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Visualizing fairness: distributional equity of urban green spaces for marginalized groups

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Previous environmental justice studies of urban green spaces (UGSs) have typically focused on issues of race/ethnicity or income level in Western countries and given limited attention to other dimensions of social disadvantage in Asian countries. To address this research gap, we examined distributional equity/inequity of UGSs among senior citizens living alone, single-mother families, individuals with disability, and basic livelihood security recipients in Seoul, South Korea. A geographically weighted regression was employed via a case study of 424 Dong districts in Seoul. Findings showed spatially heterogeneous equitable and inequitable access to UGSs; solitary seniors and single-mother families were more likely to experience inequitable access to UGSs, whereas people with disability and basic livelihood security recipients were more likely to have equitable access to UGSs. Seoul park management agencies could use the study findings to allocate resources for groups/regions that are in need of more access to UGSs.

Keywords: urban green spaces; access distributional equity; spatial heterogeneity; Seoul

1. Introduction

Urban green spaces (UGSs)[1] provide significant environmental, social, and economic benefits to local communities (Wolch, Byrne, and Newell 2014). For example, research has documented that UGSs promote nature conservation and mitigate air pollution (Vieira *et al*. 2018) and urban heat islands (Zhang, Murray, and Turner 2017). Moreover, UGSs are viewed as public health resources because of their significant associations with the lower risk of chronic diseases, higher well-being scores, and higher probability of physical activities (Evenson *et al*. 2013; Sallis *et al*. 2012; Schipperijn *et al*. 2017). UGSs can also function as tourist attractions whose revenue contributes to the local economy (Siikamäki 2011; Smith, Miller, and Leung 2020). Because of these various benefits, providing access to UGSs has been emphasized as a critical responsibility of public recreation and natural resource agencies to enhance residents' quality of life (Tan and Samsudin 2017).

However, scholars from environmental planning, landscape, geography, and leisure/recreation studies have documented significant gaps in access to UGSs. They have reported that socially disadvantaged groups, such as racial and ethnic minorities, low-

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income individuals, older adults, and people with disabilities, are less likely to utilize UGSs and tend to live in communities that have few UGSs (Byrne, Wolch, and Zhang 2009; Rigolon 2016; Rigolon, Browning, and Jennings 2018; Tan and Samsudin 2017). Increasingly, inequitable access to UGSs has been conceptualized as environmental injustice whereby those disadvantaged groups gain limited opportunities to accrue the health and social benefits that UGSs offer (Floyd and Johnson 2002; Smoyer-Tomic, Hewko, and Hodgson 2004; Wolch, Byrne, and Newell 2014).

Despite the abundant research on environmental injustice associated with UGSs, two research gaps remain evident. First, most of the previous empirical studies have focused on race/ethnicity and income to understand inequitable access to UGSs in Western countries (e.g. Rigolon 2016; Rutt and Gulsrud 2016; Sister, Wolch, and Wilson 2010). This research trend is understandable given that the environmental justice movement originated in the US state of North Carolina, USA with an explicit emphasis on racial discrimination (McGurty 1997). However, other disadvantaged groups, such as the elderly, women, and people with disability, have received relatively little research attention (Wolch, Byrne, and Newell 2014). Indeed, in a global context, some Asian countries are racially and ethnically more homogeneous, making the existing analytic perspective ineffective for understanding inequitable access to UGSs. Moreover, researchers have found spatially inconsistent relationships between race/ethnicity and parks and urged future studies to incorporate additional factors when examining equitable access to UGSs (Maroko *et al*. 2009).

Second, while previous studies have used various analytic techniques to examine environmental injustice in UGSs, multiple linear regression modeling via the ordinary least squares (OLS) approach has been one of the most widely used quantitative methods to examine statistical associations between access to UGSs and residents' demographic and socioeconomic status (Kim and Nicholls 2016a). However, the use of spatial data that includes location and access to UGSs, along with spatially referenced socioeconomic datasets, in linear equity regression models fails to account for local dynamics in the associations among the variables. Ignoring such spatial heterogeneity/variability in modeling UGS equity could give rise to violations of OLS assumptions, such as independence of residual, linearity, normality, and homoscedasticity (Kim and Nicholls 2018). Thus, the equity of UGSs should be measured via spatially explicit models that can explore spatial heterogeneity; however, only a few studies have addressed spatial heterogeneity in the equity model of UGSs (Maroko *et al*. 2009; Kim and Nicholls 2016a, 2018).

This study addresses these two research gaps by empirically exploring the spatially heterogeneous distributional equity/inequity of UGSs among senior citizens living alone, single-mother families, people with disability, and basic livelihood security recipients in Seoul, Republic of Korea. Seoul was selected in this study because of its unique sociocultural context, such as rapid aging, low birth and marriage rates, patriarchal Confucian culture, increasing poverty rate, increasing number of people with disabilities, and lack of a strong social security system (Jung and Cho 2020; Nam and Park 2020). These societal conditions have engendered the economic and social marginalization of the aforementioned groups (Kim and Park 2020). Coincidently, continuing urbanization of the city has diminished greenspaces and the natural environment (Xie *et al*. 2020). Thus, Seoul offers a unique research context to help expand the analytic perspectives of previous environmental justice studies on UGSs. Moreover, to account for spatial heterogeneity, a geographically weighted regression (GWR) was employed. As a spatially explicit regression technique developed by Brunsdon, Fotheringham, and Charlton (2010), GWR assumes that variability in the associations among variables differs from location to location (Kim *et al*. 2020). Thus, GWR can account for spatial heterogeneity in the analysis of UGS equity by exploring and visualizing spatially varying relationships between access to UGSs and the marginalized groups in Seoul.

In sum, the objectives of this study were to (1) address whether access to UGSs in Seoul is equitably distributed among senior citizens living alone, single-mother families, people with disability, and basic livelihood security recipients; (2) examine spatial variability in the relationships between access to UGSs and the above groups; and (3) assess whether the GWR-based local equity model (LEM) outperformed the conventional OLS-based global equity model (GEM). The findings from this study can provide fresh insights into the environmental justice literature and assist public park and natural resource agencies in Seoul and other Asian countries in better understanding and coping with the local patterns of UGS equity.

2. Literature review

2.1. Environmental justice and equity in UGSs

Bryant (1995) defined environmental justice as "cultural norms and values, rules, regulations, behaviors, policies, and decisions to support sustainable communities, where people can interact with confidence that their environment is safe, nurturing, and productive" (6). Environmental justice is inevitably linked to the issue of equity, which is a contextual and dynamic concept since the basic criteria to evaluate fairness are conditional (Leventhal 1980). The environmental justice movement first emerged during the 1970s with the awareness that racial and ethnicity minorities and low-income groups in the United States suffered from disproportionate exposure to environmental hazards, waste facilities, and landfills (McGurty 1997). However, researchers have included desirable environmental features such as parks and greenspace, in the environmental justice scholarship because they provide numerous social, environmental, economic, and health benefits, to which people of color and low-income groups tend to have limited access. Increasingly, the lack of UGSs has been conceptualized as one of the major environmental justice issues (Floyd and Johnson 2002; Jennings, Johnson-Gaither, and Gragg 2012).

Although researchers have introduced multiple definitions and conceptualizations of environmental justice or equity (Crompton and Wicks 1988; Walker 2010), the literature on the equity in UGSs has mainly been concerned with four types of justice: distributional, procedural, corrective, and interactional (Floyd and Johnson 2002; Low 2013; Rigolon *et al*. 2019). *Distributional justice* focuses on the scarcity and inferiority of parks and greenspaces in communities of color and lower socioeconomic statuses, whereas *corrective justice* entails specific solutions to these issues (Floyd and Johnson 2002). *Procedural justice* "involves inclusive and representative processes to define public policies about environmental amenities and hazards" and also "includes concerns about fairness in decision-making processes" (Rigolon *et al*. 2019, 3). Finally, *interactional justice* focuses on the quality of interpersonal interactions within UGSs; people of color frequently experience discrimination and harassment when they visit parks and greenspaces (Low 2013; Sharaievska *et al*. 2010).

To date, most of the previous research on environmental justice in UGSs has focused on distributional justice. Numerous studies have documented that UGSs, such as parks (Byrne, Wolch, and Zhang 2009; Maroko *et al*. 2009; Nicholls 2001; Rigolon, Browning, and Jennings 2018; Talen 1998; Tan and Samsudin 2017), trails and greenways (Lindsey, Maraj, and Kuan 2001), playgrounds (Smoyer-Tomic, Hewko, and Hodgson 2004), recreation forests (Tarrant and Cordell 1999), and beaches (Kim and Nicholls 2016a, 2018; Kim, Lyu, and Song 2019), are not equally distributed. For example, Tarrant and Cordell (1999) measured the availability of outdoor recreation settings in the northern region of the US state of Georgia and identified inequitable distribution of outdoor recreation settings corresponding to household income. Rigolon, Browning, and Jennings (2018) assessed the urban park quality in 99 large US cities and found that cities with higher incomes and lower percentages of Latino and non-Hispanic Black had a better quality of parks. Similarly, Kim, Lyu, and Song (2019) investigated access to public beaches in Metro Detroit, Michigan, in the US and found that inequitable access to public beaches was significantly associated with population density, elderly population, non-vehicle ownership, and median housing value.

Despite the growing interest in UGSs within the environmental justice literature, previous studies have been dominated by cases of Western countries and tended to focus on race/ethnicity and income level as two major explanatory factors of UGS distribution. Non-Western countries and other dimensions of social disadvantage, such as age, gender, sexual identity, religion, and disabilities, have garnered relatively little research attention (Wolch, Byrne, and Newell 2014). Importantly, researchers have found that in Asian countries factors other than race and ethnicity, such as age, population density, land values, unemployment, and nationality, played a critical role in access to UGSs (Oh, Kim, and Sohn 2020; Richards, Passy, and Oh 2017; Shen, Sun, and Che 2017). Thus, further research on these understudied areas is expected to deepen our knowledge in the distributional justice of UGSs.

2.2. Spatial heterogeneity and spatially varying relationships

Another distinctive research gap in the prior equity studies of UGSs is that they have mainly used multiple linear statistical models via the OLS approach, which does not take into account spatial heterogeneity. The equity of UGSs has been measured via several analytic techniques, including non-parametric tests (Nicholls 2001), correlation analysis (Smoyer-Tomic, Hewko, and Hodgson 2004), equity mapping (Talen 1997, 1998; Talen and Anselin 1998), and multiple linear regression analysis (Deng, Walker, and Strager 2008; Porter and Tarrant 2001; Tarrant and Cordell 1999; Kim, Lyu, and Song 2019). Among these techniques, multiple linear regression analysis via the OLS approach has been one of the most widely used quantitative approaches because it can consider multiple independent variables simultaneously (Cohen, Cohen, and Aiken 2013; Kim and Nicholls 2018). Two assumptions of traditional OLS-based multiple linear regression are (1) residuals are independent and (2) the linear association between the variables (i.e. a spatially stationary association) is able to be explained by the average (or global) regression coefficient values across the study area (Kim and Nicholls 2016a). However, these assumptions of independence and linearity cannot be met if spatially referenced variables (e.g. access to UGSs and needy groups) are used in a linear regression model because of spatial effects such as spatial heterogeneity (i.e. spatial variability) and spatial dependence (Yoo and Wagner 2016).

Spatial heterogeneity is the spatial variability of the single parameter estimate related to a global linear regression model used to discover spatial variability in the associations among variables based on different locations (Nicholls and Kim 2019). As noted by Brunsdon, Fotheringham, and Charlton (2010), spatial heterogeneity is "a condition in which a simple global model cannot explain the relationship between some set of variables" (281). Spatial heterogeneity is typically introduced together with the term *spatial dependence* (i.e. spatial autocorrelation), which is based on the first law of geography (Tobler 1970)—"everything is related to everything else, but near things are more related than distant things" (236). Sometimes, spatial heterogeneity is called the *first-order spatial effect*, whereas spatial dependence is regarded as the *second-order* spatial effect (Anselin 2010). The existence of spatial heterogeneity may cause measurement errors, which result in an inefficient estimation of coefficients and invalid significance tests (Kim *et al*. 2020).

Given the spatial nature of equity measurements, which are associated with the distribution of UGSs and the attributes of nearby residents, the equity of UGSs needs to be measured with spatially explicit analytics that can address spatial heterogeneity. Gilbert and Chakraborty (2011) noted that "the analysis of spatial data requires specialized techniques that are different from those used to analyze non-spatial data" (274). GWR has been recognized as a spatially explicit technique used to account for spatial variability in modeling spatial variables. As a spatial regression approach introduced by Brunsdon, Fotheringham, and Charlton (2010), GWR can identify spatial heterogeneity in an equity model by calculating local parameter estimates for each observation location. Recently, two UGS equity studies were conducted that employed GWR to explore spatial heterogeneity, but they have focused on a specific type of UGS (e.g. beaches) with regard to racial/ethnic and income-based minorities in the Detroit Metropolitan Area in the USA (Kim and Nicholls 2016a, 2018). Also, other aforementioned marginalized groups have not been considered in non-Western contexts. As such, this study explores spatial heterogeneity to measure UGS equity by visualizing spatially varying relationships between access to UGSs and marginalized groups in Seoul, South Korea.

2.3. Study area: Seoul, Republic of Korea

Seoul, the capital city of the Republic of Korea, was chosen for this study because of its four distinctive characteristics. First, the city is racially and ethnically far more homogeneous than the study sites of previous research on UGS distribution. Second, Seoul has the largest UGS system (86.44 km^2) among metropolitan cities in the country (2,105 of the 20,389 UGSs [10.3%] in the nation) (Kim, Yoon, and Yoon 2014). Third, it is the most populous city with the highest population density (16,204/km^2) in the country. Finally, Seoul has witnessed economic and social marginalization of senior citizens living alone, single-mother families, individuals with disability, and basic livelihood security recipients. For example, elderly Koreans who live alone experience disproportionally high poverty rates linked to the high risk of depression and suicidal thoughts (Kim, Shim, and Lee 2016). Similarly, the patriarchal culture in Korean society and its labor market has impeded the economic independence of single-mother families, making them among the poorest workers in the nation (Park and

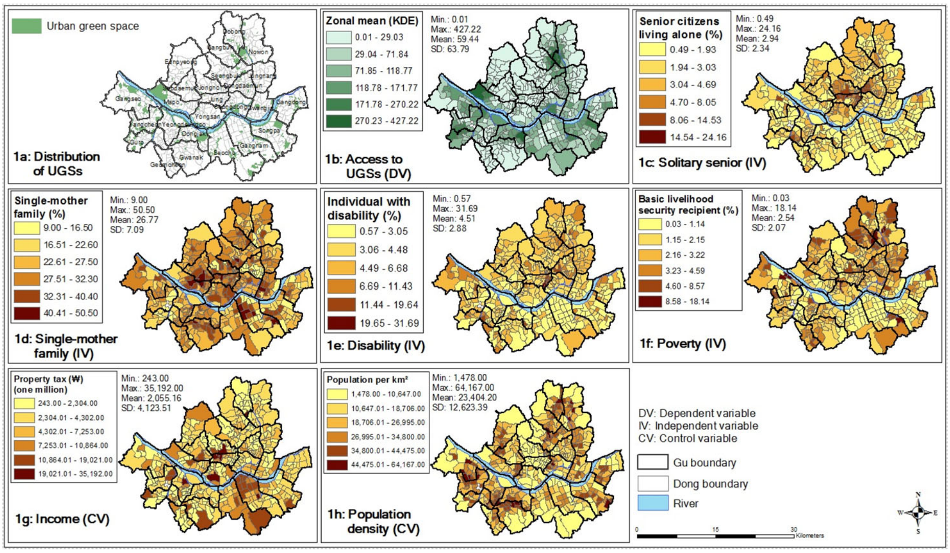

Figure 1. Spatial distribution of UGSs and variables for data analysis.

Heshmati 2019). People with disabilities in Korea also experience higher poverty rates than people without disabilities and routinely encounter discrimination and macroaggression in their occupational settings and everyday lives (Park 2017; Park and Nam 2019). Basic livelihood security recipients have been regarded as one of the most marginalized groups with regard to access to UGSs in Korea (Kim 2015). These societal conditions differentiate Seoul from other cities in the Global South marked by rapid growth, lack of public services, and short life expectancy, as mentioned by Rigolon, Browning, and Jennings (2018). Thus, investigating the extent to which the aforementioned marginalized groups in Seoul experience distributional injustice in access to UGSs is expected to broaden the analytic perspective of the literature and promote deeper understanding of the linkage between social disadvantages and UGS access.

3. Methods

3.1. Unit of analysis

Seoul includes 25 local districts, called *Gu*. As of the 2020 Seoul Open Data Plaza, the population was 9.7 million with an area of 605.21 km^2. Defining the analysis unit is essential for analyzing spatial data (Lee *et al*. 2020). A Dong is the smallest areal unit in South Korea, and several Dong comprise a Gu. Thus, a Dong was defined as the unit of analysis to minimize the ecological fallacy. Figure 1a illustrates the distribution of UGSs and the Gu and Dong boundaries within the study area.

3.2. Variables and data collection

The dependent variable was the level of access to UGSs, which was operationally defined as the average kernel density of UGSs for each Dong district. This access measure reflects the container approach, which defines accessibility as the existence of

Table 1. Variables for analysis.

Variable	Operational definition	Source	Year
Access to UGSs (DV)	Average kernel density of UGSs	SMG	2020
Solitary senior (IV)	Percent of senior citizens living alone (%)	SODP	2020
Single-mother family (IV)	Percent of single-mother families (%)	SODP	2020
Disability (IV)	Percent of individuals with disability (%)	SODP	2020
Poverty (IV)	Percent of basic livelihood security recipients (%)	SODP	2020
Income (CV)	Property tax (one million KRW)	SODP	2020
Population density (CV)	Population per square kilometer	SODP	2020

Note: DV: Dependent variable; IV: Independent variable; CV: Control variable; KRW: Won (Korean currency); SMG: Seoul Metropolitan Government; SODP: Seoul Open Data Plaza.

UGSs within an areal unit (Kim and Nicholls 2016b; Talen and Anselin 1998). The use of the kernel density is justified because, as an improved container access method, it is widely used in environmental planning and policy to quantify the heterogeneity of access to UGSs within an areal unit (Zhang, Lu, and Holt 2011). Identifying an optimal bandwidth is a prerequisite for estimating the kernel density (Kim and Nicholls 2018). Since one mile (1.6 km) is typically considered to be a reasonable walking distance to access UGSs, it was adopted as a bandwidth, and a 50-meter resolution raster surface was created (Kim, Yoon, and Yoon 2014). Because of the variation in size of each UGS, the size value was weighted when estimating the kernel density (Kim, Yoon, and Yoon 2014).

The independent variables representing marginalized groups in Seoul were (1) solitary senior (percentage of senior citizens living alone), (2) single-mother family (percentage of single-mother families), (3) disability (percentage of individuals with disability), and (4) poverty (percentage of basic livelihood security recipients). Based on the need-based equity approach (Crompton and Wicks 1988; Nicholls 2001), an equitable distribution of UGSs was deemed to be fulfilled when the marginalized groups received relatively better access to UGSs compared to the general population, whereas inequitable distribution of UGSs was identified when the marginalized groups received relatively less access to UGSs.

Two control variables, income level and population density, were also included in the present study. We included them because previous equity studies of UGSs have shown that these two variables were significantly associated with UGS access across different contexts (Boulton, Dedekorkut-Howes, and Byrne 2018; Maroko *et al*. 2009). Income level was gauged by the average property tax (one million KWR) of a Dong. Population density was estimated by population per square kilometer.

Geographic data, including Dong/Gu district boundaries and UGS locations/sizes in 2020 were compiled from the data sources available from the Seoul Metropolitan Government, which can provide GIS-based land use and land cover shapefiles. Census data for marginalized groups in Seoul were obtained from the 2020 Seoul Open Data Plaza, which is a data portal for citizens to access Seoul's public data. Table 1 describes all variables' operational definitions and data sources for UGS equity measurement.

3.3. Data analysis

Data analysis was conducted in six steps via ArcMap (version 10.6.1), GWR4, and ArcGIS Spatial Analysis extension. First, the level of access to UGSs for each Dong district was measured with a GIS-based kernel density estimation. Subsequently, the zonal mean function was used to calculate the average kernel density for each Dong district. Second, a descriptive analysis was conducted for dependent, independent, and control variables, and the distribution for dependent and independent variables was visualized. Third, a GEM was performed using OLS regression to examine the global association between access to UGSs and marginalized groups. The proposed GEM expresses Equation (1):

$$\text{Kernel density}_i = \beta_0 + \beta_1\text{solitary senior} + \beta_2\text{single} - \text{mother family} + \beta_3\text{disability} + \beta_4\text{poverty} + \beta_5\text{income} + \beta_6\text{population density} + \varepsilon \quad (1)$$

In this equation, kernel density$_i$ is the average kernel density at Dong district i, ε is the error term, β_0 is the intercept parameter, and β_1–β_6 are the parameter estimates for each explanatory variable (i.e. solitary senior, single-mother family, disability, and poverty) and the control variables (i.e. income and population density). Fourth, an LEM using the same variables from the GEM, was conducted via GWR to explore spatially heterogeneous relationships. The proposed GWR-based LEM expresses Equation (2):

$$\text{Kernel density}_i = \beta_{i0}(u_i, v_i) + \beta_{i1}(u_i, v_i)\text{solitary senior}_i + \beta_{i2}(u_i, v_i)\text{single} - \text{mother familyi} + \beta_{i3}(u_I, v_i)\text{disability}_i + \beta_{i4}(u_I, v_i)\text{poverty}_i + \beta_{i5}(u_I, v_i)\text{income}_i + \beta_{i6}(u_I, v_i)\text{population density}_i + \varepsilon_i \quad (2)$$

where i refers to Dong district i, (u_i, v_i) is the coordinate at dong district i, $\beta_{i0}(u_i, v_i)$ is the intercept parameter at Dong district i, and $\beta_{ik}(u_i, v_i)$ is the local parameter estimates for the independent and control variable k at Dong district i. A bi-square kernel approach using a kernel with adaptive bandwidth was employed because of the geographically diverse size of the Dong districts (Fotheringham, Brunsdon, and Charlton 2002). The spatial weight (w_{ij}) for the bi-square kernel was estimated as follows:

$$wij = [1 - (edij/b2)] \text{ when } dij \le b, \; wij = 0 \text{ when } dij > b \quad (3)$$

where ed_{ij} is the Euclidean distance from the center of Dong district i and the regression point j, and b is the threshold distance. The optimal kernel size was defined via an optimization process to minimize the corrected Akaike Information Criterion (AIC_c) (Kim *et al*. 2020). A Monte Carlo simulation was employed to test the significance of the spatial variability in the local parameter estimates (Lee, Jang, and Kim 2020). Fifth, GWR-based local parameter estimates and local R^2 were mapped to visualize spatial variability in the relationships between variables. Finally, the values of R^2 and AIC_c from GEM and LEM were compared to evaluate whether the GWR-based LEM outperformed the OLS-based GEM.

4. Results

4.1. Descriptive analysis

The descriptive statistics for the study variables are presented in Table 2. The average kernel density of UGSs for each Dong district (access to UGSs) was 59.44 and ranged from 0.01 to 427.22. For the independent variables, solitary senior (%) ranged from

Table 2. Descriptive statistics for all variables (n: 424).

Variable	Min.	Mean	Max.	SD.
Access to UGSs	0.01	59.44	427.22	63.79
Solitary senior	0.49	2.94	24.16	2.34
Single-mother family	9.00	26.77	50.50	7.09
Disability	0.57	4.51	31.69	2.88
Poverty	0.03	2.54	18.14	2.07
Income	243.00	2,055.16	35,192.00	4,123.51
Population density	1,478.00	23,404.20	64,167.00	12,623.39

Note: Min.: Minimum; Max.: Maximum; SD.: Standard deviation.

0.49 to 24.16, with a mean of 2.94; single-mother family (%) ranged from 9.00 to 50.50, with a mean of 26.77; disability (%) ranged from 0.57 to 31.69, with a mean of 4.51; and poverty (%) ranged from 0.03 to 18.14, with a mean of 2.54. For the control variables, income (one million KRW) ranged from 243.00 to 35,192.00, with a mean of 2,055.16. Population density (population per square kilometer) ranged from 1,478.00 to 64,167.00, with a mean of 23,404.20. The distribution of all variables for data analysis is shown in Figure 1b–h. A dark-colored areal unit shows the Dong district with a high value of corresponding variables. These wide ranges in marginalized groups across the districts represent potentially diverse needs for access to UGSs in Seoul.

4.2. OLS-based GEM

Table 3 presents the estimation results of the OLS-based GEM. The VIF values for all independent variables (solitary senior [1.68], single-mother family [1.13], disability [1.74], and poverty [1.20]) represented lack of redundancy. According to the value of the Joint F-statistic (6.72, $p < 0.05$), the overall model was significant at the 0.05 level. The value of R^2 (0.13) showed a relatively lower model fit but was consistent with prior recreation equity studies of UGSs (Porter and Tarrant 2001 [R^2: 0.18]; Kim, Lyu, and Song 2019 [R^2: 0.17]). All marginalized independent variables were significant at the 0.05 level. Based on the parameter estimates (β), disability (2.30) and poverty (3.25) were positively associated with the level of access to UGSs, whereas solitary senior (-7.20) and single-mother family (-1.65) were negative. These findings indicated that Dong districts with a higher proportion of senior citizens living alone and single-mother families had relatively less access to UGSs, whereas those with a higher proportion of individuals with disability and basic livelihood security recipients had more access to UGSs.

4.3. GWR-based LEM

Table 3 shows the results of the GWR-based LEM. The value of the local R^2 ranged from 0.04 to 0.31 (mean: 0.17). The local condition index ranged from 11.19 to 29.99 (mean: 16.25), which indicated the absence of local redundancy among the exploratory and control variables. The results of the Monte Carlo significance test indicated that all marginalized group variables showed significant spatial variability of local parameter estimates at the 0.05 level. The local parameter estimates for the marginalized

Table 3. Results of OLS and GWR models (n: 424).

Variable	OLS coefficients β	VIF	GWR coefficients (β) Min.	Mean	Max.	Range	Spatial variability	Equity (inequity) indicated when value of coefficient
Intercept	109.68*		−25.59	116.44	255.89	281.48		–
Solitary senior	−7.20*	1.68	−13.41	−5.72	10.40	23.81	Yes	Positive (negative)
Single-mother family	−1.65*	1.13	−4.87	−1.43	0.77	5.64	Yes	Positive (negative)
Disability	2.30*	1.74	−2.74	1.78	15.40	3.85	Yes	Positive (negative)
Poverty	3.25*	1.20	−15.06	1.84	20.13	18.14	Yes	Positive (negative)
Income	0.001	1.13	−0.003	−0.001	0.008	0.011		
Population density	−0.001	1.17	−0.002	−0.001	0.001	0.003		
R^2	0.13		0.04	0.17	0.31	0.35		
Adjusted R^2	0.11			0.25				
Condition index			11.19	16.25	29.99	18.8		
AICc	4,853.28			4,803.75				

Note: β (Beta): Regression coefficient;
*: $p < 0.05$; AIC_c: Corrected Akaike's Informaiton Criterion; VIF: Variance inflation factor.

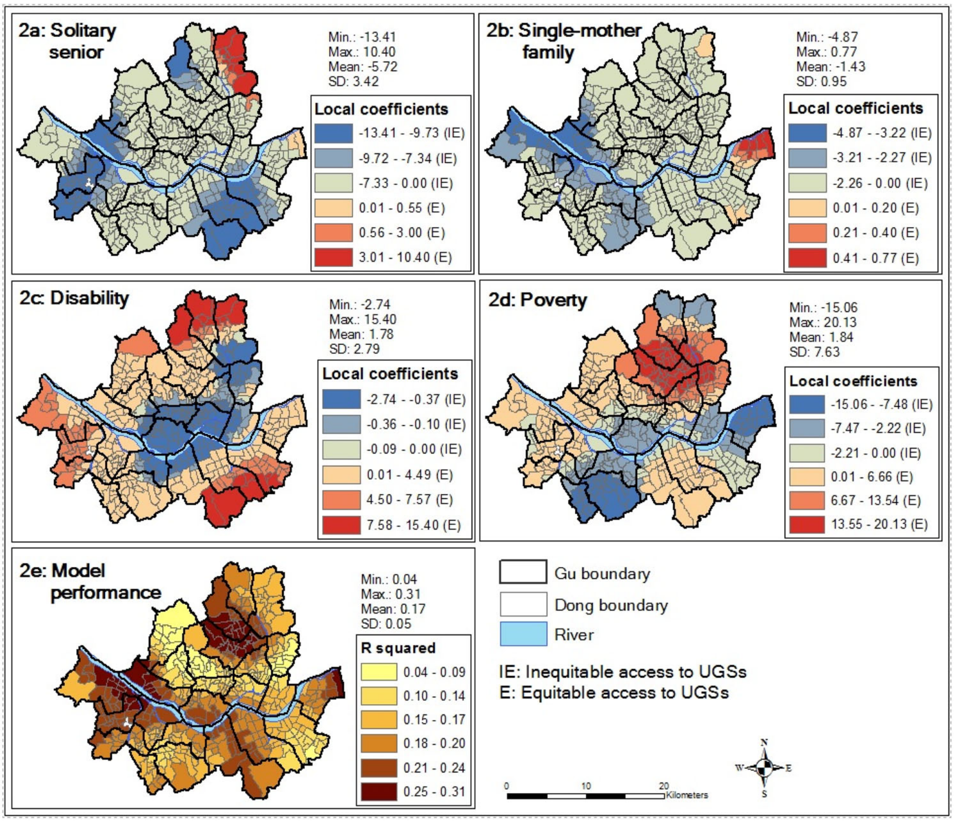

Figure 2. Spatial distribution of local coefficients for significant marginalized group variables and local R^2.

group variables ranged from −13.41 to 10.40 with a mean of −5.72 (solitary senior), −4.87 to 0.77 with a mean of −1.43 (single-mother family), −2.74 to 15.40 with a mean of 1.78 (disability), and −15.06 to 20.13 with a mean of 1.84 (poverty). Such variability of local parameter estimates represents the spatially heterogeneous equity/inequity of UGS distribution for the marginalized groups across Dong districts in Seoul. Specifically, although the OLS coefficient for the solitary senior was −7.20, its local parameter estimates ranged from −13.41 to 10.40, representing the highest spatial variability (range: 23.81).

Figure 2a–e visualizes the distribution of parameter estimates for the marginalized group variables and local R^2 in the GWR-based spatial equity model. Figure 2a shows that solitary seniors in Dong districts in the northeastern (e.g. Nowon-Gu) areas experienced more access to UGSs, whereas solitary seniors in Dong districts in northern (e.g. Gangbuk-Gu), western (e.g. Mapo-Gu, Gangseo-Gu, and Yangcheon-Gu), and southern (e.g. Gangnam-Gu and Seocho-Gu) areas suffered from relatively limited access to UGSs. Such spatial variability of local parameter estimates for the other marginalized groups (i.e. single-mother family, disability, and poverty) was also identified in Figure 2b–d. Finally, unlike the OLS-based GEM, the GWR-based LEM identified varying values of the local R^2, which ranged from 0.04 to 0.31. These findings show that the model performance that pertains to the GWR-based LEM was not stationary.

Table 4. Characteristics of Dong district segments based on equitable and inequitable access to UGSs.

	Solitary senior		Single-mother family		Disability		Poverty		
Segment	(#1) IED	(#2) ED	(#3) IED	(#4) ED	(#5) IED	(#6) ED	(#7) IED	(#8) ED	All Dong district
Number of Dong districts	406	18	407	17	143	281	174	250	424
Average kernel density of UGSs	60.12	43.37	59.82	50.03	57.50	60.54	54.50	63.21	59.44
Marginalized group (average)									
Senior citizens living alone (%)	2.97	2.24	2.97	2.19	3.75	2.48	2.78	3.06	2.94
Single-mother family (%)	26.88	24.19	26.87	24.34	27.38	26.42	27.58	26.15	26.77
Individual with disability (%)	4.51	4.39	4.52	4.24	5.18	4.12	4.34	4.64	4.51
Basic livelihood security recipient (%)	2.49	3.57	2.54	2.34	2.61	2.49	2.10	2.87	2.54
Socioeconomic attribute (average)									
Youth dependency ratio	14.13	17.56	14.18	16.37	12.74	15.13	14.20	14.31	14.27
Aging index	117.22	93.33	116.71	104.61	124.29	111.66	118.24	114.71	116.24
Elderly population (%)	12.97	11.80	12.96	11.96	13.52	12.59	12.63	13.15	12.92
Low-income elderly population (%)	0.35	0.28	0.35	0.13	0.42	0.30	0.28	0.40	0.35
Population per square kilometer	23,380.08	23,970.72	23,509.20	20,785.11	21,192.55	24,663.49	23,809.92	23,094.22	23,404.19
Property tax (one million KRW)	4,108.92	2,791.66	4,049.83	4,188.05	4,336.91	3,894.72	4,180.19	3,959.63	4,055.15

Note: ED: Equitable distribution of UGSs; IED: Inequitable distribution of UGSs.

Finally, Table 4 presents the sociodemographic characteristics of eight segments based on the GWR-based local parameter estimates in terms of equitable or inequitable distribution of UGSs. For example, segment #1 includes 406 Dong districts with relatively less access to UGSs for solitary seniors. In this segment, on average, 26.88% of the population are single-mother families; 4.51% of the population are individuals with disability; the aging index is 117.22, indicating a relatively high percentage (12.97%) of elderly population; and 0.35% of the population are low-income elderly. Conversely, segment #2 (Dong districts with equitable access to UGSs for solitary seniors) has the lowest percentage of single-mother families (24.19%), a relatively low percentage of individuals with disability (4.39%), the lowest aging index (93.33), the lowest percentage of elderly population (11.80%), and a relatively low percentage of low-income elderly population (0.28%). When segments of Dong districts with equitable/inequitable distribution of UGSs are compared across sociodemographic factors, the results show that *intersectional marginalization* could play a pivotal role in explaining the divide between two segments. Specifically, segments with inequitable access to UGSs (segments 1, 3, 5, and 7) have a relatively high percentage of the marginalized groups than do segments with inequitable access to UGSs (segments 2, 4, 6, and 8). As such, the spatially heterogeneous equitable or inequitable distribution of UGSs could be understood by examining the diverse intersectional marginalization factors.

4.4. Model performance between GEM and LEM

We compared the values of adjusted R^2 and AIC_c from OLS and GWR models to examine whether the GWR-based LEM exhibited better performance than the OLS-based GEM. The results indicated that the value of adjusted R^2 increased from 0.11 (OLS) to 0.25 (GWR), and the value of AIC_c decreased from 4,853.28 (OLS) to 4,803.75 (GWR). These findings showed that the GWR-based LEM can provide better model goodness-of-fit than the OLS-based GEM.

5. Discussion and implications

This study aimed to visualize the distributional equity/inequity of UGSs among marginalized groups in Seoul. To achieve this purpose, a GWR was employed using 424 Dong districts in Seoul. Results showed that UGSs in Seoul were less available for solitary seniors and single-mother families. To the best of our knowledge, these are new findings that have not been reported by other environmental justice studies. For example, while researchers have documented that older adults tended to experience inequitable access to parks or public green spaces in Shanghai, China (Shen, Sun, and Che 2017), and Seoul, Korea (Oh, Kim, and Sohn 2020), they did not examine the intersection of elderly status and social isolation (living alone) and its negative impact on access to UGSs. Similarly, our findings illustrate how the combination of two social statuses, being female and the breadwinner of the household, could negatively impact access to UGSs.

Collectively, our findings offer new insight into the relationship between social marginalization and distributional justice of UGSs and highlight the need for exploring localized patterns of UGS equity. Traditionally, race, ethnicity, and income-related (e.g. household income and housing value) variables have typically been used to understand inequitable access to UGSs in urban areas in Western countries (Deng, Walker, and Strager 2008). While several scholars have emphasized the importance of considering various dimensions of marginalization on recreation equity (Maroko *et al*. 2009; Smoyer-Tomic, Hewko, and Hodgson 2004), our findings reinforce their argument and call for more investigation on local patterns of social marginalization and their detrimental impact on access to UGSs.

Quantitative equity measurements begin with accessibility measures. While measuring the accessibility of UGSs, this study applied a simple density-based metric (i.e. kernel density) even though access to UGSs could also be measured as a distance-based metric, such as distance to the nearest UGS. There are multiple access measures for UGSs (e.g. container approach, minimum distance approach, travel cost approach, spatial interaction model approach, and covering approach) (Lee *et al*. 2020), each of which can produce different results in terms of accessibility and relevant equity measurements (Kim and Nicholls 2016b). Thus, future studies should employ multiple access measures to provide comprehensive equity outcomes in terms of different types of public facilities.

It is also noteworthy that the present study used the GWR-based LEM to explore spatial variability in the relationships between UGS access and marginalized groups. The spatial heterogeneity explored implies that there is spatially heterogeneous equity or inequity of UGSs, which traditional OLS-based GEM is unable to deal with. This finding is consistent with the results of Kim and Nicholls (2016a, 2018), which visualized the equitable and inequitable distributions of public beaches in Metro Detroit. Although this study successfully explored the spatially heterogeneous equity/inequity of UGSs for marginalized groups and demonstrated the feasibility of the GWR-based LEM, the findings still require additional quantitative or qualitative research to identify key variables that explain how and why inequitable/inequitable distribution of UGSs occurs.

Findings from this study suggest several implications for enhancing equitable access to UGSs in Seoul. First, although a systematic review suggested that the one-size-fits-all approach dominates the provision of greenspace worldwide (Boulton, Dedekorkut-Howes, and Byrne 2018), park agencies can use our findings to design a more sophisticated strategy for Seoul's provision of UGSs. As summarized in Figure 3, for example, the central (e.g. Seongdong-Gu and Jung-Gu) and southern (e.g. Dongjak-Gu) areas of Seoul were the neighborhoods with the most urgent need for additional UGSs for senior citizens living alone, single-mother families, people with disability, and basic livelihood security recipients. Providing sufficient UGSs in these areas is particularly important given that those marginalized groups are in most need of the health and social benefits that UGSs can provide. Such an approach responds to the request from Maantay (2013) "to replace the subjective approach by providing decision-makers with a more quantitative, evidence-based foundation for determining priority areas" (10). Since landscape planning and land-use decisions are typically managed and operated at the local government level (Gilbert and Chakraborty 2011), such information can help Seoul park management agencies to distribute limited resources more equitably by pinpointing the regions that are in greatest need of increased public service delivery, thereby promoting the formulation of location-based environmental justice planning and policy.

Second, the city needs to work closely with marginalized groups that experience inequitable UGS access to ensure that they would not be displaced or disempowered by creating new UGSs. Studies have underscored that new park development and renovations meant to address park disparities often provoked environmental gentrification

Gu district	Equitable distribution (ED) / Inequitable distribution (IED)			
	Senior citizens living alone	Single-mother family	Individuals with disability	Basic livelihood security recipients
Gangnam	IED	IED	ED	ED
Gangdong	IED	ED	ED	IED
Gangbuk	IED	IED	ED	ED
Gangseo	IED	IED	ED	ED
Gwanak	IED	IED	ED	IED
Gwangjin	IED	IED	IED	ED
Guro	IED	IED	ED	ED
Geumcheon	IED	IED	ED	IED
Nowon	ED	IED	ED	ED
Dobong	IED	IED	ED	ED
Dongdaemun	IED	IED	IED	ED
Dongjak	IED	IED	IED	IED
Mapo	IED	IED	ED	ED
Seodaemun	IED	IED	ED	ED
Seocho	IED	IED	ED	ED
Seongdong	IED	IED	IED	IED
Seongbuk	IED	IED	ED	ED
Songpa	IED	IED	ED	IED
Yangcheon	IED	IED	ED	ED
Yeongdeungpo	IED	ED	ED	IED
Yongsan	IED	IED	ED	IED
Eunpyeong	IED	IED	ED	ED
Jongno	IED	IED	ED	ED
Jung	IED	IED	IED	IED
Jungnang	IED	IED	IED	ED

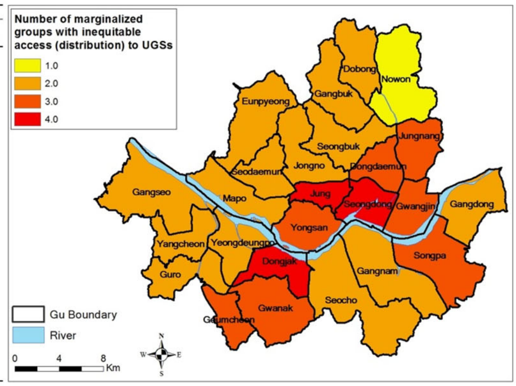

Figure 3. Gu districts with equitable or inequitable distribution of UGSs for marginalized groups.

and ended up displacing local residents who were supposed to be the beneficiaries of the park projects (Gould and Lewis 2016; Loughran 2014; Pearsall and Eller 2020; Wolch, Byrne, and Newell 2014). Given the vulnerability of solitary seniors, single-mother families, people with disability, and basic livelihood security recipients in Seoul, it is highly possible that they will be further marginalized by the development of new UGSs if the plan is not carefully designed and implemented. One specific method for preventing such an undesirable outcome might be institutionalizing laws and regulations that protect local residents, such as community benefits agreements (Baxamusa 2008; Salkin and Lavine 2008), urban anticipatory governance (De Barbieri 2018), and community benefits funds (Vance 2018).

Despite the unique findings from this study, several limitations should be noted. First, this study examined distributional justice of UGSs and did not focus on procedural, corrective, and interactional justice. To gain more comprehensive information on UGS equity in Seoul and its countermeasures, future studies are encouraged to examine other types of injustice. Second, the density-based access measure in this study could not reflect additional objective or subjective attributes of UGSs, including awareness of the location of UGSs, environmental quality, crowding, and safety. Such factors could influence residents' destination choice, and hence they are recommended to be incorporated into future research. Finally, findings were limited to a single geographic area (Seoul, South Korea) and cannot be generalized. Thus, additional case studies via other geographic areas need to be conducted to justify the use of the GWR-based LEM and to provide more empirical evidence of spatial heterogeneity.

Note

1. The term urban green space entails a wide range of geographical contexts (Brander and Koetse 2011), and researchers have used different definitions and operationalizations (Byrne and Sipe 2010). We decided to focus on public recreational spaces deemed to promote mental and physical health, such as urban parks, beaches, playgrounds, and trails.

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