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Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene?

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ABSTRACT

Access to green spaces is important to physical activities and public health, yet one concern remains as to whether the disparities in green space access exist. This study aimed to (1) introduce an approach to quantify potential spatial accessibility to green spaces in a Geographic Information Systems (GIS) environment; and (2) evaluate the racial/ethnic and socioeconomic disparities in green space access. Urban green spaces ($n = 890$) in metropolitan Atlanta, Georgia were collected from the Atlanta Regional Commission. A Gaussian-based two-step floating catchment area method was adapted to assess the spatial accessibility to green spaces at the census tract level. The Ordinary Least Squares (OLS) model and the spatial lag model were used to evaluate the racial/ethnic and socioeconomic disparities. Results suggest that the spatial accessibility to green spaces in Atlanta was not evenly distributed. Both models show that neighborhoods with a higher concentration of African Americans had significantly poorer access to green spaces ($P < 0.05$). Asian population had significantly poor access in the OLS model but not in the spatial lag model. Poor access was present in socioeconomically disadvantaged areas as well. Findings can be used for the city and regional planners to target the specific areas for green space development in order to elucidate the disparities.

1. Introduction

Urban green spaces are the natural environment connecting human beings with nature, which include parks, community gardens, urban forests, natural reserves and corridors along waterways, preservations (Chiesura, 2004; Comber, Brunsdon, & Green, 2008; Kessel et al., 2009; Richardson, Pearce, Mitchell, Day, & Kingham, 2010), among others. They vary in size, scale, function, and location (Gill et al., 2008; Verheij, Maas, & Groenewegen, 2008). Green spaces range from community gardens, city parks and greenways up to state parks and national reserves. Depending on the locations, green spaces may come in the form of private front/back yards or publically accessible parks (Chiesura, 2004). This research focused on publically available green spaces as they are beneficial to the general urban residents.

Access to urban green spaces has contributed to increased physical activities, public health advancement, and socialization of urban residents (Cranz, 1983; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Sugiyama, Leslie, Giles-Corti, & Owen, 2008). Researchers have linked poorer green space access to higher rates of overweight and obesity, poorer self-perceived health, and higher mortality risks (Ellaway, Macintyre, & Bonnefoy, 2005; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Mitchell & Popham, 2007; Mitchell & Popham, 2008). It is thus fundamental to the livability of cities (Wolch, Wilson, & Fehrenbach, 2005) and is also critical to economic development (Crompton, 2001; Garvin, 2000). Green spaces, however, are often unequally distributed between white and racial/ethnic minority communities, causing the concern of environmental injustice and its negative impact (e.g., Boone, Buckley, Grove, & Sister, 2009; Wolch et al., 2005). It is therefore important to examine the racial/ethnic and socioeconomic inequity in access to green spaces and learn where to intervene.

Many factors may influence access to green spaces in an area. These include, but are not limited to, the availability of green spaces in the area (supplies), the number of people living in the proximity of this area (demands), geographic barriers between supplies and demands, people's awareness about the benefit of green space utilization, living styles, among others. Green space access falls into two major categories: actual accessibility and potential accessibility. The former emphasizes the actual use of green spaces (e.g., Gobster, 2002; Kessel et al., 2009) and the latter highlights the amount of green spaces available in an area (e.g., Comber et al., 2008; Coombes, Jones, & Hillsdon, 2010). For

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each category, spatial accessibility (e.g., location and distance) and nonspatial accessibility (e.g., income, age, sex, and social status) interact with each other. Using Geographic Information Systems (GIS) techniques, this research introduces an approach measuring potential spatial accessibility to green spaces, because knowing the truly underserved areas lacking opportunities of accessing green spaces is critical for effective urban planning and development. By considering the racial/ethnic and socioeconomic structure in each neighborhood, this study takes into account the interaction between the nonspatial factors and spatial factors, thus proposing a comprehensive understanding of the inequity in green space accessibility.

Among the various factors that influence access to green spaces, the amount of green spaces available and population demands are critical. Their distributions often mismatch, presenting pronounced disparities in different races and social status. Gobster (2002) reported that ethnic minorities travelled longer distances and visited less frequently than white users to green spaces. Other studies (Richardson et al., 2010; Wolch et al., 2005) found limited amount of green spaces in the socioeconomically deprived residential areas. There exist a number of goals to foster green space access. The National Recreation and Parks Association, along with the Trust for Public Land and the Congress for New Urbanism, advocated for parks within 400 m of all urban residents (Boone et al., 2009). The Urban Green Spaces Task Force (2002) in the United Kingdom recommended that no person shall live more than 300 m from their nearest areas of natural green space of at least 2 ha in size. A study in New Zealand (Richardson et al., 2010) set a radius of 1300 m as a walking or biking distance to parks of at least 0.02 ha. While these thresholds help identify the neighborhoods short of walking/biking accessibility, different characteristics and functionality of these green spaces may motivate or de-motivate such travelling behaviors. For instance, size is critical because a large regional park, compared to a small pocket park, may provide more functions (e.g., football-playing or kite-flying), which becomes "a formal destination, not a place to drop in (Harnik, 2004)", and thus attracting more planned exercises (Boone et al., 2009). Therefore, it is necessary to consider the amount of green spaces when evaluating the mismatched distributions.

A variety of methods are available to estimate green space accessibility. One common approach is the availability measure calculating the rate of the supplies vs. the demands within a predefined region. For instance, accessibility could be calculated as the amount of green spaces within a neighborhood (or a buffer zone around the neighborhood). This measure is often used in previous studies (e.g., Potestio et al., 2009; Richardson et al., 2010). Another approach is to measure the nearest neighbor—the distance to the closest green space using simple Euclidean distance or distance along a road network in GIS (e.g., Comber et al., 2008; Coombes et al., 2010; Kessel et al., 2009). These two methods are straightforward but encounter two issues. On the one hand, people may not go to the closest green space because of various reasons, such as its size, fearing dogs and racial attacks, or socializing with friends (Madge, 1997). On the other hand, the population pressure (i.e., demands) from different neighborhoods on the same green space is not considered. The third approach is based on the gravity model. For each neighborhood, it summarizes all green spaces within the study area and uses the distance between each green space to this neighborhood as a travel friction (Hillsdon, Panter, Foster, & Jones, 2006). This method addresses the first issue above but the second one remains unanswered. Tackling the two issues requires the consideration of two interactions—people from the same neighborhood may visit multiple green spaces and a green space may have visitors from different neighborhoods. This challenge calls on advanced accessibility measures.

When evaluating the spatial access to green spaces, an accessibility measure considering supplies and demands as well as their interactions is desired. The two-step floating catchment area method (2SFCA), proposed in prior research (Luo & Wang, 2003; Wang, 2006), is suitable for measuring potential spatial accessibility to green spaces. Using a catchment, it explicitly takes into account resource supplies and population demands and their interactions. This method has been widely used in studies on health care access (e.g., Cervigni, Suzuki, Ishii, & Hata, 2008; Guagliardo, 2004; McLafferty & Wang, 2009). Because this method assumes uniform access within a catchment, Luo and Qi (2009) introduced an enhanced 2SFCA. The improvement includes dividing the catchment into a number of travel time zones and assigning weights accordingly. The new method delineates more spatially explicit shortage areas, but still assumes uniform accessibility within each travel time zone. To generalize this assumption in this 2SFCA and the enhanced 2SFCA, a Gaussian function was integrated into the 2SFCA (named as Gaussian-based 2SFCA) to continuously discount the access within a catchment (Dai, 2010). This method was used to effectively delineate the areas short of health care access (Dai, 2010), thus having the potential for estimating green space access.

Green spaces are very limited in metropolitan Atlanta, Georgia. The statistics from the Atlanta Regional Commission show that only 15% of the census tracts are within a 400 m Euclidean distance to green spaces, and merely 6% of the census tracts are within 300 m to green spaces with the size of two ha or more. Atlanta recently started a large urban redevelopment project—"the BeltLine". One of its goals is to create 1200 acres of new or expanded parks, as well as improvements to over 700 acres of existing parks (Atlanta Development Authority, 2005). To prioritize the neighborhoods for green space improvement, it is necessary to quantify the accessibility to green spaces and to identify the shortage areas. Besides, prioritizing the neighborhoods shall take into account the unequal distributions of different racial/ethnic groups and socioeconomic status (SES). Southern Atlanta has 80–100% of African Americans. The annual median income in several neighborhoods in the northern Atlanta is over $160,000 but is below $5000 in some areas in southern Atlanta (US Census Bureau, 2001). A meaningful redevelopment project shall take into account the justice for minorities and low SES populations.

Inspired by the challenge of current measures of green space accessibility and the pronounced unbalanced racial/ethnic and socioeconomic structure in Atlanta, this study has two objectives. First, it introduces a method quantifying potential spatial accessibility to green spaces. Second, it investigates whether neighborhoods concentrated with minorities and low SES have poor green space access. Addressing the first question will help to account for the spatial interactions between residents and green spaces. Areas with poorer accessibility to green spaces can be targeted for redevelopment with higher priorities. Addressing the second question will assist city and regional planners in understanding the racial/ethnic and socioeconomic disparities in green space access in order to develop intervention programs.

2. Study area and data sources

The study area centers on the ten core counties in the Atlanta Metropolitan Statistical Area (MSA) in Georgia (Fig. 1a). The 10-county area is managed by the Atlanta Regional Commission for regional planning and intergovernmental coordination. The selection of the area is appropriate as Atlanta is the most sprawling city in the US which results in widely spread, disconnected pockets of development, limited public space, long commutes, among others (Atlanta Development Authority, 2005; Ewing et al., 2002). The selection of this study area and the result of this study also meet the need for the "BeltLine" project, which proposes to combine green

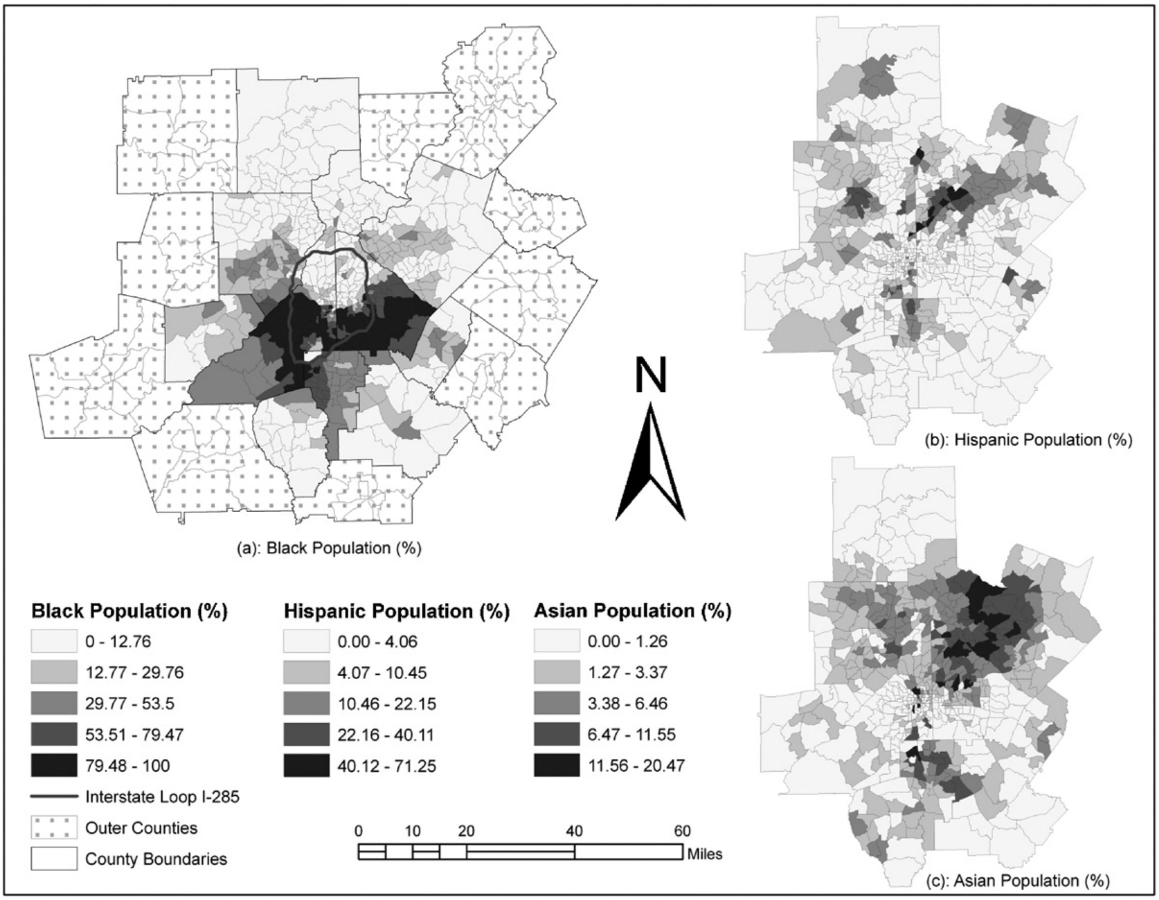

Fig. 1. Study area and the racial/ethnic structure: (a) Black population; (b) Hispanic population; and (c) Asian population.

spaces, trails, transits, and new developments in Atlanta (Atlanta Development Authority, 2005).

Data pertaining to the green spaces ($n = 890$) were obtained from the Atlanta Regional Commission. In line with previous studies (Comber et al., 2008; Kessel et al., 2009; Richardson et al., 2010), green spaces in this research included parks, recreational facilities (e.g., bike trails), public gardens (e.g., botanical gardens), greenways, cemeteries, and historical preservations (e.g., battlefields), because they are primary open spaces in the city accessible to the public. The analysis excluded Golf courses and school playing fields as previous research (Boone et al., 2009; Comber et al., 2008) suggested they are not commonly used by the general public. Each green space included its name, boundary, and size (in acres). The size was used to reflect the differences in their capacities because previous studies (Boone et al., 2009; Harnik, 2004) revealed that large green spaces may attract more planned exercises. A detailed assessment of each green space (e.g., availability of benches or trails) is necessary to quantify its characteristics and functionality in future studies.

Population data at census tract level from census 2000 Summary File 3 and a road network data (TIGER/Line files) were obtained from the US Census Bureau. The primary unit of analysis is census tract ($n = 564$) because it is the smallest areal unit for neighborhoods where extensive socioeconomic statistics are available (Helling & Sawicki, 2003; Larsen & Gilliand, 2008). In 2000, the total population in the area was 3,429,379 including 58.85% whites, 31.94% blacks, and 9.21% other minorities (US Census Bureau, 2001). This study focused on White, African American, Hispanic, and Asian groups as they are the largest racial/ethnic segments of the population. Other minorities (e.g., American Indians) were only 0.3% of the total population and therefore excluded from the analysis. Fig. 1 presents the racial/ethnic structure, where African Americans concentrate in southern Atlanta. On the contrary, Hispanic and Asian populations mainly live in the northeastern area.

Points (i.e., centroids) were used to represent census tracts and green spaces in the estimation of the travel time between them along the road network. Geographic centroids were utilized to represent green spaces. One may argue that green space entrances are more accurate than the geographic centroids. The distances between entrances of most green spaces and their geographic centroids in the study area are relatively small compared to the distances between these green spaces and all census tracts. In addition, people may prefer an entrance close to the destination in the green space and may not necessarily go to the nearest entrance. Besides, for some open green spaces, any point along the perimeter can arguably serve as the entry point (Boone et al., 2009). Therefore their centroids are used. This research used population-weighted census tract centroids to represent census tracts based on block-group level census data. Population-weighted centroids are more accurate than the geographic centroids because populations are usually unevenly distributed in census tracts (Wang, 2006).

The accessibility of each census tract (represented by its population-weighted centroid) was based on its estimated travel time to green spaces. This research used the Network Analyst tool in ArcGIS 9.3 (Environmental Systems Research Institute, Inc., Redlands, CA) to estimate the shortest travel time through the road network where speed limits serve as travel impedance. Travelling using shortest path along road networks is often seen in recent green space research (e.g., Comber et al., 2008; Coombes et al., 2010; Hillsdon et al., 2006) because it effectively captures the variability in travel impedance. It assumes that people travel through the shortest path on the road using the speed limit as the travel speed, thus making travel time a better measurement of the geographic barrier than travel distance. It is admitted that travel time would be extended in actual conditions (e.g., taking alternative paths, traffic delays, taking public transits, biking, or walking). For instance, actual travel time may be prolonged by signal delays and traffic congestions. Travel time taking public transportation shall consider the stop delays for loading/unloading passengers in addition to driving time. This assumption, therefore, presents a conservative picture of accessing a green space. Actual accessibility will decrease compared to that in this ideal condition.

Ideally, walking or biking shall be advocated because they are simple and healthy transportation modes and are also environment friendly (e.g., reduction of fossil fuel use and greenhouse gas release). Selecting driving time rather than walking or biking in this research was dictated by the urban sprawl nature and automobile dependent nature in Atlanta. Previous studies consistently ranked Atlanta as the most sprawling metropolitan area in the US (Ewing et al., 2002; Galster et al., 2001; Pendall, 1999), which is characterized by low density development, difficulty of walking, lack of transportation choices, a road network marked by huge blocks and poor access, and rigid separation between homes, shops, and workplaces (Ewing et al., 2002). It was estimated that vehicles rack up 34 miles each day for every person living in Atlanta (Ewing et al., 2002). A spatial query in GIS showed that 85% of the census tracts are beyond the 400-m walking buffer of green spaces using the threshold determined by Boone et al. (2009). Nearly half of the census tracts are beyond the biking threshold (1300 m) used by Richardson et al. (2010). People "will certainly travel further than a quarter mile but are likely to drive rather than walk" (Boone et al., 2009: 772). Thus this research focused on driving time. In countries promoting less automobile use and more walking/biking, this research may be applicable by estimating travel time based on the walking/biking speed. The estimated travel time can then be used in the proposed accessibility measure in the subsequent section.

3. Spatial accessibility to green spaces in metropolitan Atlanta

This study assessed the green space access using the Gaussian-based 2SFCA. Its pioneer work—2SFCA (Luo & Wang, 2003)—defined the accessibility using a dichotomous measure. That is, locations within a travel threshold are equally accessible and locations beyond are equally inaccessible. The authors argued that the gravity-based accessibility measure uses a travel-friction coefficient β to account for the distance decay, thus considering resources at any locations accessible by residents, though to different degrees, yet accessibility or inaccessibility to a resource for individuals is a dichotomous decision (Luo & Wang, 2003). By experimenting different β values in the gravity-based model and different travel thresholds in the 2SFCA, the authors proved that the gravity-based model tends to give higher accessibility scores to areas with low accessibility, thus concealing the local pockets of poor accessibility (for a proof, see Luo & Wang, 2003). This difference was further evidenced in other studies (Wang, 2006; Yang, Goerge, & Mullner, 2006).

Given that the 2SFCA assumes equal accessibility within a catchment, Dai, in a prior study (2010), integrated a Gaussian function with the 2SFCA to continuously differentiate access within the catchment. Green spaces beyond this catchment were assumed to be inaccessible to the residents within it, because, in reality, people will not regularly travel too far (e.g., 1 h) to visit a green space. The Gaussian-based 2SFCA is summarized as follows.

At the first step, for each green space location j, search all population locations (k) that are within a threshold travel time d_0 from j, thus formulating the catchment for green space location j. Populations at k will be weighted using a Gaussian function (G). Sum up the weighted populations within the catchment for j as the potential users for the green space at j. The ratio (R_j) of the green space to the populations is written as:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} G(d_{kj}, d_0) P_k}, \tag{1}$$

where P_k is the population at location k whose centroid falls into the catchment (i.e., $d_{kj} \le d_0$) from green space location j; d_{kj} is the travel time between population location k and green space location j; S_j is the capacity (i.e., size in acres) of green space at j; G is the friction-of-distance listed below:

$$G(d_{kj}, d_0) = \begin{cases} \dfrac{e^{-(1/2)\times(d_{kj}/d_0)^2} - e^{-(1/2)}}{1 - e^{-(1/2)}}, & \text{if } d_{kj} \le d_0 \\ 0, & \text{if } d_{kj} > d_0 \end{cases}. \tag{2}$$

At the second step, for each population location i, search all green spaces l within the threshold time d_0 from i, thus formulating the catchment for the population at i. Discount each R using the Gaussian function (G). Sum up discounted R within the catchment area i to obtain the spatial accessibility at population location i as follows:

$$A_i = \sum_{l \in \{d_{il} \le d_0\}} G(d_{il}, d_0) R_l, \tag{3}$$

where l denotes all green spaces within the catchment of population location i, and all other notations are the same as in Eq. (1). The accessibility score (A_i) suggests the amount of green spaces (in acres) for every 1000 residents in a neighborhood.

Choosing the catchment size (d_0) is important because it determines whether a green space is accessible. In this study, five thresholds ranging from 10 to 30 min with a 5-min increment have been tested. Given that residents in some neighborhoods will need to drive 13 min to reach the closest green space, a 10-min catchment can reflect the spatial variation in the green space access. Catchments less than 10 min will result in zero accessibility in many census tracts, making it difficult to reveal the racial/ethnic and socioeconomic disparities. Catchments larger than 30 min will over-smooth the accessibility, thus concealing the variation in accessibility. The 5-min increment was chosen to examine the variation in accessibility resulted from different thresholds, which is in line with previous studies (Dai, 2010; Luo & Wang, 2003). The following results rely on the 10-min threshold but their sensitivities on d_0 will also be explored. The commonly known "edge effect" may skew the accessibility along the border; that is, residents within the border may use green spaces outside of the study area and vice versa. To address this issue, this study obtained the outer counties (see Fig. 1a) including 114 green spaces and 112 census tracts surrounding the study area. Estimating the accessibility took into account all 1004 green spaces in all 676 census tracts. It was assumed that the residents in the 10-county study area would only routinely visit the green spaces within the 20 counties and will not regularly go beyond.

Fig. 2 presents the spatial accessibility to green spaces using the Gaussian-based 2SFCA based on the 10-min catchment. It clearly shows the disadvantage of green space access in residents living in the central city enclosed by I-285 (the interstate loop surrounding the central city). Assuming that people are willing to travel 10 min, the central city has very low green space access—less than 20 acres per 1000 residents. The southern suburb has poor spatial access to green spaces as well. In contrast, areas with great access are scattered in the suburbs outside of I-285, ranging up to 501 acres for every 1000 residents. Living in the north and northwestern suburbs apparently benefits from a number of large green

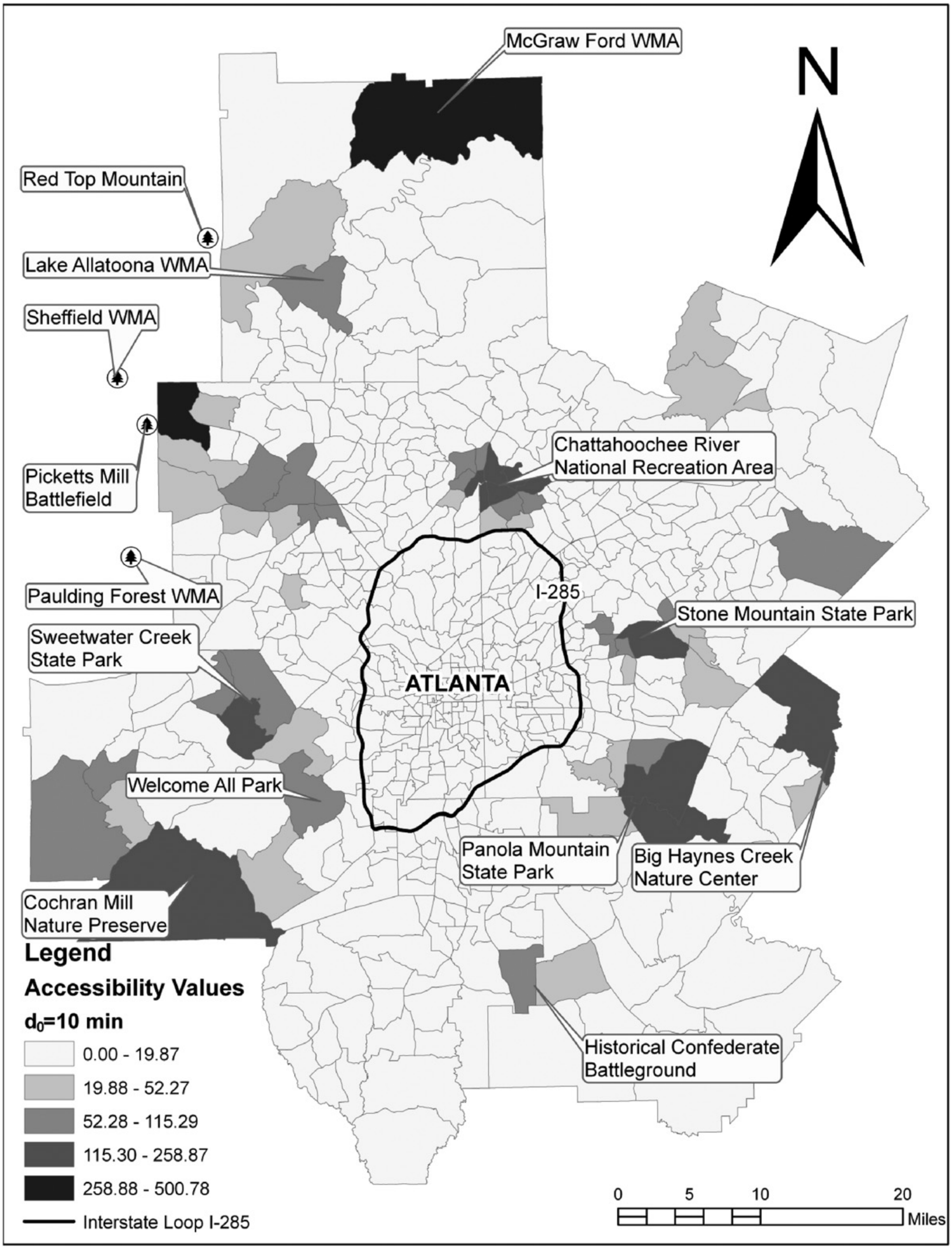

Fig. 2. Spatial accessibility (acres per 1000 residents) to green spaces when d_0 = 10 min.

spaces nearby. Due to the "edge effect", interpreting the accessibility scores along the north and southeastern borders requires caution because green spaces outside of the 20 counties were unavailable. This study alternated the catchment using the four aforementioned thresholds to examine how the green space access changes. The results (Fig. 3) consistently reveal the advantage of the northwestern suburb and the disadvantage of the southern region.

4. Racial/ethnic and socioeconomic disparities in green space access

Evaluating disparities in green space access included bivariate correlation and multivariate regression analyses. Fifteen variables (Table 1) at the census tract level (Summary File 3 from Census 2000) were used to describe SES. All were measured by percentage except the last three which were measured by US dollars.

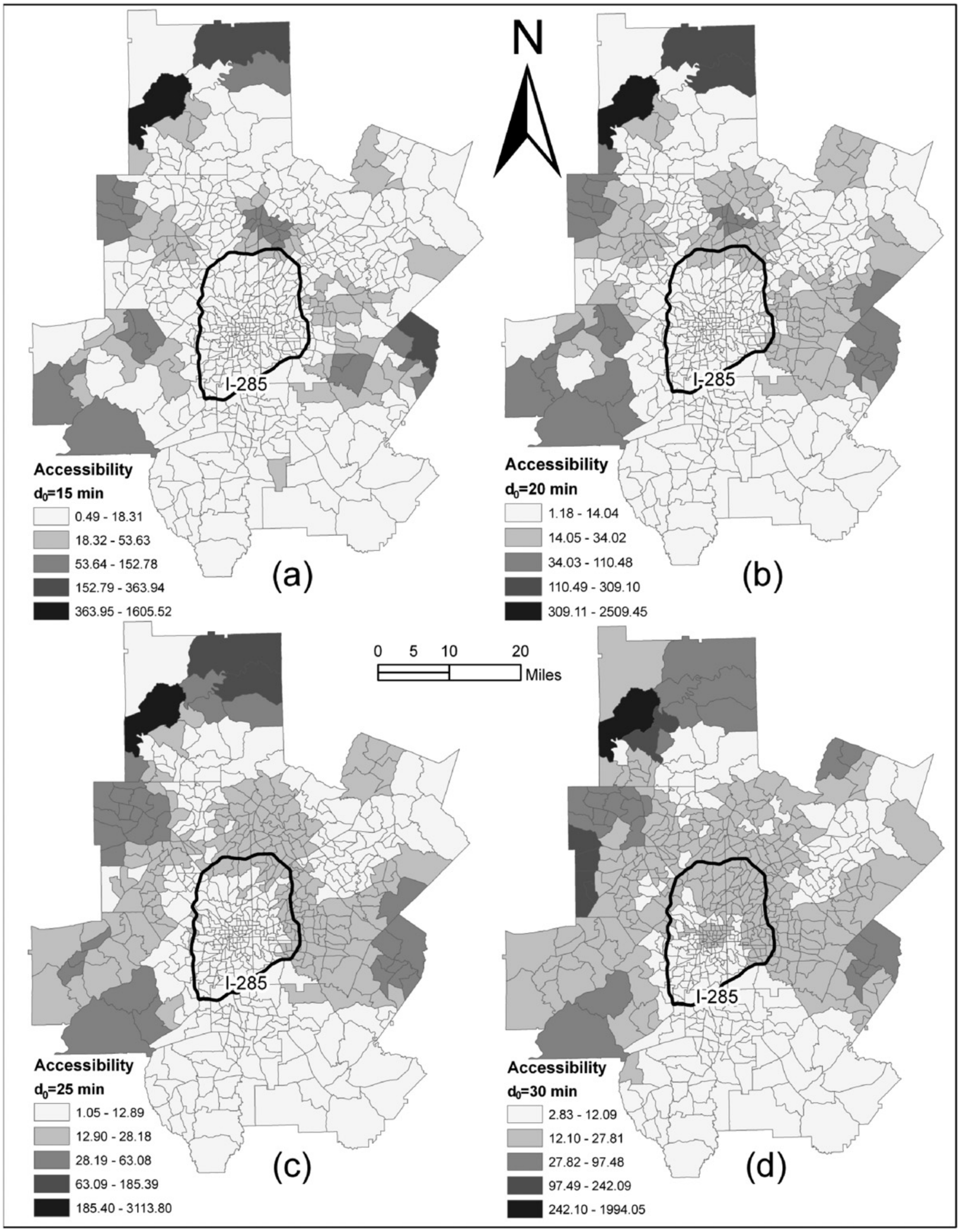

Fig. 3. Spatial accessibility (acres per 1000 residents) to green spaces when (a) d_0 = 15 min; (b) d_0 = 20 min; (c) d_0 = 25 min; and (d) d_0 = 30 min.

Table 1 shows the bivariate correlation between green space access and each of the 15 variables. Poorer green space access is significantly associated with neighborhoods with higher percentages of black populations, households with more than one occupant per room, female headed households, populations below poverty line, and carless households. The accessibility is correlated insignificantly with the rest of the variables. This observation may be supported by the spatial structure of Atlanta in terms of median household income and median gross rent (Fig. 4). The north portion of the central city within I-285 has seen revitalization in the last 20 years for housing redevelopment. Very small undeveloped land remains for new and in-fill construction of green spaces. Because most of these 15 variables are highly correlated (e.g., unemployment vs. poverty), factor analysis (FA: Wang, 2006) was used to account for the multicollinearity before the multivariate regression analysis.

FA began with a principle component analysis (PCA) on the 12 variables. A Varimax rotation was then applied to the factors with

Table 1
Bivariate correlations between green space access and socioeconomic variables.

Variable	Access[a]
Black population (%)	−0.085[*]
Hispanic population (%)	−0.046
Asian population (%)	−0.06
Household with more than one occupant per room (%)	−0.100[**]
Female headed household (%)	−0.099[**]
Population (17+) below the poverty line (%)	−0.082[*]
Household without cars (%)	−0.079[*]
Unemployed population (16+) (%)	−0.075
Population (25+) without high-school degree (%)	−0.042
Linguistically isolated household (%)	−0.050
Occupied home ownership (%)	0.063
Professional and managerial jobs (%)	0.03
Median housing value ($)	0.061
Median household income ($)	0.068
Median gross rent ($)	0.007

[a] $d_0 = 10$ min.
[*] Significant at the 0.05 level.
[**] Significant at the 0.01 level.

Table 2
Twelve socioeconomic variables and the three rotated factors after factor analysis.

Variable	Factor 1	Factor 2	Factor 3
Population below the poverty line	0.892	−0.281	0.076
Household without cars	0.887	−0.242	−0.033
Female headed household	0.849	−0.267	−0.082
Unemployed population	0.769	−0.132	−0.004
Black population	0.625	−0.508	−0.262
Occupied home ownership	−0.780	0.073	−0.398
Median household income	−0.655	0.614	−0.121
Median gross rent	−0.568	0.457	0.065
Professional and managerial jobs	−0.314	0.887	−0.125
Median housing value	−0.171	0.875	−0.027
Population without high-school degree	0.577	−0.650	0.240
Linguistically isolated household	0.048	−0.112	0.942
Hispanic population	−0.066	−0.208	0.894
Asian population	−0.048	0.348	0.654
Household with more than one occupant per room	0.505	−0.444	0.631

Note: Shaded are the variables mainly loaded into each factor.

eigen values greater than one (Griffith & Amrhein, 1997: 179) to maximize the contribution of each variable to each factor and to facilitate the interpretation of these factors. The resulting three factors (Table 2) in this study accounts for 77.6% of the total variance in the original data.

Factor 1 captures 50.47% of the original variation and represents eight variables (the shaded variables under factor 1 in Table 2). Factor 1 suggests "socioeconomic disadvantages" as it is positively associated with all eight variables except the last three. Factor 2 accounts for 18.05% of the original variation and represents three variables (the shaded variables under factor 2). Factor 2 suggests "social status" as it is positively associated with the first two variables. Factor 3 captures 9.09% of the total variance and represents four factors (the shaded variables under factor 3). Factor 3 is positively correlated with all four variables. Because three of them are related to racial and ethnic minorities, factor 3 is labeled as "cultural barriers". Factor maps (Fig. 5) show that the socioeconomic disadvantage factor (factor 1) has high values in the southern area of the central city, while high social status predominately exists in the northern Atlanta. The third factor suggests the concentration of non-black minorities having linguistic barriers and crowded living environment in the northeastern Atlanta.

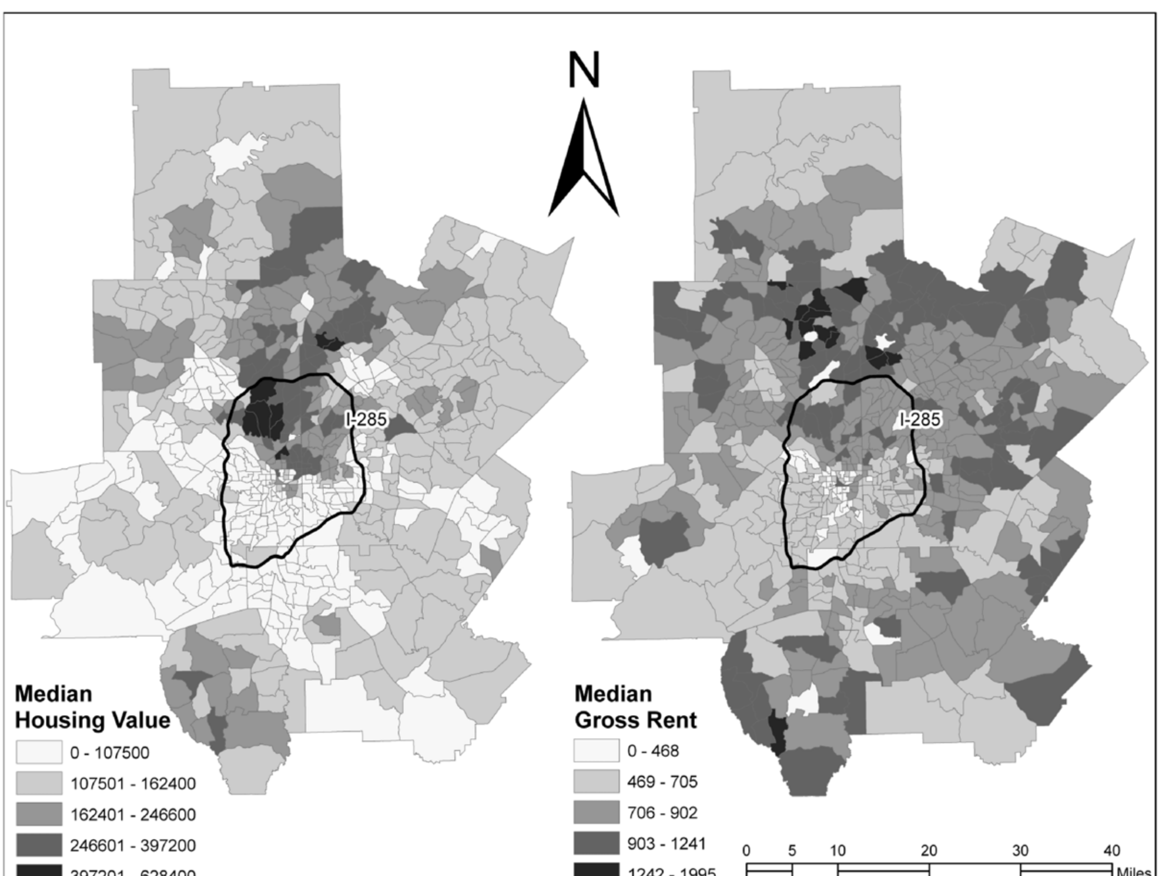

Fig. 4. (a) Median household income and (b) median gross rent in Atlanta at census tract level.

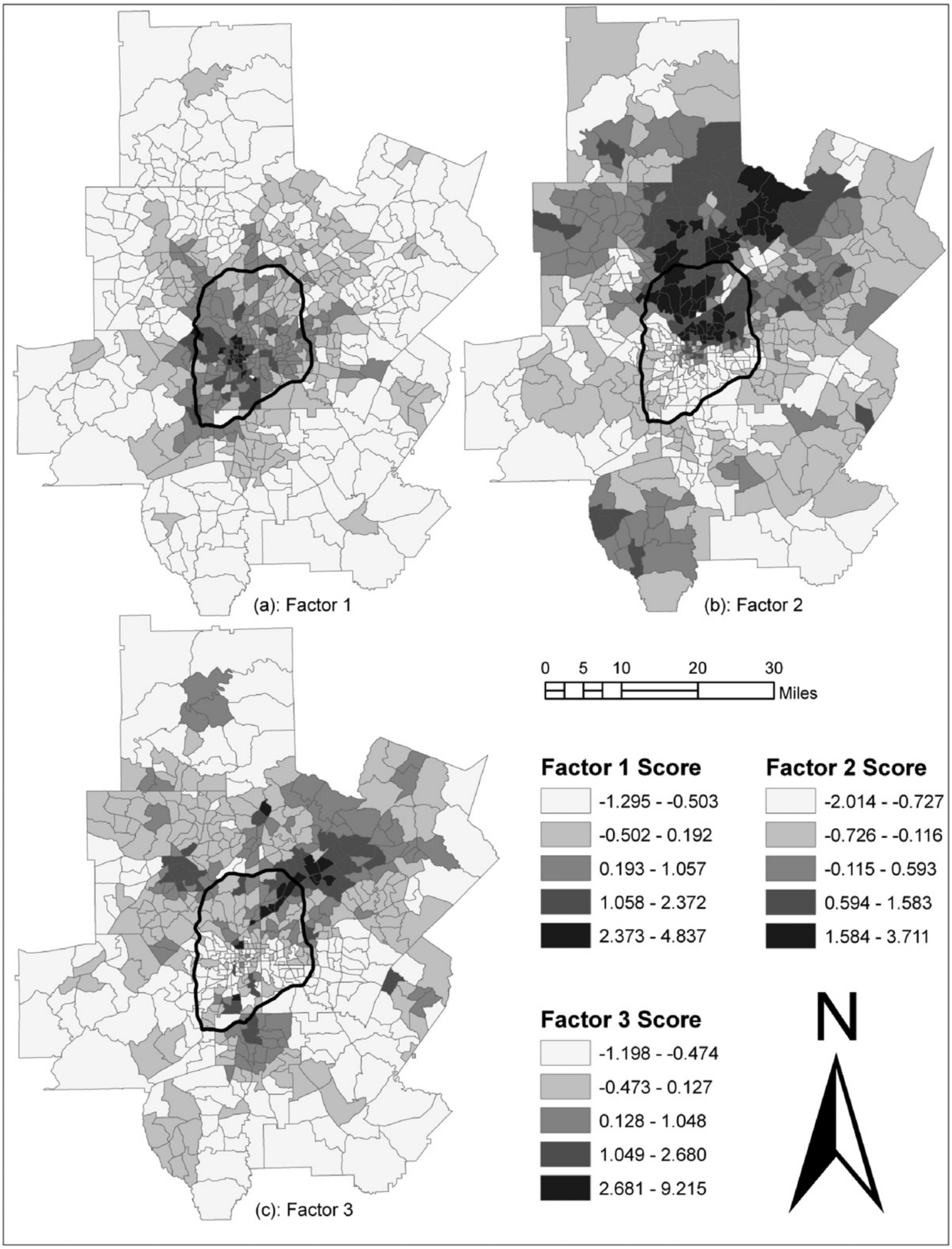

Fig. 5. The distributions of socioeconomic groups: (a) factor 1 (socioeconomic disadvantages); (b) factor 2 (social status); and (c) factor 3 (cultural barriers).

Graphing the rate ratios (Fig. 6) by quartile reveals a clear gradient in spatial accessibility to green spaces. The census tracts were classified into four quartile groups (Table 3). The average green space accessibility was calculated in each group. Using the accessibility in the first quartile group as a reference, this study then calculated and graphed the rate ratios by comparing the accessibility of each quartile group with that of the first quartile. Fig. 6a indicates that the gradient holds for all three minorities. African Americans experience a sharpest decrease in green space access compared to Hispanics and Asians. Green space access for African Americans in the 2nd quartile decreases more than 50% compared to predominately white neighborhoods (1st quartile). Both Hispanics and African Americans have better access in the 3rd quartile compared to the 2nd and 4th quartiles. Asian dominated neighborhoods (3rd and 4th quartiles) have poor access which decreases more than 20% compared to white neighborhoods. For

Table 3
Socioeconomic characteristics and green space accessibility at census tract level in Atlanta.

	Mean	Min	Max	Standard deviation	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Black population	36.7%	0%	100%	34.5	(0, 7.4%) *21.9*	(7.5%, 21.3%) *10.4*	(21.4%, 69.6%) *13.5*	(69.7%, 100%) *11.0*
Hispanic population	6.7%	0%	71.3%	9.2	(0, 1.8%) *18.2*	(1.9%, 3.5%) *12.3*	(3.6%, 7.2%) *16.2*	(7.3%, 71.3%) *10.1*
Asian population	3.3%	0%	20.5%	3.8	(0, 0.6%) *16.7*	(0.7%, 2.0%) *15.7*	(2.1%, 4.5%) *12.1*	(4.6%, 20.5%) *12.2*
Factor 1	0	−1.3	4.8	1	(−1.3, −0.8) *20.4*	(−0.7, −0.2) *14.1*	(−0.1, 0.4) *14.2*	(0.5, 4.8) *8.0*
Factor 2	0	−2.0	3.7	1	(−2.0, −0.8) *14.8*	(−0.7, −0.2) *15.6*	(−0.2, 0.6) *11.1*	(0.7, 3.7) *15.3*
Factor 3	0	−1.2	9.2	1	(−1.2, −0.6) *15.2*	(−0.5, −0.3) *17.6*	(−0.2, 0.2) *14.8*	(0.2, 9.2) *9.2*

Note: Bracketed is the range of each quartile. Italicized is the average green space accessibility (acres per 1000 residents) in each quartile.

the three factors (Fig. 6b), the accessibility decreases more than 60% in the most socioeconomically deprived neighborhoods (4th quartile). Neighborhoods with high social status (4th quartile), which is represented by high factor 2 scores, has slightly increased green space access for approximate 3%. Areas with cultural barriers (4th quartile) have a decrease of 40%.

The multivariate regression models including the Ordinary Least Squares (OLS) model and the spatial regression models were then employed to evaluate the disparities in accessibility. The OLS model assumes an independent residual (Anselin, 1988). Yet the possible spatial autocorrelation of green space access, which suggests green space access scores in closer census tracts are more similar (Figs. 2 and 3), may cause the OLS model to be no longer applicable. Both spatial lag model and spatial error model (Baller, Anselin, Messner, Deane, & Hawkins, 2001), which account for spatial autocorrelation, were tested. They returned consistent results and thus only spatial lag model is presented here. In the spatial lag model, the first-order queen contiguity weight was used as the spatial weight matrix. Second-order queen contiguity and first-order rook contiguity weights were used alternatively to examine the variation in the results.

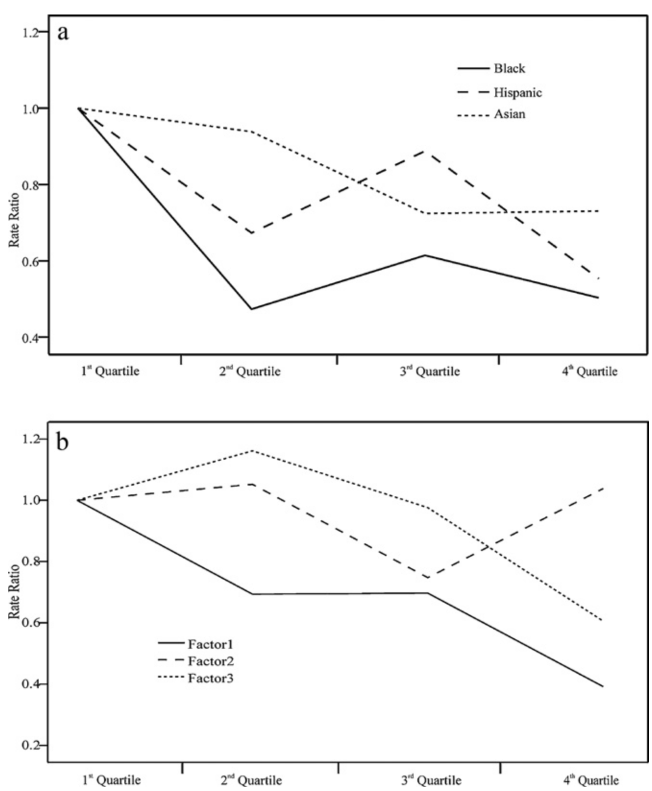

Fig. 6. Variation in the spatial access to green spaces (d_0 = 10 min) by races (a) and socioeconomic factors (b). Rate ratios indicate the average accessibility for residents who reside in a neighborhood compared with residents who live in the area classified into the first quartile.

The regression results (Table 4) show apparent disparities in green space access. When only races were included, both OLS and spatial lag models show neighborhoods with higher percentages of African Americans have significantly poorer access. Areas where Asian and Hispanic populations concentrate also present poor accessibility, yet only the Asian group shows a statistically significant disadvantage in the OLS model. When the three factors were included, the OLS model suggests that neighborhoods with stronger socioeconomic disadvantages (factor 1) have significantly poorer access to green space. This model also suggests that neighborhoods with lower social status (factor 2) and higher non-black minorities (factor 3) have lower accessibility. Yet both relationships are not statistically significant. The spatial lag model suggests that none of the three factors is significantly associated with green space access. The diagnostic of the OLS model indicates that residual spatial autocorrelation is present. Introducing the spatial lag model increased the model fit, yet the spatial effects were still persistent. The goodness of fit (R^2) reveals that the green space disparities are stronger among different races than that among different socioeconomic status. FA removed multicollinearity in both models as the multicollinearity condition numbers (4.067 in OLS model and one in spatial lag model) are lower than the criterion of 30 suggested by Anselin (2005).

This study explored how sensitive the regression results are in two aspects. First, besides the 10-min catchments, green space accessibility using the other four thresholds (i.e., 15-, 20-, 25-, and 30-min) was alternatively used as the dependent variable. For the races, both OLS and spatial lag models suggest that areas with high percentages of black populations are significantly disadvantaged except the 25-min catchment. For non-black minorities, Asian-dominated neighborhoods have statistically significant disadvantages in the OLS model using the 15-min catchment. For the

Table 4
OLS model and spatial lag model for green space accessibility(d_0 = 10 min).

	OLS model		Spatial lag model	
	Coefficients	*t* Values	Coefficients	*t* Values
Three races				
Constant	24.444**	7.514	15.461**	7.052
Black (%)	−0.149**	−3.014	−0.099*	−2.089
Asian (%)	−1.000*	−2.154	−0.650	−1.478
Hispanic (%)	−0.223	−1.194	−0.178	−1.008
Spatial lag, ρ			0.405**	7.052
R^2	0.023		0.122	
Diagnostic[a]	0.175**		43.279**	
Three factors				
Constant	14.187**	8.784	8.489	4.869
Factor 1	−3.982*	−2.464	−2.442	−1.592
Factor 2	1.018	0.630	0.661	0.433
Factor 3	−2.773	−1.715	−1.988	−1.303
Spatial lag, ρ			0.411**	7.184
R^2	0.017		0.120	
Diagnostic[a]	0.177**		44.738**	

[a] Moran's *I* is used to test the residual spatial autocorrelation.
* Significance at the 0.05 level.
** Significance at the 0.01 level.

factors, neighborhoods with socioeconomic disadvantages are significantly deprived in the OLS model using a 15-min catchment. Second, the spatial lag models alternatively using the other two spatial weights return the consistent results. The agreement indicates that the main statistical conclusions are reliable.

5. Discussions and conclusions

Opportunities to access green spaces have critical implications to active physical activities, public health, and environmental justice (Boone et al., 2009; Coombes et al., 2010; Coutts, Horner, & Chapin, 2010). This study introduced a GIS-based approach to quantify spatial accessibility to green spaces and explored its racial/ethnic and socioeconomic disparities.

Using the Gaussian-based 2SFCA to estimate green space accessibility has a number of advantages. First, this approach delineates a more realistic accessibility than the aforementioned measures (i.e., availability, distance to the closest green space, and the gravity model). It considers the interactions between green spaces and populations. For each neighborhood, this method takes into account not only the surrounding green space availability, but also the population demands from neighboring neighborhoods. Second, the accessibility score in a neighborhood can be interpreted as the amount of green spaces that residents can potentially access. If the catchment size is defined using a walking or biking distance, e.g., 400 m (Boone et al., 2009) or 1300 m (Richardson et al., 2010), this approach allows one to estimate the amount of green spaces that residents can access via walking or biking, thus helping identify the shortage area and determine the sizes of new green spaces needed to elucidate the disparities. Third, the travel time along the road network used in this research reveals the travel friction better than Euclidean distance or network distance (Luo & Wang, 2003; Wang & Luo, 2005) because it explicitly differentiates arterial roads and local streets. Fourth, this method accounts for "edge effect" by including the green spaces and populations outside of the study area, which is important for measuring accessibility (Comber et al., 2008). Fifth, this method can be extended to targeting specific populations. The accessibility to children (or seniors), for example, may use the children (or senior) population in the model.

This research evaluated the pronounced disparities in green space access among different racial/ethnic and socioeconomic groups. Consistent with previous research (Boone et al., 2009; Wolch et al., 2005), this study clearly reveals the deprivation of African Americans to access green spaces. It also shows that socioeconomically disadvantaged neighborhoods have poor green space access, which is in line with prior research (Comber et al., 2008; Gobster, 2002; Richardson et al., 2010). The consistency in results using alternative catchments and spatial weights confirms their disadvantages. The 25-min catchment did not show the statistically significant deprivation of African Americans in both models. It is partially due to the fact that the spatial variation in green space access was not strong enough using this threshold. The less pronounced disadvantages in green space access for Hispanics and Asians are possibly attributable to their small populations. They account for less than 9% of the total population in Atlanta, compared to nearly 32% of African Americans. The study further reveals the deprivation in spatial access in the central city. However, this disadvantage may not hold true for the inner-city wealthy families (high social status with high income levels, well paid jobs, high housing values, and high car ownership) who can afford private green spaces (e.g., golf courses). On the contrary, the urban poor minority residents often have less mobility because of the lower car ownership, poor private green space affordability, low-wage jobs, and single-mother families (Boone et al., 2009; Wolch et al., 2005). Therefore, the impact of inner-city disadvantage in green space access on the poor minorities deserves closer attention.

Findings from this research have important policy implications. While many cities advocate walking and biking as healthy and environment-friendly travel modes, Atlanta still faces the challenge that many of the census tracts are beyond the walkable distance to the nearest parks. The lack of bike lanes put the bicyclists in danger when they have to share roads with motorists, which may discourage biking to parks (Herbst & Herbst, 2006). In the short term, city planners should pay attention to the areas short of green space accessibility and prioritize the socioeconomically deprived areas when establishing new parks or expanding existing parks. In the long term, an evaluation of areas short of walking and biking access to green spaces is needed. More sidewalks and bike lanes are necessary to encourage such travel modes.

This study has a number of limitations which could be addressed in future studies. First, the research uses a Gaussian function to reflect the travel friction between green spaces and residents. Surveys of the actual green space usage in each neighborhood may provide a realistic use pattern about the true catchment size. Second, besides the size of green spaces, an environmental audit (e.g., tree coverage, picnic areas, accessible water bodies, and benches) will be necessary to describe the green spaces. Third, the accessibility is based on the travel time using private vehicles. Other travel modes such as walking, biking, and taking public transit may be necessary in order to have a complete understanding of green space access.

In summary, this study introduced a green space accessibility measure and analyzed its racial/ethnic and socioeconomic disparities in metropolitan Atlanta. The findings can assist in delineating shortage areas for city planners to target and evaluating the justice of green space improvement so as to ensure the equity in accessibility. The GIS-based accessibility model allows for the detection of shortage areas that would not otherwise have been suspected. Furthermore, the deprivation of access to green spaces for African Americans (e.g., neighborhoods in southern Atlanta) can be used to target the specific neighborhoods to elucidate the disparities.

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