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An accessibility-based integrated measure of relative spatial equity in urban public facilities

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The achievement of equity in the distribution of urban public facilities is a goal of paramount importance to urban planners, who must analyze whether and to what degree their distribution is equitable. Recent efforts have probed into the equity of one type of facility, leaving an overall examination unconsidered. In this paper, integrated equity indices with which planners can analyze the relative equity status of facility distributions are presented, integrating GIS and spatial analysis models. Ren-de, Taiwan is the test site for this prototype method, and results show it allows users to understand the characteristics of spatial equity both for disaggregated and aggregated levels, and it demonstrates significant differences between urban public facilities.

Keywords: Spatial analysis models, geographical information systems, integrated equity indices

Introduction

The issues of spatial equity of urban public facilities have proliferated during the past two decades (Jones and Kirby, 1982; Kirby et al., 1983; Pinch, 1984; Smith, 1994; Hay, 1995; Talen and Anselin, 1998; Ogryczak, 2000). However, planners have been unable to give spatial equity a comprehensive evaluation, for spatial equity has not heretofore been readily operationalizable (Kinman, 1999). Specifically, there has been no reasonable mechanism available to integrate results of urban public facility measures into an overall evaluation scheme suitable for easy and intuitive use by planners. It was not until recently that empirical studies in urban public facility equity planning were conducted (Meier et al., 1991; Miranda and Tunyavong, 1994; Kinman, 1999) although early researchers, such as Cingranelli (1981), Mladenka (1980), and Mladenka and Hill (1977), had noted the issue. Nevertheless, these applied studies focused primarily on the equity of a single type of public facility. However, to urban residents, each type of public facility possesses its own unique characteristics and satisfies particular needs. Thus, residents have different preferences for different types of public facilities, known as variant attraction/repulsion. If a study focuses on only one type of public facility allocation and ignores the relationship between other public facilities, it cannot reveal the inter/intra effects of overall public facilities on urban residents. Furthermore, there has been scant attention paid to the effect of spatial analysis technology on comprehensive public facilities about spatial equity drawn from previous studies and public facility policies. Consequently, it is hard to tell whether the spatial distribution of public facilities is equitable to the residents and equally hard to ascertain the residents' preferences for public facilities with respect to the whole urban area. Lacking such detailed spatial data processing capability or supporting research literature, previous empirical research on spatial equity used aggregate indices to compare and analyze larger analytical spatial units, such as cities, and townships (e.g., Yan and Han, 1999) whereas equity within a city or town based on geographic or neighborhood units was seldom studied. Some researchers utilized Geographical

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Information Systems (GIS) to boost spatial data processing capabilities in an attempt to yield more precise results, while other studies adopted a simple mapping approach. The application of integrated approaches to equity assessment of the overall public facilities remained only poorly articulated (Karkazis and Boffey, 1997; Kinman, 1999).

As any geographical analysis of spatial equity in this context relies on a measure of access to services, it is important to gain an understanding of the sensitivity of the conclusions from conceptualization and measurements of accessibility. Typically, access is loosely defined on the basis of a simple count of facilities or services by some geographical unit, without regard to factors such as spatial externalities, the structure of the transportation network, the frictional effect of distance, properties of the supply side, and measurement issues related to the geographical scale of analysis. Such lack of attention to methodological aspects contrasts sharply with the recent surge of interest in defining, computing, interpreting, and visualizing accessibility in the literature from spatial analysis and GIS (Arentze et al., 1994; Frost and Spence, 1995; Geertman and Ritsema Van Eck, 1995; Talen and Anselin, 1998).

To fill the void in the existing literature, this paper proposes integrated equity indices (IEI), based on a spatial analytical perspective, such as accessibility theories, GIS, and spatial analysis models, and then to indicate briefly how these could be operationalized, to examine whether and to what degree the distribution of urban public facilities is equitable. Specifically, this paper focuses on the factors affecting spatial equity as well as the spatial patterns of equity in entire public services, based on the IEI. We approach this issue with an empirical examination of the distributions of 12 types of public facilities in Ren-De, Taiwan. Besides the typical measure of access (count of facilities in an area unit), we use average travel distance, a potential measure based on the gravity model that considers average travel distance and distance to the nearest facilities as indicators of accessibility. We are particularly interested in the similarities and differences between the spatial patterns in these measures determined from (1) spatial analysis models and spatial autocorrelation theory (SAA: see Anselin, 1995); (2) local indicators of spatial association [LISA: see (Anselin, 1995); and (3) other spatial techniques like 3D-GIS.

The paper is organized as follows. We review pertinent literature about spatial equity in ‘‘Spatial equity and accessibility’’. ‘‘Characteristics of urban public facilities’’ classifies urban public facilities according to three service factors. GIS is also integrated into the research to enhance the effectiveness and precision of measuring IEI, a new spatial equity index system, based on the features of spatial equity and urban public facility services (‘‘Development of a new integrated equity index for spatial equity’’). From both disaggregate and aggregate perspectives, a set of integrated multi-stage spatial analytical processes and methods are constructed in ‘‘Operating process for IEI with GIS-based spatial analytic techniques’’. The proposed tools allow presentation and analysis of the spatial distribution patterns of equity measurements. Furthermore, the equity levels of public facilities within the whole urban space are assessed. In application, the package enables researchers to fully discern the spatial equity of public facility planning. The results of IEI are in two parts: presentation of spatial distribution, based on 3D-GIS simulation, and analysis of spatial correlation, based on spatial autocorrelation techniques. To illustrate the entire process, Ren-De, Taiwan will be presented as an example in ‘‘The emperical case study’’. Finally, we discuss how different characterizations of access can alter the results of the IEI of spatial equity for both the individual and for the entire public facility.

Spatial equity and accessibility

Definition of spatial equity

Researchers of spatial equity dimensions have spanned the social sciences, and their definitions and ambitions have varied, as do the indicators with which they tried to measure the postulated goal (Kunzmann, 1998). For some, spatial equity is just equal access to basic public facilities, measured in distance (Smith, 1994; Talen and Anselin, 1998; Kinman, 1999; Ogryczak, 2000), such as accessibility to school, health facilities or culture events. For others, spatial equity is more ambitious and would include a choice of jobs and a choice of accessible educational institutions. Also, it would include a choice of cultural events, not just a local or regional amateur theatre, for different target groups and different age groups (Kunzmann, 1998). Specifically, this paper evaluates the utility of linking the concept of equity with spatial analysis of users at a micro scale, supplemented by an individual resident survey. Here, spatial equity implies that there is an even distribution of services in relation to the needs, preferences and service standards of each resident.

This paper recommends a spatial analytical perspective to evaluate suitability of urban public facilities in assessing whether or not, or to what degree, the distribution of urban public facilities is equitable. First, it should be made clear that this paper neither absorbs itself in the so-called equity issues nor does it explore the dimensions of justice, fairness, or propriety in the distribution of travel distances; instead, it addresses relative equity in spatial allocation of each type of public facility for each inhabitant of the city.

The general connotation of spatial equity is that all residents should be equally treated, wherever they live. This idea is, theoretically, an extended form of social equity. Though its definition has varied to some extent, previous studies have generally emphasized the relationship of equity and location (Kunzmann, 1998). In some research, spatial equity may carry broader meanings; for example, it could mean that similar job opportunities are offered to individuals from distinct regions. In the context of urban public facility planning, spatial equity means equal spatial separation from or spatial proximity to public facilities among residents. Of the many available means for measuring spatial equity, accessibility indices have heretofore been the most widely used (Talen and Anselin, 1998).

Definition of accessibility

Accessibility is defined as the relative nearness or proximity of one place to another. Numerous efforts have been made to develop suitable accessibility indices (Pooler, 1995). Usually such measures of nearness balance the benefit of locating at or visiting a place *j* with the costs of moving or traveling to that place from a fixed location *i* around which accessibility is being calculated. In generalized terms, the measure can be defined as either Eq. (1) or Eq. (2)

$$A_i = \sum_j f(W_j, S_{ij}), \tag{1}$$

where W_j is some index of the attractiveness of *j*; and S_{ij} is a measure of spatial separation, typically the distance or travel time from *i* to *j*.

$$A_i = \sum_{\substack{j=1 \\ i \neq j}} f(S_{ij}), \tag{2}$$

where accessibility A at location i varies directly with S_{ij}.

Depending on the research focus, the above equations may be developed differently, thereby generating different measures of W_j and S_{ij}. Before proper indices can be established, it is essential to analyze the character of urban public facilities so those factors affecting spatial equity index and parameter measurement can be fully understood.

Characteristics of urban public facilities

Two major functions of urban public facilities are to provide services to residents and maintain the environmental quality of urban living. Urban public facilities exhibit a variety of characteristics that are important to the urban planner. These characteristics include service range/impact area and spatial separation, preference of residents for different types of facilities, and the different sizes of public facilities of the same type that have varying effects on the residents. We will discuss these characteristics of urban public facilities as follows.

Service/impact range of public facilities and spatial separation

This paper uses the term accessibility as a starting point within the empirical model. In urban studies, ''accessibility'' has different definitions despite its increasing spatial application. Our intent is to capture some of the main methodological variations that come into play when using IEI [''Development of a new integrated equity index for spatial equity'']. Therefore, we will not enter into an in-depth discussion of accessibility commonly used for different purposes in urban studies, but rather limit the concept of accessibility to the delivery relation between the locations of the public facilities and the locations of their users.

Service/impact range of public facilities. The coverage of public facilities affects residents in two ways. One is the service range of the public facility, which is equivalent to the accessibility to a public facility such as a park or school that supplies services via traffic networks (Thill and Rushton, 1992; Talen and Anselin, 1998). The other one is the impact range that results from site-noxious facilities; its effect on residents is determined by the shortest distance, a straight-line distance where possible (Geertman and Ritsema Van Eck, 1995). According to the service/impact range, urban public facilities are subdivided into three levels: municipality, community, and neighborhood. For example, the service range of municipal facilities such as town parks, universities, museums and dump sites covers the entire city. The service radius of community facilities, including junior and senior high schools, transformer stations, etc., are typically in the 2 km range. The service range of neighborhood facilities like playgrounds and elementary schools is typically in the 1 km range. Various levels (municipality, community, and neighborhood) possess different service/ impact ranges. If the spatial unit (*i*) is out of the service range/impact range of facility *A*, then it is not suitable to include the facility *A* into the consideration of spatial equity. Hence, GIS is used to determine the areas that are properly covered by existing public facilities.

Spatial separation. Spatial separation is the other significant characteristic of a public facility with respect to accessibility in ''Service/impact range of public facilities and spatial separation''. The analysis of spatial equity compares the spatial distribution of public facilities or services to the location distribution of various residents. Interaction between public facilities and residents usually takes one of two forms as stated in ''Service/impact range of public facilities''. Therefore, we measure S_{ij} (the spatial separation index) by actual street network distance and a straight-line distance, instead of by travel time and/or travel cost.

Resident preferences for different types of public facilities

Public facilities must satisfy residents' preferences. However, the residents' preferences of facility sitting are quite different for different types of facilities and can be classified as follows: site-noxious facilities, such as dumps (negative place utility closest to the facility, becomes positive with increasing distance); site-neutral facilities, such as schools (equal effect on place utility at all distances from the facility); and site-preferred facilities, such as parks (positive place utility close to the facility but drops off with increasing distance). In other words, not all facilities have the same impacts and it follows that one should pay closer attention to the preference of residents and the type of facility being modeled.

IEI uses these preferences for different facilities as the weight, P_k, and then the attitude scale (Likert scale) is applied to assessing resident preferences. This paper's version of IEI utilizes a five-point Likert scale, ranging from strongly disagree (the point −2) to strongly agree (the point +2), to obtain preferences for different types of facilities.

Different sizes of public facilities of the same type have varying effects on residents

Although public facilities of the same type have similar basic characteristics, different sizes causes varied influence on the residents. For a spatial unit (i), W_j is typically a function of the service radius of a facility, which in turn may be a function of the size of the facility in Eq. (1). For instance, the influence W_j of two different parks could be computed according to size; however, some researchers (Allen et al., 1993) argued that various influences in the same type of facility could be ignored and thus assigned 1 to the parameter W_j, thus yielding Eq. (2).

Convenient as Eq. (2) is, it ignores the fact that varying effects among the same type of facility do exist. To solve this discrepancy, IEI modifies Eq. (2) and proposes Eq. (4) ("Development of a new integrated equity index for spatial equity") based on a linear transformation. For those facilities with clearly relative effects, W_j, as in the above case involving the parks of the same type, the size of facility is linearly transformed into weighted W_j.

The characteristics mentioned above are used to formulate the three indices used in IEI to evaluate the spatial equity of urban public faculties in this paper in the following section.

Development of a new integrated equity index for spatial equity

Most accessibility indices are based on Eq. (3), which was derived from Eq. (1) (Stewart and Warntz, 1958). The concept of Eq. (3) can be traced back to "the law of retail gravitation" by Reilly (1931), which has been frequently applied to interactive potentials or spatial interactive effects in GIS. Jiang et al. (1999) used Eq. (3) as a tool for measuring geographic accessibility (A_i) at the disaggregated level

$$A_i = \sum_{\substack{i=1 \\ i \neq j}} W_j \times S_{ij}^{-\alpha} \quad \alpha: \text{parameter of spatial separation.} \tag{3}$$

Eq. (4) integrates Eq. (3) and the three above-mentioned public facility indices to compute the spatial equity in IEI

$$E_{ij(k)} = P_k \times W_{j(k)} \times S_{ij}^{-\alpha}, \tag{4}$$

where

$E_{ij(k)}$ is the value of spatial equity of the public facilities $j(k)$ in the spatial unit i, $i = 1,2,\ldots,I$; k is the kth type of all public facilities, $k = 1,2,\ldots,K$;
$j(k)$ is the jth public facility of the kth type of public facility, $j = 1,2,\ldots,J$;
P_k is preference of residents to the kth type of public facility, which was mentioned in "Resident preferences for different types of public facilities". $P_k = AS_k/\sum AS_k$, AS_k is the score of preference attitude toward the kth type of public facility with $\sum P_k = 1$;
$W_{j(k)}$ is the relative effect of the jth of the kth type public facility, which is mentioned in "Different sizes of public facilities of the same type have varying effects on residents";
$W_{j(k)} = Q_{j(k)}/Q_k$, $Q_{j(k)}$ is the service/impact range of the jth of the kth type public facility;
Q_k is the serviceable service/impact range of the kth type public facility;
S_{ij} is the spatial separation mentioned in "Service/impact range of public facilities and spatial separation";
a is the parameter of spatial separation;
Note. According to "Service/impact range of public facilities and spatial separation", the service range/impact area of the jth public facility must cover the ith spatial unit; otherwise, other facilities can not be computed in Eq. (4).

One methodological issue in Eq. (4) must be addressed—the magnitude of the separation parameter, a, that reveals the equity of resource distribution. Accepted practice is to calibrate this parameter for a particular application, and set it between 1 and 2, 2 being the most popular (Houston, 1998; Pooler, 1995; Talen and Anselin, 1998). Our IEI assumes the usual value of $a = 2$.

A valid use of Eq. (4) is for equitable comparison purposes. Furthermore, the spatial equity of the jth public facility of the kth type public facility in the ith spatial unit can be measured by Eq. (5)

$$E_{ij(k)} = P_k \times W_{j(k)} \times S_{ij}^{-2}. \tag{5}$$

Then, the overall spatial equity of the ith spatial unit at the aggregate level becomes

$$T_i = \sum_{k=1}^{K} \sum_{j(k)=1}^{J} E_{ij(k)}, \quad (6)$$

where T_i is the aggregate spatial equity of ith spatial unit in urban public facility.

Consequently, the integrated measure index for spatial equity of the whole urban public facility is defined as

$$T = \sum_{i=1}^{I} T_i, \quad (7)$$

where T is the spatial equity of the entire urban public facility.

Based on the integrated measure index presented in Eq. (7), the average spatial equity ($\overline{E}$) is measured by

$$\overline{E} = \frac{T}{I}, \quad (8)$$

where I is the total of spatial units.

Eq. (8) calculates the average spatial equity, providing an aggregate value and avoiding the effects of individual spatial unit i. It can be normalized as

$$\overline{E}' = \frac{T}{I-1}. \quad (9)$$

Although the integrated equity indices reveal the degrees of equity, it is not easy to tell whether or not the urban public facility is equitably distributed. Hence, we attempt to translate the numerical measurements, which are outcomes from integrated equity indices, into a readily understood presentation of the event undergoing spatial equity analysis, from both disaggregate and aggregate perspectives.

Operating process for IEI with GIS-based spatial analytic techniques

IEI offers a display and analysis of spatial equity based on the integrated equity indices [“Development of a new integrated equity index for spatial equity”]. GIS techniques, spatial autocorrelation analysis (SAA) and local indicators of spatial association (LISA) are important methods for this integration.

Tools for GIS-based model implementation

In recent years, GIS, with its power and versatility for processing, managing and analyzing spatially distributed data, has attracted significant attention in various fields (Zhou et al., 2003). In this paper, a GIS-based integrated approach is proposed for operating and displaying spatial equity of urban public facilities. GIS is actively used in the following roles: (1) to store and analyze the spatial distribution of each public facility; (2) to quantitatively process the spatial data and provide for IEI; (3) to support the discovery and verification of spatial equity of urban public facility; and (4) to display the results of IEI.

We construct the macro-instruction set and the individual and flexible computing modules for computing the value of spatial equity through the above equations; these are included in ArcGIS (8.1) to assist computing spatial equity of urban public facilities. Meanwhile, a buffer is employed to assist in identifying the service/ impact range of the jth public facility to the ith spatial unit (“Service/impact range of public facilities and spatial separation”). Consequently, network analysis has been incorporated into IEI to compute spatial separation, S_{ij}.

Furthermore, the 3D-GIS system provides efficient spatial analysis tools able to use all capabilities of the third dimension, and yields a visualization that could operate on the results of queries (de la Losa and Cervelle, 1999). Thus, 3D-GIS as applied to IEI not only show the locations of facilities, but the degree of spatial equity for the corresponding IEI. Through 3D simulation, site-preferred facilities and site-noxious facilities can be easily pinpointed, with resulting positive and negative values of IEI simultaneously displayed.

Spatial equity analysis based on spatial autocorrelation techniques

Spatial autocorrelation analysis. To learn more about the characteristics of equity distribution of public facilities in each spatial unit i, spatial autocorrelation techniques are integrated into the analysis, allowing exploration of possible spatial structural relationships and spatial equitable patterns of public facilities in disaggregate and aggregate levels, respectively. SAA is concerned with the degree to which objects at some place are similar to other objects located nearby (Griffith, 1978). Since SAA deals simultaneously with both location and attribute information, it is in some situations a powerful, analytic technique. Similar objects in proximity to one another are positively spatially autocorrelated, and vice versa, zero autocorrelation occurs when attributes are distributed independently in space. Moran’s I, as expressed in Eq. (10), is the most widely used for measuring spatial autocorrelation (Anselin, 1995; Sokal et al., 1998). It can determine whether spatial autocorrelation exists by use of locational proximity matrices and attribute-similarity matrices.

A weight matrix $\boldsymbol{W}$ has elements x_{il} representing the connections in a set of spatial unit i. The x_{il} may assume any value, but in this paper we shall confine ourselves to a binary weight matrix consisting of ones (connected) and zeros (not connected). The diagonal elements of W are zero. The variable X is mapped onto the I spatial units. The spatial autocorrelation analysis coefficient, Moran’s I, is

$$I(d) = \sum_i \sum_l \omega_{il} z_i z_l / S_0 m_2, \quad (10)$$

where $S_0 = \sum_i \sum_l \omega_{il}$, $m_2 = \sum_i z_i^2/I$, and $z_i = x_i - \bar{x}$; Z_i is the value of equity for each zone. $i = 1,2,\ldots,I$.

Moran's I is a product-moment coefficient analogous to the Pearson correlation coefficient and is strongly affected by marked joint departures of neighbors from the mean of the studied variable.

The value of Moran's I is positive when nearby objects tend to be similar in attributes; a positive Moran's I suggests an equitable distribution, with Moran's $I = 1$ as the best equitable distribution. On the contrary, the value of Moran's I is negative when they tend to be more dissimilar than what is normally expected. With respect to spatial equity of a public facility, a negative Moran's I suggests an inequitable distribution, with Moran's $I = -1$ as the worst equitable distribution. Moran's $I = 0$ when attribute values are arranged randomly and independently in space.

Local indicator of spatial autocorrelation. Because SAA often hides interesting local patterns in the data, in the form of small clusters or outliers, LISA is applied to provide an alternative perspective by focusing on patterns surrounding individual observations. Anselin (1995) defined a local indicator of spatial association (LISA) as any statistic satisfying the two requirements: (1) the LISA for each observation gives an indication of the extent of significant spatial clustering of similar values around the observation; (2) the sum of LISAs for all observations is proportional to Moran's I of spatial association. The first requirement means that the LISA is a measure of local spatial autocorrelation. The second requirement permits the decomposition of Moran's I into separate parts, making it possible to identify the individual locations that are major contributors to SAA (Anselin, 1995; Sokal et al., 1998). The local Moran coefficient at spatial unit i is defined as

$$I_i = (z_i/m_2) \sum_l \omega_{il} z_l. \tag{11}$$

All terms are as previously defined.

LISA provides information on the relative important of four types of spatial association: (1) high–high, high values (above the mean) associated with high neighboring values; (2) low–low, low values (below the mean) associated with low neighboring values; (3) low–high, low values associated with high neighboring values; and (4) high–low, high values associated with low neighboring values. The first two reflect positive spatial association, or local spatial clustering of similar (high or low) values. In contrast, the second two are examples of spatial outliers, in the sense that they point to locations that are different from their neighbors. The mapping of locations with significant LISA statistics, together with an indication of the type of local spatial association as given by the quadrants in the Moran scatterplot, provide the basis for a substantive interpretation of spatial clusters or spatial outliers (Bhana, 1998; Anselin and Bao, 1997).

The empirical case study

This paper deals with preliminary attempts to empirically consider these kinds of issue, related to IEI in Ren-De, Taiwan, to investigate the city's resources base and the impacts and effects of its distribution. Spatial equity of 12 types of urban public facilities in Ren-De were surveyed and analyzed by the integrated equity indices of ''Development of a new integrated equity index for spatial equity'' and then displayed according to the spatial analysis techniques of ''Operating process for IEI with GIS-based spatial analytic techniques''.

The research area

Numerous medium-sized cities face public facility equity issues as they grow rapidly and are unable to satisfy the needs of their increasing populations. Ren-De is a typical growing medium-sized city. It is situated in southwestern Taiwan, covers 5077 hectares, is divided into 18 townships, and had a total population of about 66,200 in 2003, served by a national airport, two railway stations, a freeway interchange and a convenient road network. Therefore, it has become the gateway of southern Taiwan, and has developed rapidly over the last decade. It is a typical urban center with five main clusters and several scattered clusters. The population is concentrated in the northern, mid-northern and central areas, with good road network connecting them (*Figure 1*).

The public facilities in Ren-De include 12 types of facility, totaling 82 overall, (*Table 1*), clustered into five main groups. The public facilities serve those in the main clusters more readily.

Empirical results

Descriptive statistical results of IEI and 3D-GIS displays. First, we analyze equity of public facilities in Ren-De from the point of descriptive statistical characteristics of IEI for each block, for disaggregated and aggregated levels, respectively (*Tables 2 and 3*).

With respect to the disaggregated level, every type of public facility exhibits obvious spatial inequity, especially neighborhood parks, community parks, elementary schools, cemeteries and green belts, based on their values of standard deviation and means based from Eq. (3) (*Table 2*). For example, the value of standard deviation of neighborhood parks is 6.23, and the value of the mean is 0.99, indicating a huge variation in park distribution. Every type of public facility is either poorly located or does not satisfy the needs of residents in Ren-De. Furthermore, comparing the spatial equity for two types of community public facilities—community parks

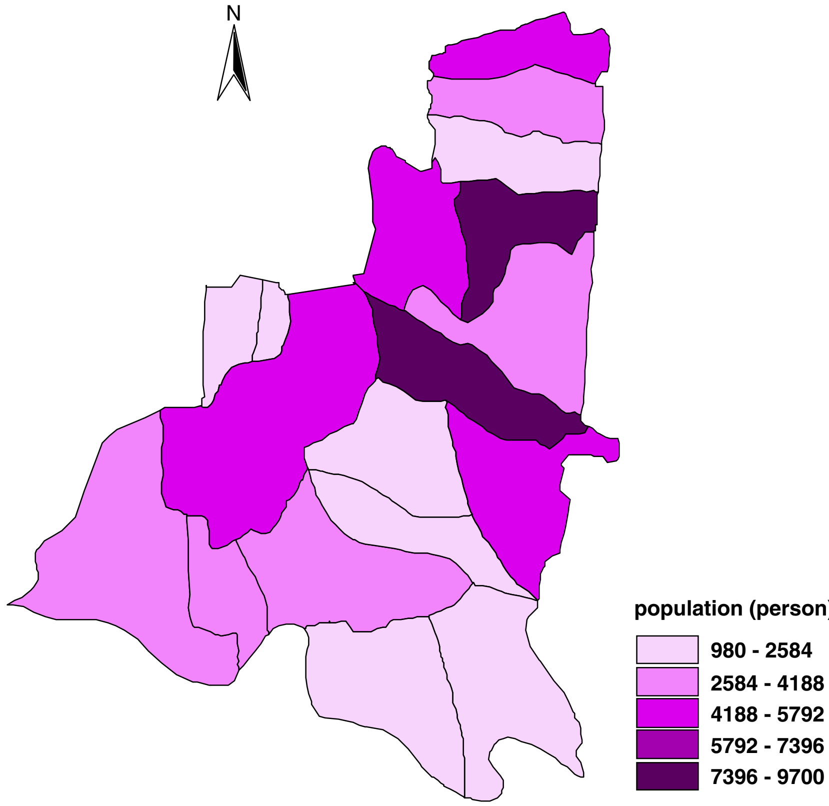

Figure 1 Population distribution of Ren-De.

Table 1 Public facilities in Ren-De

Facility	Number	Total area (ha)
Municipal parks	3	15.73
Community parks	2	4.45
Neighborhood parks	25	6.13
Libraries	3	3.7
Green belts	3	6.96
Junior high schools	3	10.84
Elementary schools	11	27
Retirement centers	1	0.23
Community centers	9	0.72
Traditional Chinese markets	8	3.41
Cemeteries	13	167.01
Dump Site	1	0.92

(unassigned public facility) and elementary schools (assigned public facility)—reveals that the spatial equity of elementary schools is far from community parks (for P_k of elementary schools is 0.75, and P_k of community parks is 0.55: *Table 2*), although they are in the same service range (''Service/impact range of public facilities and spatial separation''). The elementary school belongs to the assigned public facility category because it was set up with more facilities for the expected larger load. On the other hand, spatial equity of public facilities is uneven at the disaggregated level; centralized residents have more public facilities in a growing mid-sized city, which

Table 2 Descriptive statistical characteristics of IEI (disaggregated level)

Facility	Mean	Standard deviation	P_k[a]
Municipal parks	0.22	0.61	1.23
Community parks	0.45	1.66	1.23
Neighborhood parks	0.99	6.23	1.22
Libraries	1.02	3.80	0.98
Green belts	0.06	0.77	0.81
Junior high schools	0.19	0.60	0.77
Elementary schools	0.25	0.49	0.75
Retirement centers	0.82	8.97	0.63
Community centers	0.66	3.79	0.55
Traditional Chinese markets	−0.97	3.14	0.15
Cemeteries	−0.35	0.89	−0.64
Dump Site	−0.39	1.59	−1.09

[a] P_k is public facility preference of residents (Kuder–Richardson estimates of reliability = 0.863).

Table 3 Descriptive statistical characteristics of IEI (aggregated level)

Descriptive statistics items	Value
Mean	8.84
Standard deviation	9.57
Minimum	−43.24
Maximum	86.84

is inequitable, in contrast to unassigned public facilities. Moreover, regarding spatial equity of public facilities, the densely populated areas attract more public facilities and services (municipal parks, junior high schools, elementary schools and green belts) which are concentrated at the north part (*Figures 1* and *2*), and the number of those facilities is higher than elsewhere (*Table 1*), while the standard deviation is lower (*Table 2*). In other words, the public facilities are not equitable because planners pay close attention to the needs of centralized locations and ignore the needs of disadvantaged minorities in Ren-De.

In order to consider the overall spatial equity of public facilities, we examine the aggregated level with Eq. (9). To understand the preference of residents for different types of public facilities (P_k) the first step involved a questionnaire with a five-point Likert scale that was distributed to Ren-De residents. A total sample of 260 with simple random sampling was obtained in the survey. For a measure to be useful, it must have reliability. Analyzing the consistency in individuals' responses to the items tested the reliability. Overall, highly consistent responses across the items are found, showing high reliability in *Table 2* (Kuder–Richardson estimates of reliability = 0.863). From the survey of the residents for preferences of various facilities in Ren-De, we find that most of the residents preferred open spaces with recreation equipment adjacent to their houses, such as neighborhood parks, community parks and municipal parks. Unsurprisingly, the dump site is the most unpopular choice by the residents. Moreover, with the increasing supermarkets and

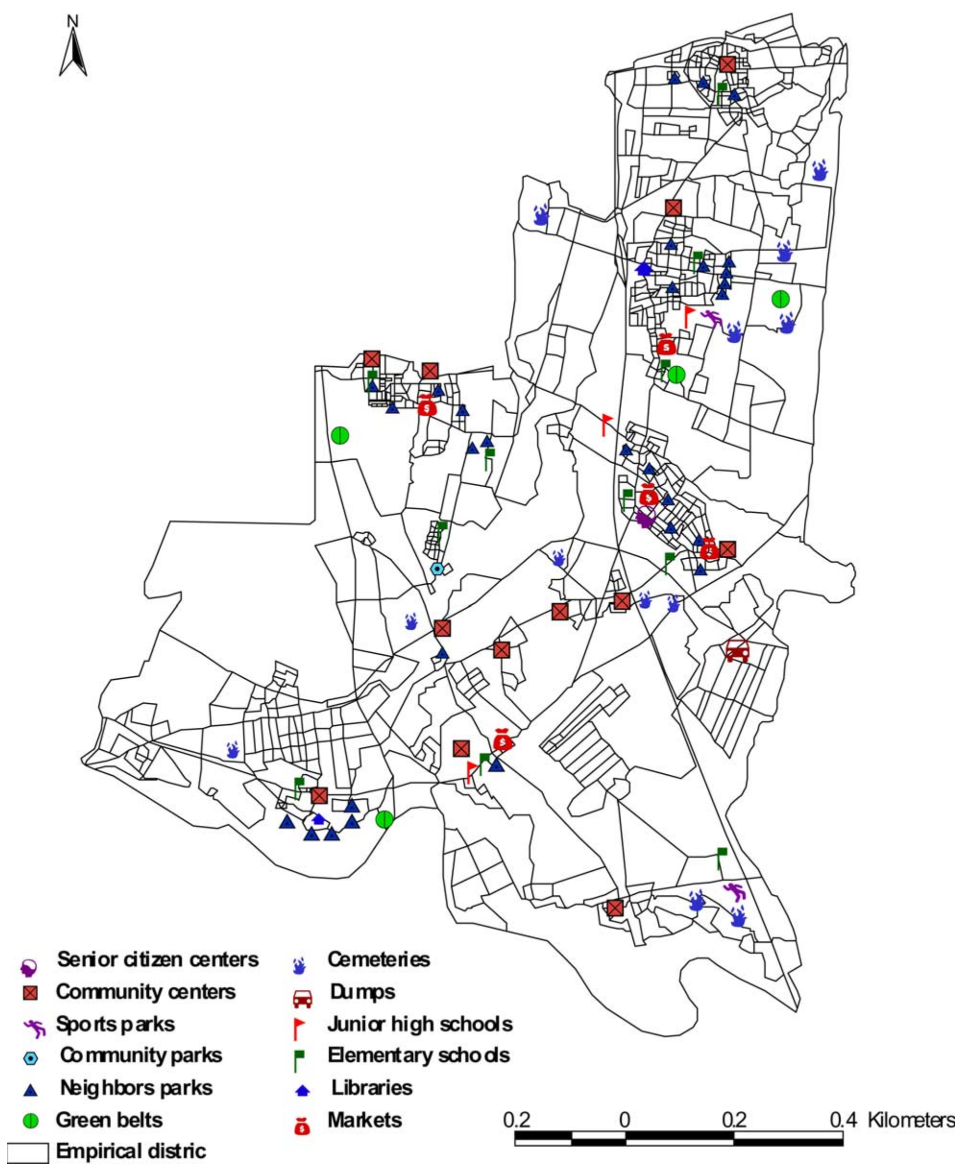

Figure 2 Distribution of urban public facilities in Ren-De.

changing consumer behavior, the residents judge traditional Chinese markets differently, so the P_k of traditional Chinese markets is not high.

Subsequently from *Table 4*, we see that the standard deviation of IEI (*Table 3*), that was computed by Eq. (9), is up to 9.57, which indicates that public facilities are unevenly distributed in Ren-De. The range of IEI values reveal the great inequity as well. Furthermore, descriptive statistics results of IEI displayed by 3D-GIS (*Figure 3*), were generated to present and simplify further analysis of the variations of spatial equity of each block, giving us a spatial cognitive map, from which it can be seen that most of the site-preferred urban public facilities are located in the northern main clusters and site-noxious urban public facilities are located in the southwestern and southeastern areas, where there is low population. There are four high peaks and a valley of spatial equity measurement in the case study. A valley reveals public reaction to these public facilities (site-noxious facilities) is negative. The highest peak is located in the northern and middle areas, where there are more public facilities than for any other area. Use of this 3D map provides an immediate and easily interpreted overall view of Ren-De's spatial equity. According to *Figure 3*, the whole public facility system is inequitable, particularly for the southern area. Again, this is because site-preferred urban public facilities are located around the areas of high population with the northern and middle locations having better access. On the contrary, site-noxious urban public facilities are located far from these areas. Perhaps this is what may be called efficiency, but it is definitely not equitable. The residents who live in the southern area pay more time/money to approach public facilities, according to our results.

Table 4 **Moran's *I* of public facilities**

Facility	Moran's *I*
Municipal parks	−0.0132
Community parks	−0.0151
Neighborhood parks	−0.0017
Libraries	−0.0137
Green belts	−0.0017
Junior high schools	−0.0065
Elementary schools	−0.115
Retirement centers	−0.0042
Community centers	−0.0027
Traditional Chinese markets	−0.0049
Cemeteries	−0.0030
Dump site	−0.0146
All public facilities	−0.1354

Note. $p < 0.001$.

Empirical results based on spatial autocorrelation techniques. To comprehend the significant statistical characteristics of spatial equity, IEI, SAA and LISA ("Spatial equity analysis based on spatial autocorrelation techniques") were applied. The outcomes of SAA support existing spatial inequity of each public facility, for all of values of Moran's I are negative (*Table 4*). The negative value means that the units of space tend to be more dissimilar than what is normally expected. The aggregated level value is smaller than the disaggregated level, implying that there is less spatial inequity from each individual public facility, but with respect to the entire public facility, there would be much more spatial inequity. In other words, a planner cannot only focus on the spatial equity of individual public facilities, but must also consider the entire public facility system. While all values of Moran's I approach zero, that is, the spatial structure of each public facility is not clear, each of them is scattered randomly and independently in space.

LISA provides an alternative perspective by focusing on patterns surrounding individual observations and some outliers. Regarding the aggregated level, the values of high–low or low–high occupy most of the area in Ren-De, implying there is spatial inequity in urban public facilities (*Figure 4*). Moreover, *Figure 5* shows the evidence that the spatial distribution of each public facility is

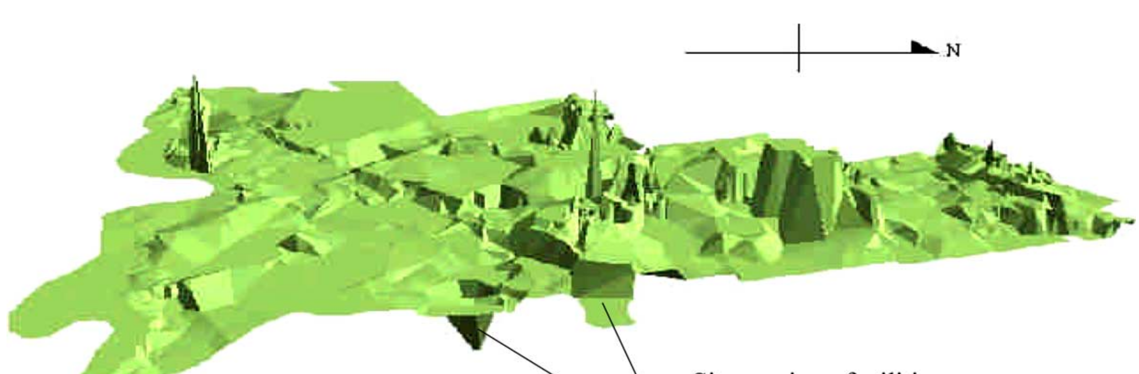

Figure 3 The 3D-GIS version simulation of IEI in aggregated level.

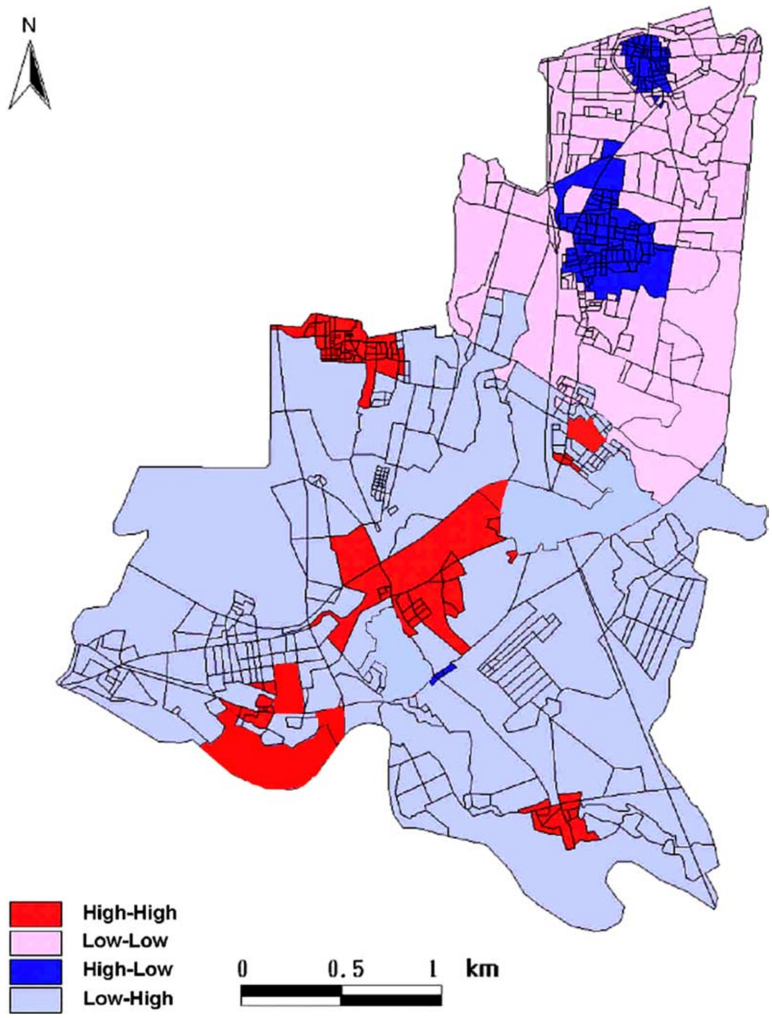

Figure 4 Local spatial autocorrelation patterns of public facilities (aggregated level).

inequitable, as shown in *Figure 3*. For instance, for community parks, the values of LISA in the northern and middle areas are low–high, which shows uneven spatial distribution. On the other hand, most of the public facilities are located in the northern and middle areas, a result consistent with that of ''Descriptive statistical results of IEI and 3D-GIS displays''.

Conclusions

Spatial equity of urban public facility planning has become a critical issue in many countries. The literature has so far witnessed a steady growth of studies using accessibility to services and facilities as the index of measure, although this is not always dealt with explicitly. Often, the measure of access used is one-dimensional, where the presence or absence of a given service or facility is measured by virtue of whether or not it is 'contained' within a given defined boundary. In fact, access to services is a multidimensional issue. Most of the studies have, nevertheless, targeted the spatial equity of a single type of public facilities. As urban public facility investigations involve various types of public facilities with complex characteristics, existing indices fail to meet this need. To solve the problem, this paper proposes IEI as a set of integrated indices to measure spatial equity.

In addition to a review of the concept and studies of spatial equity, three service features of urban public facilities, namely, spatial separation and service/impact range of public facilities, preference of residents for different type of public facilities, and the different sizes of public facilities of the same type have varying effects on the residents, are discussed.

As a working approximation in this paper, the service/impact range of facilities is set as a function of the size of the facility. Thus, the service range of a large park is greater than that of a small park, and likewise for differentially-sized power transformers. The effects of different sizes of public facilities of the same type are computed on the basis of comparative sizes or service ranges. Preference of residents

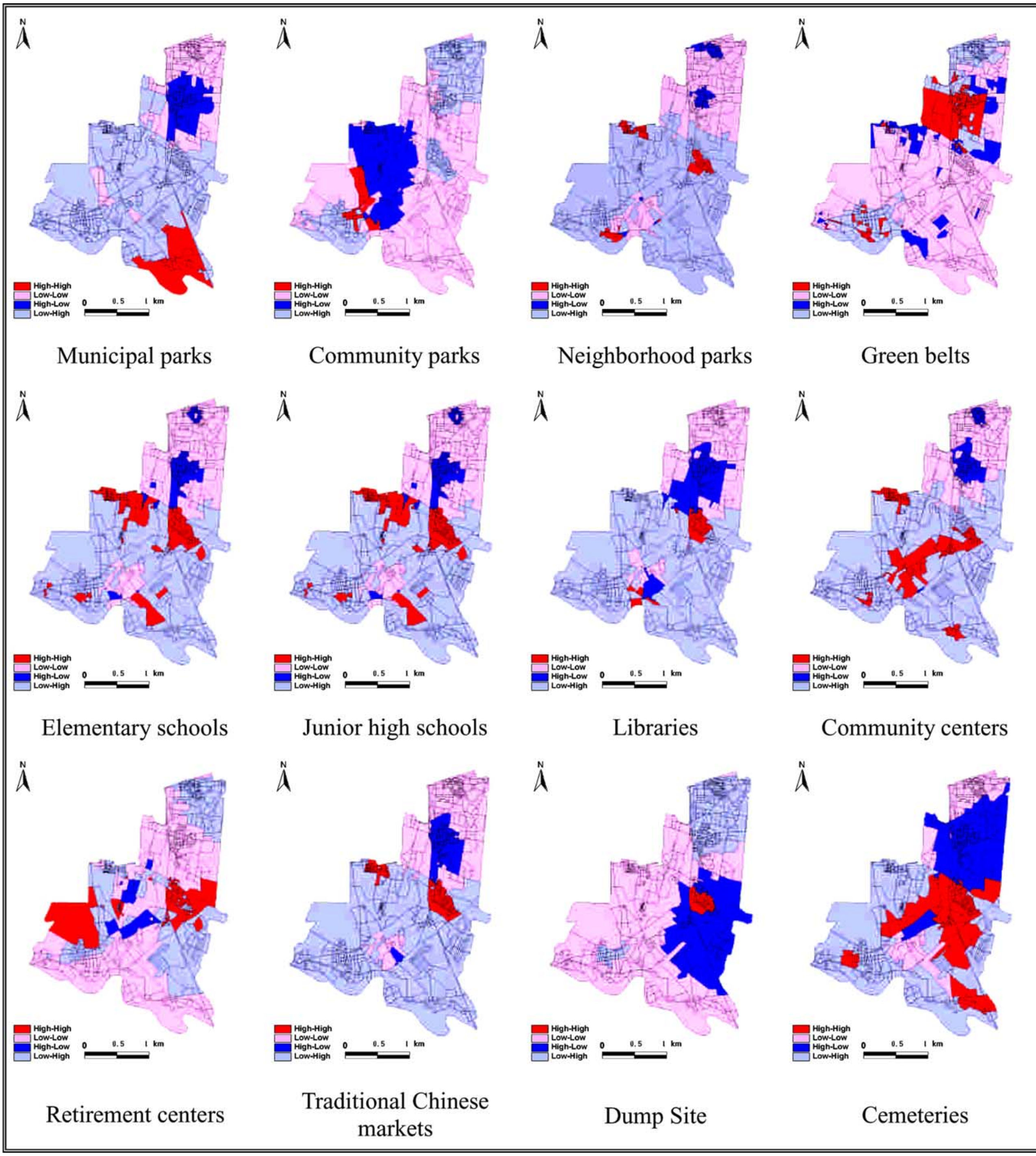

Figure 5 Local spatial autocorrelation patterns of public facility (disaggregated level).

for different type of public facilities is determined by the attitude scale survey. Finally, GIS techniques are applied to measure spatial separation in terms of actual street networks, or minimum distance.

IEI can measure the spatial equity of urban public facilities; it, like other current models, falls short of fully interpreting the real relationships among public facilities. However, unlike other current models, IEI, with the assistance of GIS and spatial analysis techniques, offers an easily and intuitively interpreted summary of the data. IEI includes two elements: (1) the spatial display based on 3D-GIS and (2) the spatial equity analysis based on spatial autocorrelation techniques.

Spatial inequity of the urban public services or facilities in Ren-De was used as an empirical example.

The empirical outcomes show that the method allows users to easily understand the characteristics of spatial equity in urban public facilities for both disaggregated and aggregated levels, and to find significant differences between urban public facilities. From IEI and the techniques mentioned above in the empirical study, we find that spatial equity of public facilities is more uneven for the aggregated level than for the disaggregated level. Consequently, we must also consider the spatial equity of the entire public facility system.

The usefulness of the integrated methodology in measuring and analyzing the spatial equity of the urban public facilities is, to some extent, verified. However, future studies should: (1) calibrate a for different categories of facilities in the research area to boost the accuracy of measurements, and (2) consider using gravity, traveling cost, traveling time, and/or other measures to compute S_{ij} if the facilities provide services through urban traffic networks. By doing so, the spatial equity of urban public facilities at different levels can be better discerned.

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