
|----------|-----------------------|--------------------------|
| % of households with only one person | \(-332.8 (-1015.9, 350.5)\) | \(-872.4 (-1999.6, 254.7)\) |
| % of households with female head-of-household | \(-45.9 (-751.0, 659.0)\) | \(405.4 (-763.3, 1574.3)\) |
| % of households not living in an apartment | \(-750.2 (-1742.0, 242.0)\) | \(-1363.4 (-2604.5, -121.8)\)* |
| Divorce rate (case/1000 population) | \(-98.1 (-559.3, 363.0)\) | \(-199.8 (-670.8, 271.3)\) |
| % of individuals older than 65 years | \(553.9 (-173.0, 1280.8)\) | \(333.2 (-560.0, 1232.4)\) |
| % of individuals with disability | \(608.9 (74.7, 1143.1)*\) | — |
| Average number of cars per household (car/household) | \(-464.8 (-1114.9, 185.2)\) | \(-1028.1 (-1953.6, -102.6)\)* |
| % of population who are beneficiaries of social low-income support program | \(447.6 (-112.3, 1007.4)\) | \(180.1 (-503.6, 863.8)\) |

Notes. * p-value < 0.05.
for the health impact of the parks. Using accessibility of parks based on the spatial interaction models can be especially justified for studies focusing on countries or cities, such as those in South Korea, where the exact addresses of participants are classified in the public health datasets.

Our results show that residential areas in the southern east area of Seoul had lower accessibility to parks compared to the central and the northern east areas. A contrasting result was found in a previous study finding that southeast areas had more residential areas serviced by accessible parks in Seoul in 2002 (Oh and Jeong 2007). A potential reason for the inconsistency is the differences in definitions between park accessibility and park service area; the park accessibility is defined by both the distance and park areas that are located within buffer areas around residential areas, whereas the park service area is calculated as the percentage of residential area within buffers from urban parks of the total areas excluding park areas. Due to the definition, the park accessibility calculated in our study showed higher park accessibility in regions in which large-scale parks are located such as the northern east parts of Seoul. Also, the changes in land use and park provisions over the past decade might have contributed to the inconsistent study results.

We stratified our analysis between special use parks and residential parks considering they would have different attractive factors for residents based on their different legal definitions in the Laws of City Parks and Greenspaces. Theoretically, entry fee and limited opening time of special use parks may reduce frequency of visits. Some empirical evidence suggested that frequency of park use can differ by types of park with smaller and closer parks being visited more easily and frequently. For instance, a previous Korean survey study for Gyeongsan City reported that the type of parks visited most frequently by the respondents was pocket parks around homes followed by children parks, riverside parks, cultural parks, natural parks, and sports parks (Lee and Kim 2015). Small parks that are easy to access can be crucial for improving quality of life and well-being for city residents, especially when an urban region has limited space for building larger parks. The type of park (e.g. pocket park, grand park, children park, cultural park) is also often related with park size and vegetation coverage that can modify the temperature cooling effects in parks. We assessed park provision separately for residential parks in order to investigate health disparities expected by the inequity of provision of parks near residential areas.

Our measurements of geographical pattern of urban parks differs from some previous Korean studies that used different measures of parks or greenspace. For example, the amount of urban parks in our study indicates different geographical patterns of greenspace compared to a study that calculated the amount of all types of greenspace not only limited to parks in Seoul using the normalized difference vegetation index (NDVI) (Son et al 2016). Our measurements of park provision and its geographical patterns can also be different from those results of a study that considered natural parks as well as residential and special use parks in assessing provision of parks in Seoul (Oh and Jeong 2007). We note that different types of greenspace other than parks can provide benefits. For example, forests can contribute to reduced urban heat island effects (Zupanic et al 2015). The calculated total area of park or accessibility of parks in this study, therefore, may not represent the overall effects of all greenspace or vegetation area, such as on mitigating the heat island effects in Seoul. As mentioned in the section 2, our study focused on implications of planned parks. As natural parks are preserved areas designated to existing forests or mountain areas in a region, they are less artificial and less related with urban planning in a given community or city. Thus, excluding natural parks from our analysis is appropriate for studying the potential inequalities of planned parks or greenspace in urban settings. On the other hand, studies have used the area of parks or greenspace of a region, including natural parks, to assess their effects on health status or degrees of physical activities of residents. Due to their much larger geographical scales, natural parks may have different mechanisms for attracting people compared to urban parks. For instance, the purpose of visiting and activities performed by visitors may differ between the natural and urban parks.

Size of park as an indicator of attraction might not be comparable between the natural and urban parks as their scales and nature of the parks are extremely different.

We note that the definition of accessibility of parks may vary widely by discipline and study. The terms ‘accessibility’ and ‘proximity’ to parks are often used interchangeably to refer to likelihoods of park uses and visits of study populations in environmental health studies. In urban design and planning, accessibility to parks can be defined by the distance to the parks from residential areas or by area (e.g. acres) of parks within a certain distance from residential areas. In other disciplines, accessibility can be a term that refers to handicap accessibility (e.g. wheelchair-accessible parks) or safety of parks (e.g. levels of dangerous activities occurring at parks) (Zhang et al 2011). Access to parks also can be evaluated by the entry and exit points and price for entry. Congestion within parks has been also considered as a measurement of inequity of park provision in US studies (Boone et al 2009). Quality of facilities and amenities within parks have been recognized as important because the quality of parks may vary across a city and affect usage rates and physical activity levels (Gililand et al 2006). A study subjectively measured park access based on park access amenities (e.g. parking,
external amenity (e.g. restroom, drinking fountain, litter, animal waste bags), and maintenance, safety, and environment to characterize park quality by interviewing individuals (Kaczynski et al. 2016). Further, safety in parks matters for accessibility to high-quality parks. Depending on the location and context, park can be perceived as a disadvantage in communities where people experience or perceive risks from anti-social behavior (e.g. crime) within parks, which would lead to fewer uses or visits (Troy and Grove 2008, Bahryn and Bell 2020).

While these factors all affect quality and preferences of parks, measuring park accessibility using GIS data has been widely applied. In our study, we use the term ‘accessibility’ to reflect the measure of the likelihood of visiting and using parks estimated by the spatial interaction modeling. However, other features of parks are relevant and should be investigated in future studies. In South Korea, 64.2% of urban parks include appropriately built handicap-friendly facilities (Ministry of Health and Welfare 2018), which indicates that not every urban park is usable for everyone. The safety levels around park areas and the distance to parks in relation to exit and entrance points (i.e. where parks are accessible for entry or exit rather than the parks’ boundary) were not considered in our study due to lack of available data. Safety levels of parks should be further studied in relation to social and economic benefits provided by parks, as studies exploring people-parkland ratios have suggested that parks were often located in dangerous and degraded areas in Phoenix, AZ (Ibes 2015). The spatial interaction model can be modified to incorporate other features of parks including safety and quality by applying an attractiveness parameter of a park in calculating the park access (Zhang et al. 2011). Hence, we urge the relevant ministries to estimate these data and provide them for future research to better understand usability of urban parks in Seoul.

Our study has several strengths. First, the GIS data of urban parks used in our study can represent the distribution and boundaries of park areas built in urban planning. This addresses the limitation of widely used greenness metrics such as the NDVI or enhanced vegetation index (EVI), which do not distinguish among types of greenspace (i.e. open space, park, crop land, etc). Second, we calculated the park accessibility index considering where people live (i.e. residential areas). We created 30 × 30 m grid cells overlapping with residential land cover and their 1 km buffers so that we could calculate more sophisticated accessibility to parks. By doing so, we could also avoid the modifiable areal unit problem, which is caused by the bias of assigning only parks within a defined boundary of the administrative district for the residential areas even though there can be parks close to the residential areas yet outside the boundary of the administrative district. Third, we used Dong-level (i.e. neighborhood-level) SES data for investigating socioeconomic inequity of urban parks in Seoul, while the Gu is the basic administrative unit for which the government provides most official statistical data.

Our study has several limitations as well. First, the walking distances calculated by the cost distance analysis do not have information of the locations for gates of parks, crosswalks, overpasses, and underpasses. Not considering these features may identify a longer distance through a farther intersection as the closest distance. Also, we did not apply different friction rates to different road types or scales to the road connectivity data when calculating walking distance, although people may choose routes to their destination based on walkability of road. However, the main purpose of the study was not to calculate the most precise distance from residential areas to parks but to compare the park accessibilities among regions and thereby subpopulations. As the omission of this data was not applied only to some regions but to the entire study regions, we anticipate no significant errors in comparing park accessibility among our study regions. Second, the park accessibility for residents living near the city boundary might be underestimated due to lack of data on parks beyond the Seoul boundary although we avoided errors of not assigning proximal parks outside of a Gu (or Dong) boundary for residents inside that Gu (or Dong) in calculating the park accessibility index. Even though we anticipate that this type of bias was not significant as the land cover intersecting with the Seoul boundary is mainly mountainous area and forest rather than industrial or residential areas, further validation with additional park data outside of Seoul would improve estimation of park accessibility for Seoul residents. Third, some SES variables used in calculation of the deprivation index were not available for the Dong-level (i.e. neighborhood-level). Due to the difference in the available SES indicators between Gus and Dongs, the regression analysis of individual SES indicators performed for Dongs in our main results had unmeasured SES indicators (e.g. education level, owning a house, and living with more than 1.5 persons per room). Thus, our results could not provide the effects these unmeasured variables on socioeconomic inequality of park provision. Further analysis, especially at a finer resolution such as Dong, is needed for these variables to identify underlying determinants for access to parks in future studies. Fourth, income was not considered in the deprivation index in this study. Income was considered in measuring neighborhood deprivation index in previous studies in other countries such as the US (Singh 2003) and the UK (Payne and Abel 2012). However, the SES indicators for characterizing deprivation index in administrative regions in South Korea as recommended by the Korea Institute for Health and Social Affairs did not include income variables. A potential reason for not including income in the Korean deprivation index is...
the low response rate for the population of household income in the nationwide population-based health survey in South Korea (Kim et al 2013). The difficulty of measuring income per person considering the number of family members per household may lead to bias in reliability of income data. Income was not considered in calculating deprivation indexes in several previous Korean studies (Jeong et al 2006, Shin et al 2009). Further, only disadvantages are considered in the deprivation index we used, which may be insufficient to capture socioeconomic advantages within Seoul, although the variables reflect the inverse of advantages (e.g. low education versus high education). Nonetheless, deprivation indexes have been widely applied in equality studies. To more accurately characterize deprivation level, income should be considered in future studies, as data become available, and further efforts to build reliable databases will be essential. Fifth, our park accessibility index was based on spatial proximity to parks and park size but it does not capture other important factors of parks, which may affect actual uses of parks from local residents. These factors include size, shapes, quality, facilities, amenities, safety, and congestion within parks. While there is no consensus on how to measure access to parks and many studies have used GIS data to measure spatial accessibility to park based on presence of parks near residential areas (Wolch et al 2014), considering these additional characteristics of parks would profoundly improve the measurement of park provision and its socioeconomic equity in Seoul.

Based on the identified different inequity results among various metrics, future work should analyze how the application of the accessibility to urban parks from residential areas in administrative units affects the health effects of parks on relevant health outcomes, including psychological health, chronic diseases, and likelihood of physical activity, for residents in Seoul.

5. Conclusion

In this study, we examined if socioeconomic inequity of access to park exists in Seoul using two different metrics: TPPC and park accessibility index. We found that use of different metrics of access to parks can produce varying results on the disparities in park access by SES. We found that accessibility of parks was significantly higher in regions with higher percentages of persons who are elderly or beneficiaries of the government low-income support program, whereas the metric of TPPC was only associated with percentage of persons who were elderly. The accessibility index was, however, higher in regions with higher divorce rates. In summary, there was no strong pattern indicating that urban parks were more accessible for socioeconomically affluent groups in Seoul. This research implies that measurements of spatial distribution of parks within a region considering park’s varying size and spatial proximity from residential areas may be more realistically related with population’s access to parks, and thus should be considered in examination of socioeconomic inequity in park access. We expect that further analyses on the health effects of parks based on different metrics of access to parks would provide information of the health benefits of various types of parks, including how these health impacts differ by SES.

Data availability statement

The data generated and/or analyzed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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ORCID iDs

Seulkee Heo https://orcid.org/0000-0002-0786-5002
Amruta Nori-Sarma https://orcid.org/0000-0003-2335-6811
Sera Kim https://orcid.org/0000-0002-9213-2080

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