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Towards vertical spatial equity of urban facilities: An integration of spatial and aspatial accessibility

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ABSTRACT

To ensure adequate access to urban facilities, it is important for urban planners to achieve equity in the geographical arrangement of such facilities. For the evaluation of vertical spatial equity in the geographical organization of urban facilities, there is a requirement to examine whether and to what degree the variation in spatial accessibility to urban facilities corresponds to the variation in aspatial accessibility for such facilities. While no studies so far measure vertical spatial equity in accordance with 'need' and 'demand' based approaches of equity with a focus on both spatial and aspatial accessibility. Therefore, this paper attempts to measure an integrated spatial accessibility index for the evaluation of geographic variation in spatial accessibility to urban facilities, and then, seeks to integrate spatial accessibility and aspatial accessibility in one framework to evaluate vertical spatial equity in the geographical arrangement of urban facilities. This paper measures integrated spatial accessibility index for urban facilities following the concept of 2SFCA method incorporating supply and demand for urban facilities, the travel distance or time that users are willing to cover to reach such facilities, and the interaction of residents across geographic boundaries. Aspatial accessibility to urban facilities is defined through demographic-demand index and social-need index for those facilities. Spearmen correlation coefficient, spatial analysis models (local spatial autocorrelation in this case), and overlay are used to assess the association between spatial accessibility and aspatial accessibility to urban facilities. The results indicate there exists a variation (inequality) in spatial accessibility to urban facilities in the case study area (DCC). Urban facilities are inequitably distributed within DCC, as high-social-need areas and high-demographic-demand areas have low spatial accessibility to such facilities. These areas should be prioritized in distributing urban facilities in the future, and thus, it can help urban planners to achieve an equitable distribution of urban facilities.

1. Introduction

Adequate access to public service facilities can be regarded as a paramount important indicator for the improvement of quality of life which is one of the cornerstones of equity policies (Altschuler, Somkin, & Adler, 2004; Jacobs, 1961; Lloyd & Auld, 2002). It helps to achieve the satisfaction of the basic needs of urban residents, as it has a profound influence on the participation of urban residents in particular physical activities (Forrest & Kearns, 2001; Littig & Griessler, 2005; Dempsey, Bramley, Power, & Brown, 2009). As a result, poor spatial accessibility to urban facilities can exacerbate the quality of life of residents for the affected neighborhoods (Lee & Miller, 2018). Therefore, to attain a sustainable distribution system of urban facilities, to ensure adequate and easy access of urban residents to such facilities, and to improve the quality of life of affected residents, it is important for urban planners to examine the

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level of spatial equity in the distribution of urban facilities. The spatial equity concept in the context of geographic provision of urban facilities helps urban planners to appraise the consequences of current urban facilities allocation strategies, and to examine 'the inter as well as intra effects of overall urban facilities on urban residents (Dadashpoor, Rostami, & Alizadeh, 2016; Liao, Sheng & Tsou, 2009; Rahman & Neema, 2015; Smoyer-Tomic, Hewko, & Hodgson, 2004; Talen & Anselin, 1998; Tsou, Hung, & Chang, 2005).

For quantitative evaluation of spatial equity, accessibility has been the widely used measure in literature (Liao, Chang, & Tsou, 2009; Rahman & Neema, 2015; Talen & Anselin, 1998; Tsou et al., 2005). However, the majority of the accessibility based studies only consider spatial accessibility in assessing spatial equity, and, thus, measure horizontal spatial equity as these studies examined the equality rather than equity of access to urban areas. These studies assume that the distribution of urban facilities will be equitable only when all urban residents, regardless of their location or socioeconomic condition, can enjoy an equal ease and convenience to arrive at a service within a particular travel distance or travel time (Liao, Sheng & Tsou, 2009; Nicholls & Shafer, 2001; Rahman & Neema, 2015; Talen & Anselin, 1998; Tsou et al., 2005). Facilities are distributed discretely over space while the user populations are located continuously. Therefore, it is obvious and logical that there will be some inequality in the level of spatial accessibility across space (Dear, 1974). Furthermore, there may be inequality in the distribution of urban facilities over space due to the allocation priority to facilitate socially disadvantaged or highly needed areas resulting in inequality but equity in access to such facilities. In this regard, Rawls (1971) suggests that inequalities should be distributed in a way so that it can facilitate the most disadvantaged. As without consideration of aspatial accessibility, it is quite impossible to uncover the need of urban residents and socially disadvantaged residents, these studies can not assess vertical spatial equity in terms of residents' needs, constraints, and demands. Therefore, these studies also can not provide any information about whether and to what degree better spatial accessibility to urban facilities corresponds with the need of socially disadvantaged populations or the demand of urban residents.

However, though few studies assess vertical spatial equity, these studies have several limitations. Most of the studies assess spatial equity considering a particular facility (Boone, Buckley, Grove, & Sister, 2009; Chang & Liao, 2011; Kelobonye et al., 2019; Smoyer-Tomic et al., 2004; Yuan, Xu, & Wang, 2017). While researchers argue that in the context of spatial equity, the shortage of a particular urban facility can be compensated with the abundance of another urban facility implying that spatial accessibility measurement technique should include all types of urban facilities in a single framework (Dadashpoor et al., 2016; Rahman & Neema, 2015; Tsou et al., 2005). Besides, these studies take accounts only a particular indicator to characterize aspatial accessibility in terms of local demand or social disadvantage (Boone et al., 2009; Kelobonye et al., 2019; Smoyer-Tomic et al., 2004; Yuan et al., 2017). As a single indicator depicts only a partial picture of aspatial accessibility (Pratschke & Haase, 2007), these studies can not uncover the comprehensive scenario of aspatial accessibility.

To fill the gap for the assessment of spatial equity of urban facilities, this paper attempts to assess vertical spatial equity considering different types of urban facilities and, most importantly, integrating spatial and aspatial accessibility. In other words, this paper seeks to consider the demands of local residents, and the needs of socially disadvantaged residents (that is, 'need' and 'demand' based approaches of equity) for the assessment of whether and to what degree urban facilities' geographical distribution is equitable.

2. Study context

2.1. Accessibility

Accessibility has been a widely used concept in transportation study to examine transportation and land-use interactions, to assess the impact of transportation plans, and to understand transport as well as urban facility equity. Hansen (1959) defined accessibility as "the opportunity which an individual or type of person at a given location possesses to take part in a particular activity or set of activities". Basically, accessibility can be defined as a measurement of the relative nearness or proximity between origin and destination.

Accessibility has two dichotomous dimensions: spatial accessibility and non-spatial or aspatial accessibility (Penchansky & Thomas, 1981; Saurman, 2015; Wang & Luo, 2005). Spatial accessibility to urban facilities is associated with the geographic distributions of facilities, the number of users, and spatial separation between the location of facilities and users (Wang and Luo, 2003, 2005). Aspatial accessibility depends on the socioeconomic and demographic characteristics and constraints such as income, disability, sex, illiteracy, etc. of the user population. (Joseph & Phillips, 1984; Lindsey Maraj, & Kuan, 2001; Mitchell, 1996; Wachs & Kumagai, 1972).

According to the theory of access, established by Penchansky and Thomas (1981), access is the 'degree of fit' between an origin and a destination which is directed by 'availability', 'accommodation', 'accessibility', 'affordability', and 'acceptability'. While Saurman (2015) modifies the dimensions of access developed by Penchansky and Thomas, and adds 'awareness' as a new dimension of access. 'Availability', 'accessibility', and 'accommodation' of a facility can define spatial accessibility while 'affordability', 'awareness', and 'acceptability' of a facility are related with non-spatial or aspatial accessibility (McLaughlin & Wyszewianski, 2002; Penchansky & Thomas, 1981).

Spatial accessibility can be defined as physical accessibility by which an individual can reach to the desired destination conveniently, or the ease of residents to reach a destination from an origin (Kwan & Weber, 2003; Pirie, 1980). While Handy and Niemeier (1997), Penchansky and Thomas (1981) emphasize the ease to reach a destination with its type of opportunities served, quantity, and quality. On the other hand, aspatial accessibility refers to the socio-economic and cultural accessibility one possesses to the desired destination. It can be defined through the socio-economic, demographic and cultural constraints and characteristics of the user population that obstruct or facilitate access to a facility (McLaughlin & Wyszewianski, 2002; Penchansky & Thomas, 1981; Wang & Luo, 2005; Polzin, Borges, & Coelho, 2014). For example, in most of the cases, the disabled population have lower access to the urban facilities compared to the abled. Again, people living below the poverty line could not afford of urban facilities resulting in low access to such facilities.

In literature, there are three common measures of spatial accessibility (Deboosere & El-Geneidy, 2018). Utility-based accessibility measure defines accessibility at individual level based on random utility theory. It measures economic benefits including individual traveler preferences and socio-economic and cultural constraints that people obtain from reaching a particular destination (Dong, Ben-Akiva, Bowman, & Walker, 2006; Handy & Niemeier, 1997; Koenig, 1980). Despite having several advantages, its intricacy in measurement, data intensity, and complexities in comparing utility functions between individuals create impediments for the rigorous implementation of it (Ben-Akiva & Lerman, 1977).

The second set of frequently used measures of spatial accessibility is cumulative opportunity measure which determines how many potential opportunities or destinations can be reached from a particular origin within a threshold travel time or distance (Ingram, 1971; Morris, Dumble, & Wigan, 1979; Vickerman, 1974; Wickstrom, 1971). On the other hand, gravity-based accessibility measures discount these opportunities with increasing spatial separation or travel impedance; the further away a destination from an origin the less will be accessibility to the destination (Dalvi & Martin, 1978; Geertman & Ritsema, 1995; Handy & Niemeier, 1997; Hansen, 1959; Koenig, 1980). The main advantage of gravity approach is that it overcomes the limitations of the cumulative opportunity approach by assigning a dampening effect that devalues opportunities far away from the origin (Bhat et al., 2002). In contrast, this approach has two drawbacks. First, it only includes supply to estimate spatial accessibility while researchers argue for measuring adequate accessibility, it is paramount important to achieve congruity between the spatial distribution of supply and demand (Langford & Higgs, 2006; 2010; Lee & Hong, 2013; Rekha et al., 2017). To address this problem, Joseph and Bantock propose a population demand adjustment factor as a denominator to the established gravity equation. Second, there is an ambiguity regarding the factor of impedance (Bhat et al., 2002). Many researchers have explored the appropriate nature of the impedance factor of the gravity equation. Ingram (1971) claimed that the Gaussian form of impedance factor may be apt for gravity equation as it values nearby destinations with higher importance and then falls more quickly with increasing distance or time. However, all of these models assume that residents residing within a particular geographic area, only have access to urban facilities located on that geographic boundary. Through this assumption, these models are not considered the interaction of residents across geographic boundaries. Whereas, in reality, urban residents do not only travel to facilities within the geographic boundary but also nearby neighborhoods. Actually, in this case, willingness to travel to a facility depends on the travel distance or time (Kleinman & Makuc, 1983; Wing & Reynolds, 1988).

Radke and Mu (2000) proposed two-step floating catchment area method which is a special case of Joseph and Bantocks' improved gravity model. This method models the population demand factor by counting provider-to-population ratio within a certain catchment area. It assumes people enjoy the same level of ease to reach a destination within a certain catchment area (Luo & Wang, 2003, 2005). While enhanced two-step floating catchment area method discounts population demand for a destination, and values nearby destinations by assigning a travel impedance factor (Polzin et al., 2014; Rekha et al., 2017). Enhanced 2SFCA approach measures accessibility for a particular facility while Ashik, Mim, and Neema (2019) add a new step to this method to calculate integrated spatial accessibility index including different types of facilities in one comprehensive scheme.

2.2. *Spatial equity*

Equity means ‘a social or political consent about the 'fairness' or ‘justice’ of the distribution of costs and benefits of a policy or program’ (Dear, 1978). The concept of spatial equity in facility distribution can be classified into two broad categories: horizontal spatial equity and vertical spatial equity. Horizontal spatial equity means equal distribution of facilities among residents regardless of their location or socioeconomic condition (Bennett, 1983; Tsou et al., 2005). This approach is aimed to increase equality in terms of access of residents to facilities. While vertical spatial equity refers to an equitable distribution of facilities over space in relation to the need or demand of the user population (Litman, 2007; Wang & Yaung, 2013). The focus of this approach is to reduce inequities in the distribution of facilities by ensuring an unequal treatment with inequalities (Dadashpoora & Rostami, 2017).

However, Lucy (1981) defined five alternative conceptions of equity: as ‘equality’ (each resident consumes equal services); as ‘need’ (consumption level on the basis of need of residents); as ‘demand’ (residents having an active enjoyment to a facility should get more allocation); as ‘preferences' (services equal to the preferences of residents); as ‘willingness to pay’ (consumption level depends upon the willingness to pay). The need-based approach to equity suggests that most socially disadvantaged populations should receive more services to ensure these groups with auspicious circumstances that they might not enjoy otherwise (Nicholls, 2001). Therefore, the redistribution policy should be in a compensatory manner. According to the demand-based approach, there should be more services where there is a potential consumer as with the increase of potential users, competition among users for accessing the service is also augmented (Kelobonyea et al., 2019). The concept of ‘equality’ follows the principles of horizontal spatial equity while ‘need’ and ‘demand’ based approaches are consistent with the idea of vertical spatial equity.

Accessibility can be used as a measure for the evaluation of the level of equity in the geographical arrangement of urban facilities as accessibility to urban facilities can be estimated over space. The existing gap in the level of accessibility can be utilized as a measurement technique of inequity across space (Martens, Golub, & Robinson, 2012). For the evaluation of horizontal spatial equity of urban facilities, it is required that all urban residents should have equal spatial access to urban facilities (Liao, Sheng & Tsou, 2009; Nicholls & Shafer, 2001; Rahman & Neema, 2015; Talen & Anselin, 1998; Tsou et al., 2005). While for vertical spatial equity, there should be inequality in spatial access which should be arranged following the needs of the socially disadvantaged population and the demand of the urban residents. To implement ‘need’ and ‘demand’ based approaches, it is prerequisite to identify need and demand. Low-income, poverty, and minority, etc., aggregately termed as socially disadvantaged, can be identified as need (Lucy, 1981), and demand can be measured by identifying actual users of a facility (Kelobonye et al., 2019). As aspatial accessibility measure deals with the socio-economic, demographic and cultural constraints characteristics of user population (‘acceptability’, ‘affordability’, and ‘awareness’ of a facility), through this measure ‘need’ and ‘demand’ based approaches of equity can be assessed.

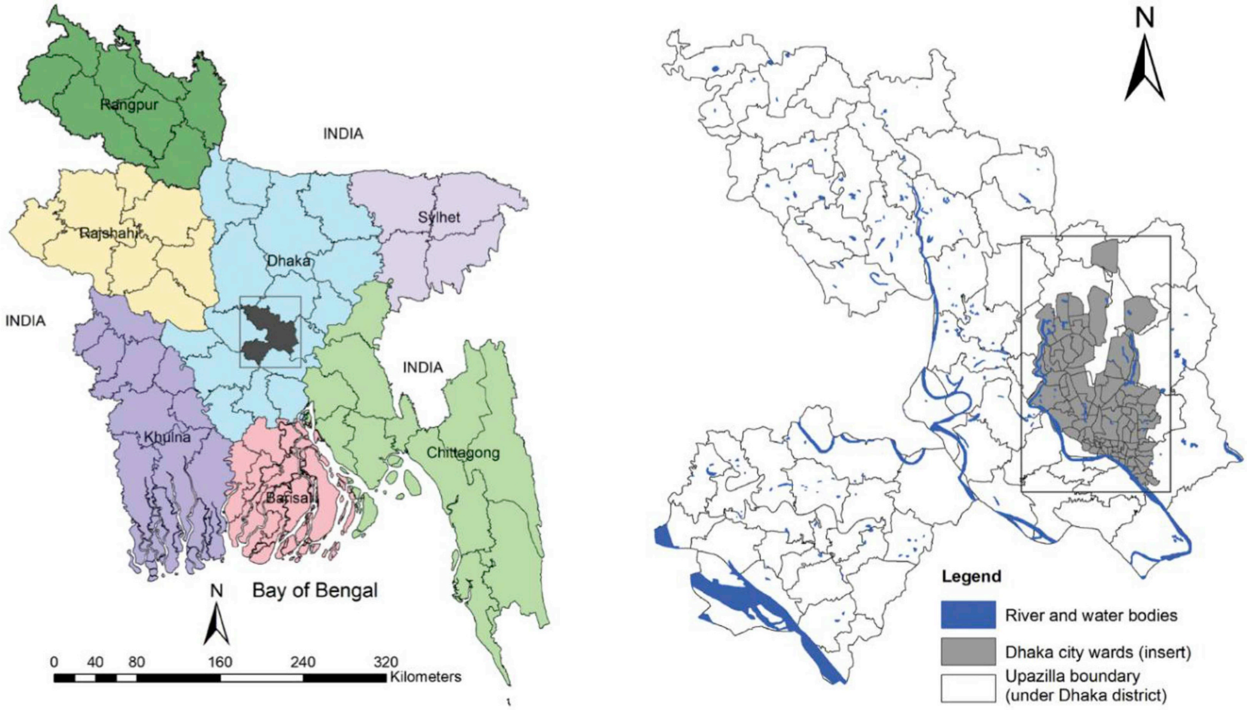


Fig. 1. Geographic location of DCC. (Source: Author, 2018).

3. Case study

Data availability is a major concern to select a study area as there is a considerable lack of data management in most of the cities of Bangladesh. However, during the last four decades, Bangladesh has observed rapid growth in its urban population while 33.8% of the national urban population live in Dhaka Mega City in 2011. Dhaka City Corporation (DCC) is accounted for 49.3% of the total urban population of Dhaka (BBS, 2011). In DCC area, the high rate of urbanization increases the demand for facilities while there are severe shortages in the provision of facilities (Jahan & Oda, 1999). The distributive inequity and increasing demand for urban facilities are aggravating access of urban populations to such facilities. Therefore, a decision has been taken to select DCC as the study area (see Fig. 1). DCC consists of 92 wards (the smallest administrative unit). The total population of this area is about 7.03 million, and the density of population is about 64,922 per sq.km. Above 10 percent of the total population live below the poverty line in this area.

4. Data and methods

4.1. Data

Three types of data are used to conduct this study: the spatial distribution of the population with demographic and socioeconomic attributes, the spatial distribution of selected urban facilities with the corresponding size as an attribute, and the spatial layout of the transportation system. Considering data availability, primary schools, secondary schools, and colleges as educational facilities, parks, and playgrounds as recreational facilities, and hospitals as health care facilities are taken into consideration.

Point data of the location of primary and high schools, colleges, parks, playgrounds, and hospitals were collected from RAJUK (Development authority). The area of urban facilities was extracted from the structure polygon shapefile of RAJUK to calculate the service capacity of such facilities. Demographic and socioeconomic data were collected from the Population and Housing Census: Community Report Dhaka 2011 and 2001, and Bangladesh Poverty Maps 2005 and 2010 projected for 2018 by following the equation:

$$P_n = P(1+r)^n, \tag{1}$$

Where, P_n = population at the end of n years; P = Present population; n = Number of years; r = Population growth rate.

4.2. Method

4.2.1. Integrated spatial accessibility index

This study measures integrated spatial accessibility considering: 1) integrate several numbers of urban facilities; 2) supply of facilities; 3) demand for facilities; 4) the travel distance or time that users are willing to cover to reach such facilities; 5) the interaction of residents across geographic boundaries. To acknowledge such considerations, this study measures the index according to the proposed method by Ashik et al., 2019.

Step 1. Determine supply to demand ratio: For each k type of facility at location j, at first, identify the catchment area of facility k according to a threshold travel distance (d_o) or travel time from the center point of location (j). Explore all population locations or demand points (l) within that catchment area, and determine travel distance between facility location (j) and population locations (l). Calculate travel impedance using the determined travel distance and threshold travel distance in the Gaussian function. Finally, determine the supply-to-demand or facility-to-population ratio, R_j^k for k type facility within that catchment area.

$$R_j^k = \frac{S_j}{\sum_{l\in\{d_{lj}\le d_o\}} P_l G(d_{lj}, d_o)} \tag{2}$$

Here, P_l is the population of location l within the threshold travel distance of j ($d_{lj} \le d_O$), S_j is the service capacity of facility k at location j. G (d_{lj}, d_o) is the Gaussian or travel impedance function, depending on distance d between facility and population representing the distance decay of access to the k type facility at location j.

$$G(d_{lj},\, d_o) = e^{-\frac{1}{2}\left(\frac{d_{lj}}{d_o}\right)^2} \tag{3}$$

Here, d_{lj} is the travel distance of k type facility at location j from the centroid of population point l, and d_o is the threshold travel distance.

Step 2. Determine spatial accessibility: For each population location i, draw catchment area according to the threshold travel distance (d_o) or travel time, and identify all k type facility locations (j) within the catchment area, and summarize the supply-to-demand ratios R_j^k, at population location i:

$$A_i^K = \sum_{j\in\{d_{ij}\le d_o\}} R_j^k G(d_{ij}, d_o) \tag{4}$$

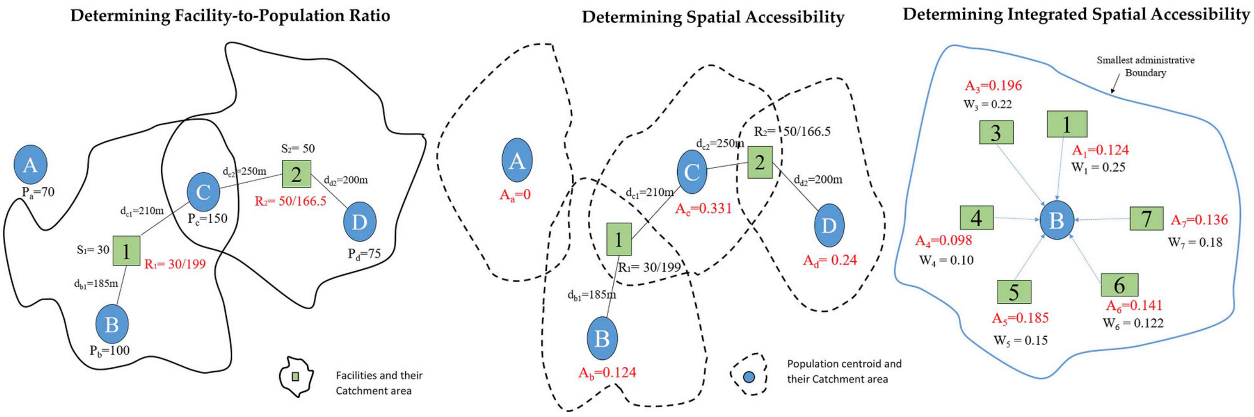
Here, A_i^K represents the spatial accessibility to k type facility at resident location i. d_{ij} is the travel distance between population centroid, i and location of k type of facility, j.

Step 3. Calculate integrated spatial accessibility: After calculating spatial accessibility for each type of facilities, calculate integrated spatial accessibility, A_i through the weighted summation of A_i^K at population location i to all types of facilities (n).

$$A_i = \sum_k^n W_k A_i^k \tag{5}$$

Here, $A_i$represents the integrated spatial accessibility at resident location i. The higher value of A_i indicates better spatial accessibility to urban facilities at resident location i. W_k is the score of preferences for k type of facilities.

This method can be applied to measure spatial accessibility considering different types of urban facilities and smaller geographic units. Using smaller geographic units, it can reveal additional details of spatial variation. The index is not limited within the administrative or geographic boundaries; instead, it includes residents living outside such boundaries. This method uses Gaussian function to measure spatial separation which provides a dampening effect for which access has been reduced with distance from the starting point. The flatness and higher values of Gaussian function near the origin imply that nearby activities are more accessible than those farther away. An illustrative example is shown in Fig. 2 to understand the calculation procedure of the integrated spatial accessibility index.



(caption on next page)

Fig. 2. Development of integrated spatial accessibility index (Source: Author, 2018).

Step 1 Determining facility-to-population ratio at facility location:

Suppose, threshold travel distance for both facility 1 and 2 is 300m and size of the facilities are S_1=30 and S_2= 50

Gaussian function, $G= e^{\left(-\frac{1}{2}\right)*\left(\frac{distance\ from\ facility\ to\ population\ location}{catchment\ area}\right)^2}$ $G_{b1}=e^{\left(-\frac{1}{2}\right)*\left(\frac{185}{300}\right)^2} = 0.82$;

$G_{c1}=e^{\left(-\frac{1}{2}\right)*\left(\frac{210}{300}\right)^2} = 0.78$;

$G_{c2}=e^{\left(-\frac{1}{2}\right)*\left(\frac{250}{300}\right)^2} = 0.71$; $G_{d2}=e^{\left(-\frac{1}{2}\right)*\left(\frac{200}{300}\right)^2} = 0.80$;

Facility-to-population ratio,

$R_1=\frac{30}{(100*0.82)+(150*0.78)}=\frac{30}{199}$; $R_2=\frac{50}{(150*0.71)+(75*0.80)}=\frac{50}{166.5}$

Step 2 Determining spatial accessibility at population centroid:

Same catchment area is taken for the population centroid.

Within the catchment multiply facility-to-population ratios with their corresponding travel impedance and sum the resulted products.

Here, Accessibility

For population centroid a, A_a= 0, as there is no facilities within catchment;

For population centroid b, $A_b= R_1* G_{b1} = \frac{30}{199}* 0.82 = 0.124$

For population centroid c, $A_c= R_1* G_{c1}+ R_2* G_{c2} = \frac{30}{199}* 0.78 + \frac{50}{166.5}*0.71$

$= 0.331$

For population centroid d, $A_d = R_2* G_{d2} = \frac{50}{166.5}*0.80 = 0.24$

Step 3: Determining integrated spatial accessibility at smallest administrative unit

Now consider all types of facilities within the boundary of smallest administrative unit.

Multiply spatial accessibility value of each type of facilities with their corresponding weightage.

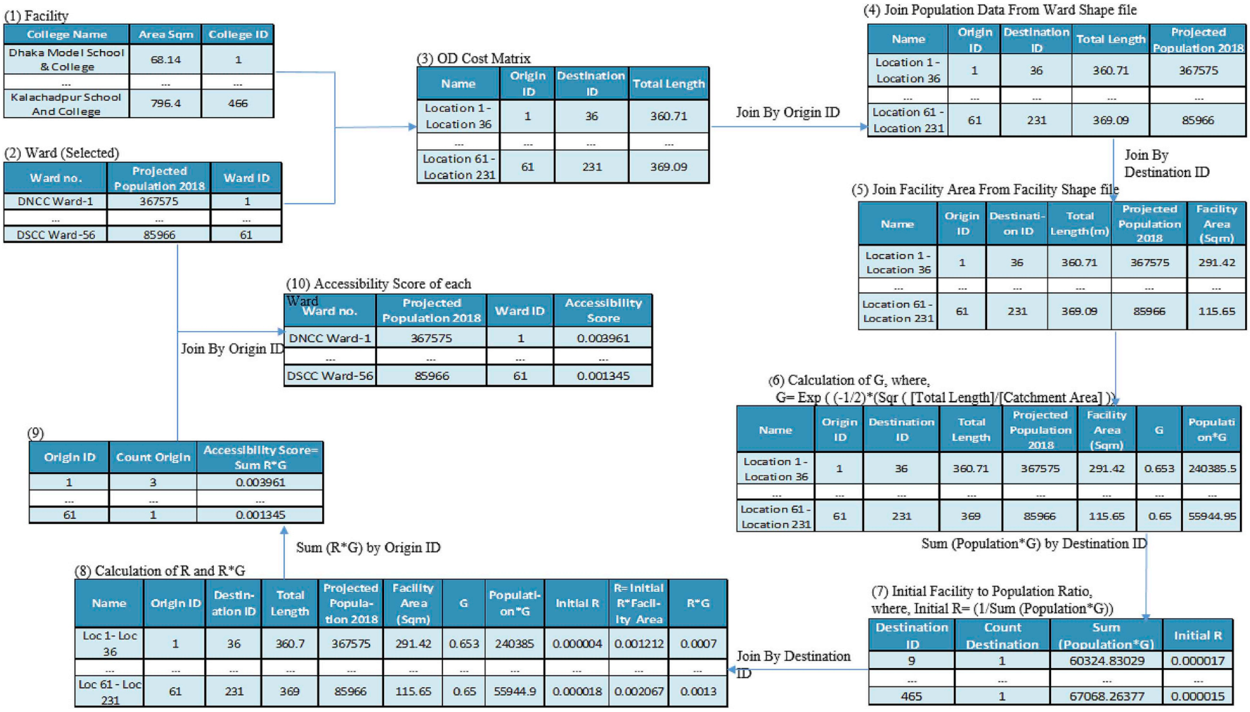
Integrated spatial accessibility for residents at B,

$A_b= \sum(Accessibility\ of\ particular\ facility * weightage)$

$= (0.124*0.25 + 0.136*0.18 + 0.141*0.122 +0.185*0.15 + 0.098*0.10 + 0.196*0.22)$

$= 0.153$

The methodology followed for calculating the index in a GIS environment is illustrated in Fig. 3. For the measurement of integrated spatial accessibility index in a GIS environment, at first, the threshold travel distance of each facility has been determined based on existing standards shown in Table 1. The ward (lowest administrative unit of Dhaka) centroids represent the population point or demand point (Table 4 of Fig. 3). Then network dataset has been created from the road network of DCC. Here the only cost for the network dataset is the travel distance which was determined by the length attribute of the shapefile. For the performance of OD Cost Matrix analysis, the selected ward centroid point shapefile and the facility point or supply point shapefile have been used as the origins and destinations respectively. Analytical Hierarchical Process (AHP) is followed to determine preference (that is weight) of different types of urban facilities in this study. Weights found from the AHP method are shown in Table 2.



(1) Facility

College Name	Area Sqm	College ID
Dhaka Model School & College	68.14	1
...	...	...
Kalachadpur School And College	796.4	466

(2) Ward (Selected)

Ward no.	Projected Population 2018	Ward ID
DNCC Ward-1	367575	1
...	...	...
DSCC Ward-56	85966	61

(3) OD Cost Matrix

Name	Origin ID	Destination ID	Total Length
Location 1 - Location 36	1	36	360.71
...	...	...	...
Location 61 - Location 231	61	231	369.09

(4) Join Population Data From Ward Shape file

Name	Origin ID	Destination ID	Total Length	Projected Population 2018
Location 1 - Location 36	1	36	360.71	367575
...	...	...	...	...
Location 61 - Location 231	61	231	369.09	85966

(5) Join Facility Area From Facility Shape file

Name	Origin ID	Destination ID	Total Length(m)	Projected Population 2018	Facility Area (Sqm)
Location 1 - Location 36	1	36	360.71	367575	291.42
...	...	...	...	...	...
Location 61 - Location 231	61	231	369.09	85966	115.65

(6) Calculation of G, where,
G= Exp ((-1/2)*(Sqr ([Total Length]/[Catchment Area]))

Name	Origin ID	Destination ID	Total Length	Projected Population 2018	Facility Area (Sqm)	G	Population*G
Location 1 - Location 36	1	36	360.71	367575	291.42	0.653	240385.5
...	...	...	...	...	...	...	...
Location 61 - Location 231	61	231	369	85966	115.65	0.65	55944.95

(7) Initial Facility to Population Ratio,
where, Initial R= (1/Sum (Population*G))

Destination ID	Count Destination	Sum (Population*G)	Initial R
9	1	60324.83029	0.000017
...	...	...	...
465	1	67068.26377	0.000015

(8) Calculation of R and R*G

Name	Origin ID	Destination ID	Total Length	Projected Population 2018	Facility Area (Sqm)	G	Population*G	Initial R	R= Initial R*Facility Area	R*G
Loc 1- Loc 36	1	36	360.7	367575	291.42	0.653	240385	0.000004	0.001212	0.0007
...	...	...	...	...	...	...	...	...	...	...
Loc 61 - Loc 231	61	231	369	85966	115.65	0.65	55944.9	0.000018	0.002067	0.0013

(9)

Origin ID	Count Origin	Accessibility Score= Sum R*G
1	3	0.003961
...	...	...
61	1	0.001345

(10) Accessibility Score of each Ward

Ward no.	Projected Population 2018	Ward ID	Accessibility Score
DNCC Ward-1	367575	1	0.003961
...	...	...	...
DSCC Ward-56	85966	61	0.001345

Fig. 3. Work flow for calculating supply-to-demand ratio and spatial accessibility (Step 1 and 2) (Source: Author, 2018).

4.2.2. Assessment of spatial equity integrating spatial and aspatial accessibility

This study seeks to define aspatial accessibility through social-need index which measures social disadvantage (that would help to assess need-based equity) and demographic-demand index which measures local demand for facilities (that would help to assess demand-based equity) at ward level. The study selected age of user population as a variable for calculating demographic-demand index (Table-3). For example, hospitals are badly needed for seniors and children while playground is only needed for children.

To calculate social-need index, several socioeconomic indicators are selected as variables that are as follows: Household living below the poverty line, Extreme poor households, Disabled population, Ethnic population, Female population, Households with non-sanitary and no toilet facility, Households living in Katcha and Jhupri type structure[1], Illiterate population rate.

To integrate different needed groups into one comprehensive index for measuring demographic-demand index for urban facilities and socioeconomic variables into one social-need index, this study used Z score method to standardize the data by following the equation.

$$Z = \frac{(x - \mu)}{\sigma} \tag{6}$$

Where, x = Value of a variable; μ = Mean of the variable; σ = Standard deviation of the variable.

Three exploratory methods are used to assess whether and to what degree the spatial access to a particular facility corresponds to the aspatial access (represented by social-need index and demographic-demand index) to that facility. Spearman rank correlation coefficients, Hot-spot analysis, and overlay are used to serve this purpose. Spearman rank correlation coefficients are calculated using social-need index, demographic-demand index, and spatial accessibility index as inputs to assess the degree of association between those indices. The second measure applied to identify the relation between spatial and aspatial accessibility is Hot spot analysis (that is, local spatial autocorrelation). Hot spot analysis indicates whether high values or low values (i.e. spatial accessibility) tend to cluster in a specified location. For the assessment of vertical spatial equity, this study examines how well statistically significant local patterns of spatial accessibility and aspatial accessibility geographically correspond to each other. For this, geographic coverage of statistically significant hot spots (local clusters of high values over space) and cold spots (local clusters of low values over space) are detected for Ward level social-need index values, demographic-demand index values, and spatial accessibility index values which are illustrated in Fig. 7, Fig. 10 and Fig. 8, respectively. Then Spatial overlay analysis (union) is conducted to identify the association between Cold spot and Hot spot of those indices, as shown in Figure-9 and Figure-11. Hot-Hot cluster represents high-social-need or high-demographic-demand cluster that corresponds with high-spatial-accessibility cluster. Hot-Cold cluster represents high-social-need or high-demographic-demand cluster that corresponds with low-spatial accessibility cluster. Cold-Hot cluster represents low-

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[1] Katcha and Jhupri type structure means low quality housing

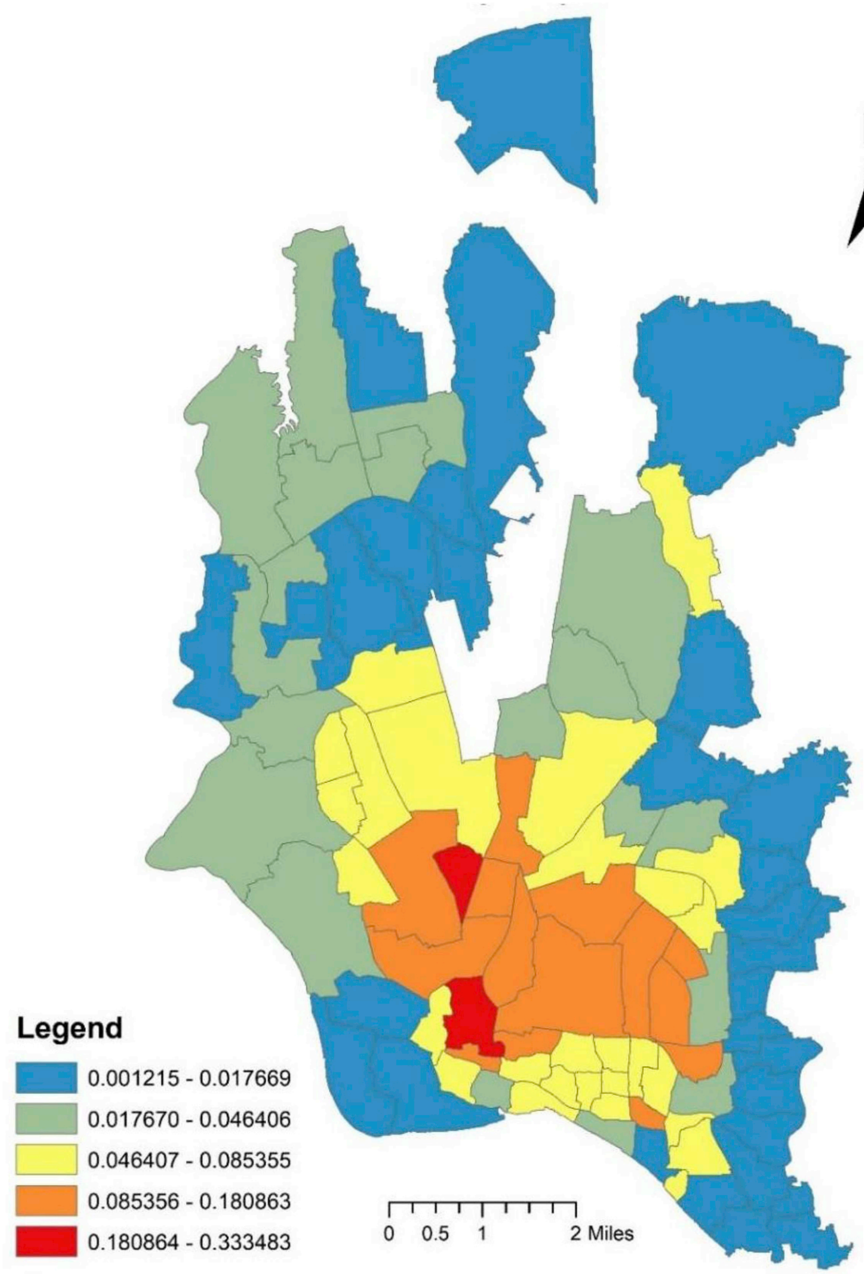

Fig. 4. Geographic variation of spatial accessibility index values (Source: Author, 2018).

social-need cluster or low-demographic-demand corresponds with high-spatial accessibility cluster. Percentages of areas within specified cluster types are shown in Table-5.

5. Results

Fig. 4 illustrates the geographic extents of spatial accessibility to urban facilities in DCC area. From the figure, it is quite evident that there exists an obvious spatial variation in spatial accessibility to urban facilities within DCC area. The central part of DCC area keeps higher spatial accessibility to urban facilities while the peripheral area is predominantly overspread by the wards having low spatial accessibility values. Areas surrounding the central area to the north and south possess moderate spatial accessibility to urban facilities.

Fig. 5 and Fig. 6 illustrate spatial extents of social-need index and demographic-demand index in DCC area. It is clear that northwestern, northern and north-eastern parts of the study area possess higher social and demographic need to urban facilities.

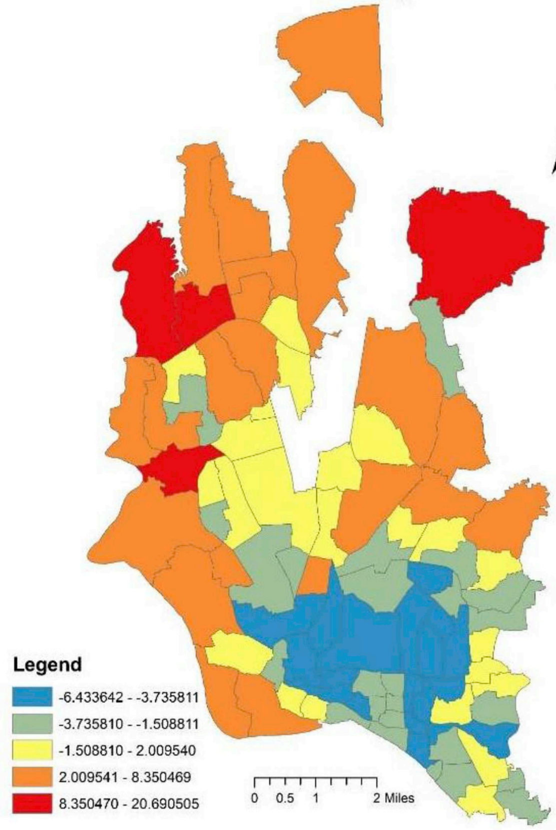

Fig. 5. Spatial distribution of social-need index values in DCC area (Source: Author, 2018).

While populations with low social-need and demographic-demand to urban facilities reside in the central, and southern part of the study area. So, it can be deduced that spatial extents of social-need index and demographic-demand index match to some extent.

To achieve an equitable distribution of urban facilities, the variation in spatial accessibility to urban facilities should correspond to the variation in social-need index and demographic-demand index. The correlation coefficient indicates (Table 4) that spatial accessibility to urban facilities is negatively associated with both indices. The negative relation represents that both higher-social-need populations (socially disadvantaged populations) and higher-demographic-demand populations reside in spatially disadvantageous accessible areas. From this criterion, the distribution of urban facilities in the study area could be considered as inequitable as the variation in social-need index and demographic-demand index is negatively reflected by the corresponding variation in spatial accessibility to those facilities. Spatial accessibility to urban facilities demonstrates a strong negative correlation with demographic-demand but a moderate negative association with social-need. That means the distribution of urban facilities is more inequitable according to demographic-demand perspective.

Geographic extents of statistically significant local patterns of social-need and demographic-demand indices values are illustrated in Fig. 7 and Fig. 10 respectively. Local clusters of higher-social-need index and higher-demographic-demand index values are located primarily in north-western, northern, and north-eastern parts of DCC area. While local clusters of these indices of low values are concentrated in central, south-eastern, and southern parts of DCC area.

Fig. 8 shows Geographic extents of significant local patterns of spatial accessibility index values. High-spatial-accessibility clusters are concentrated in the central, southern, and south-western parts of DCC area. Low-spatial-accessibility clusters are primarily located in the northern, and north-western parts of DCC area. From Fig. 7, Fig. 8, and Fig. 10, it can be deduced that high-spatial-accessibility clusters match neither to the high-social-need nor to the high-demographic-demand clusters.

From Fig. 9 and Fig. 11, it is clear that Hot-Cold cluster (for both cases, social-need and demographic need perspective) is located in the northern and north-western part of DCC. In these areas, both higher-social-need and higher-demographic-demand clusters are geographically matched with low-spatial-accessibility cluster. It implies these areas (nearly 25 percent of total areas of the study area) with both higher-social-need and higher-demographic-demand populations have disadvantageous spatial access to urban facilities.

From Fig. 9, it is evident from social-need perspective that Cold-Hot cluster is located in central and southern part of DCC, and a significant proportion of areas (nearly 20 percent of areas) is identified within this cluster where socially advantaged populations have advantageous spatial access to urban facilities. In other words, the location of socially advantaged populations spatially corresponds to the advantageous accessible areas. Likewise, Fig. 11 illustrates that Cold-Hot cluster (Demographic-demand perspective) is located in central, south-western and southern part of DCC, and there is a significant proportion of areas (above 20 percent of areas)

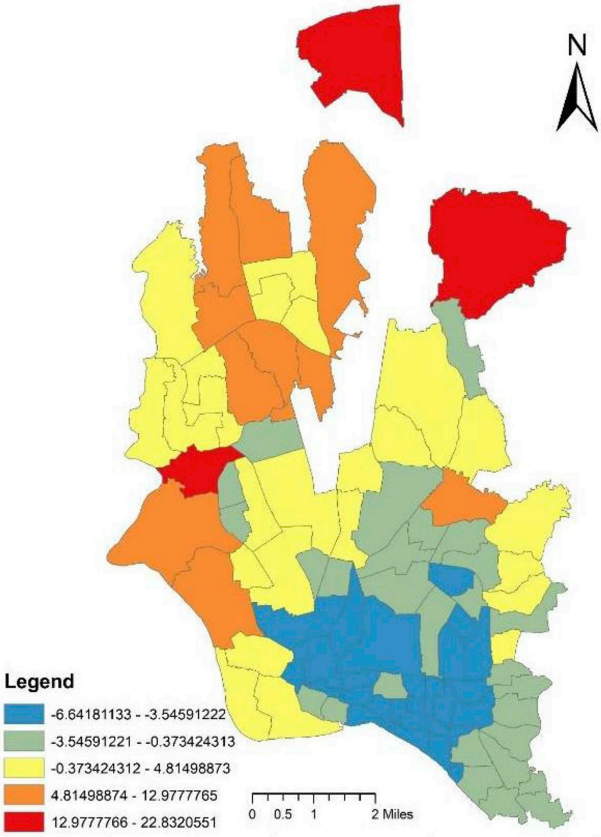

Fig. 6. Spatial extents of demographic-demand index values in DCC area (Source: Author, 2018).

Table 1
Threshold travel distance for the service facilities.
(Source: Detailed Area Plan (DAP), 2010; Dhaka Structure Plan, 2016-2035; Poormohammadi, 2008; Razavian, 2002)

Facilities	Primary School	Secondary School	College	Hospital	Playground	Park		
						Small Park	Medium Park	Large Park
Catchment Radius	300 m	360 m	360 m	1200 m	805 m	805 m	1609 m	3219 m

Table 2
Estimated weight for different urban facilities using AHP.
(Source: Author, 2018)

Facilities	Primary School	High School	College	Hospital	Playground	Park
Weight	0.25	0.22	0.18	0.122	0.15	0.10

Table 3
Needed group of the population for different types of urban facilities.
(Almudaris, 2011; Islam, Kawser, & Ahmed, 2002; Tabassum & Hossain, 2017; Tasnim, 2016; Wang & Luo, 2005)

Type of urban facility	Primary School	Secondary School	College	Playground	Park	Hospital
Higher needed age group	6–10	11–15	16–18	4–18	18–30	0-4 and above 65

Table 4
Correlation coefficient between spatial accessibility and aspatial accessibility.

Measures	Spatial accessibility index
Social-need index	-0.505 (P = 0.000)
Demographic-demand index	-0.600 (P = 0.000)

*P indicates correlation is significant at the 0.01 level (Source: Author, 2018).

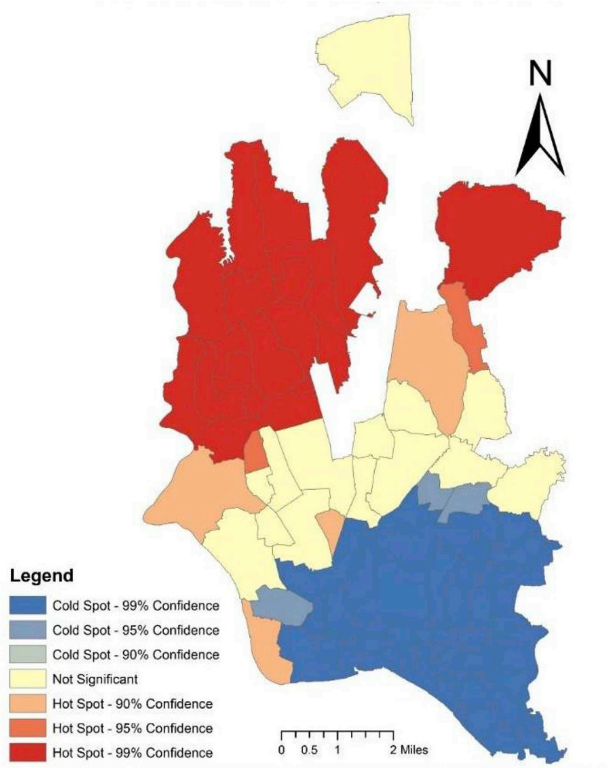

Fig. 7. Geographic extents of significant local patterns of social-need index values (Source: Author, 2018).

in this cluster. Lower-demographic-demand clusters are closely associated with high-spatial-accessibility clusters in these areas. It indicates lower-demographic-demand populations reside in these spatially advantageous accessible areas.

From vertical spatial equity ('need' and 'demand' approaches of equity) perspective, spatial access to urban facilities should be superior in socially disadvantageous areas and higher-demographic-demand areas. This expectation is separately fulfilled only by four localities in DCC area (Hot-Hot cluster) where socially disadvantaged populations or populations with higher demographic-demand reside in spatially advantageous accessible areas. While, from the above discussion, it is clear that the distribution of access to urban facilities in DCC area facilitates superiorly socially advantaged populations and lower demographic-demand populations rather than the socially disadvantaged populations and higher-demographic-demand populations. Therefore, from vertical equity perspective, it can be deduced that the geographical disposition of urban facilities is substantially inequitable in DCC area as it can not respond to the demand of urban populations and needs of socially disadvantaged population.

6. Discussion

In this study, the factors influencing the spatial accessibility measurement technique are the size of facility, the number of population, and travel distance via the road network. According to the index used in this study, the more populations with a constant size of facility within a particular threshold travel distance, the lower will be the population-to-facility ratio and, thus, leads to a lower spatial accessibility index. The higher number of populations and smaller size of facilities are predominant in peripheral areas which results in poorer spatial access to facilities in these areas. On the other hand, the central area retains better spatial access to facilities due to a relatively smaller number of populations and greater size of facilities. Besides, the central area has a well-connected road network compared to the urban fringe which also exacerbates spatial access of urban residents living on the periphery. Thus, the further away one resides from the central area, the more disadvantaged they are in terms of their spatial access to urban facilities.

In North American and Canadian cities, high-social-need populations usually reside in close proximity to the central area and low-

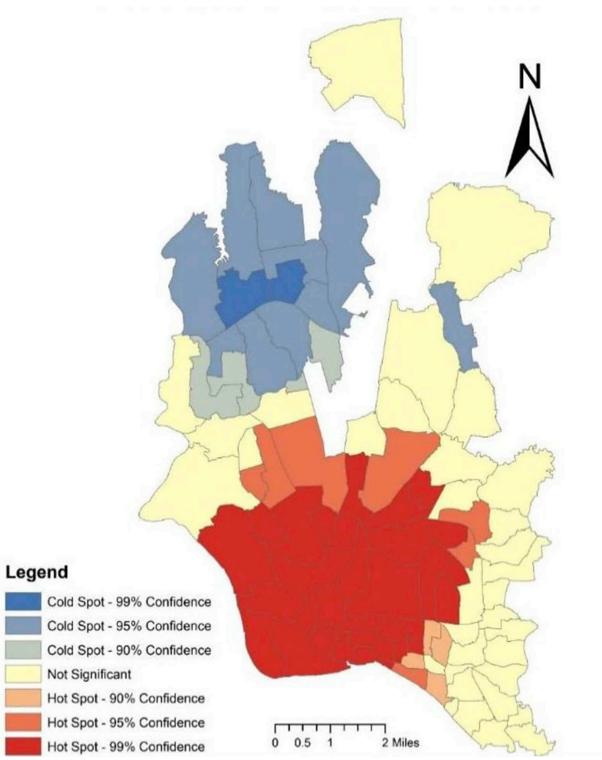

Fig. 8. Geographic extents of significant local patterns of spatial accessibility index values (Source: Author, 2018).

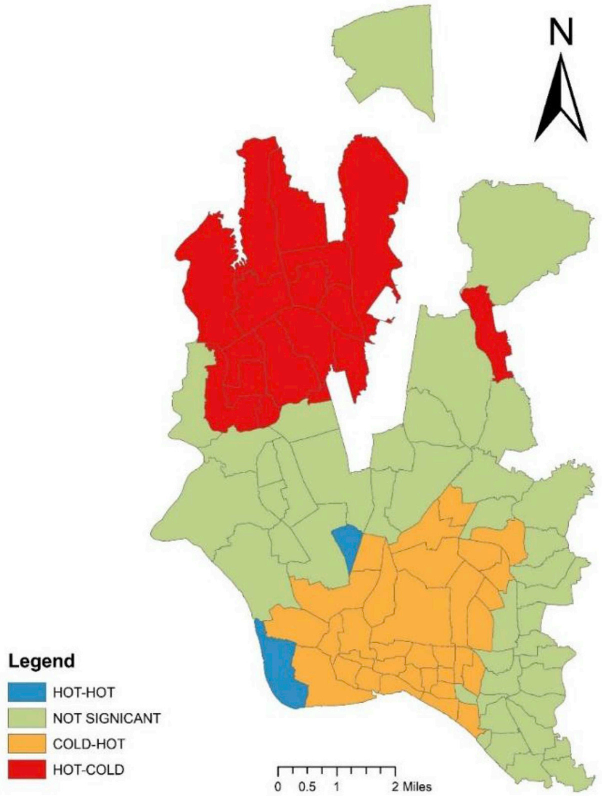

Fig. 9. Geographic extents of integration of significant local patterns between social-need spatial accessibility index values (Source: Author, 2018).

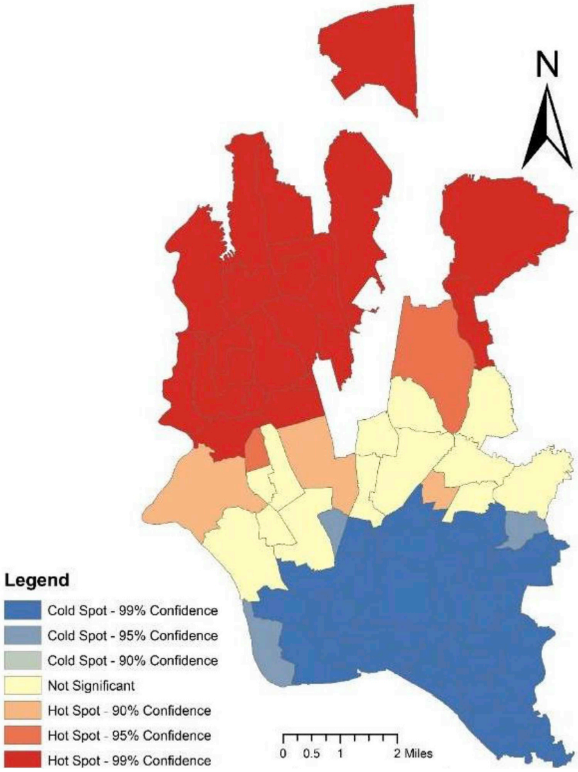

Fig. 10. Geographic extents of significant local patterns of demographic-demand index values (Source: Author, 2018).

social-need populations live farther away from the central area (Bourne, 1993; Smoyer-Tomic et al., 2004). Low-social-need populations may move towards the periphery due to huge congestion and pollution of the central area. This settlement pattern can favor high social needs as the central area retains higher accessibility to facilities. On the other hand, in this study, we maintain that urban facilities including primary school, secondary school, college, park, playground, and hospital are inequitably distributed within Dhaka city as an aggregated way. It suggests that the settlement pattern of Dhaka city disadvantages high-social need populations in terms of being not capable of maintaining a favorable allocation policy for these disadvantaged populations. Similarly, this spatial mismatch is also prevalent in other developing large cities throughout the world, and is mainly contributed by the rapid and unplanned growth of low-income settlements without a commensurate development of urban facilities on the periphery of these cities. However, the difference between cities of developed and developing countries may be attributed to the urban spatial structure, congestion cost, and urban management and governance of those cities (Cohen, 2006).

More specifically, in the case of Dhaka city, this spatial inequity is mainly influenced by two factors: unplanned growth of urban fringe, and the reluctance of authorities to provide adequate facilities in this area. The disproportionate rapid growth of Dhaka city with its industrial development mainly triggers to generate low-income settlements like a slum and squatter settlements mostly concentrated on the periphery of the city (CUS, 1990; Gruebner et al., 2014; Hossain, 2008; Islam, 1996; World Bank, 2007). Rural-urban-migration also contributes greatly to its rapid growth (Ullah, 2004), and many of the poor migrated populations are initially concentrated in slums and squatter settlements (Burkart, Gruebner, Khan, & Staffeld, 2008). Due to the higher demand for land in the central area, slums are also resettled in the periphery area. Unfortunately, though urban fringe of Dhaka city possesses high-social-need for urban facilities, responsible authorities (Government organizations, NGOs and Donors) are typically reluctant to provide facilities in the fringe but much interested to serve the city's upper- and middle-class neighborhoods located in the central area (Low-social-need area). The constant threat of evictions and the financial profit maximization principle of agencies create obstacles in the provision of urban facilities in those areas (World Bank, 2007). The integration of spatial and aspatial accessibility avers an implication that if high-social-need settlements continue to develop in fringe than central areas, the spatial imbalance will be exacerbated by hampering responsible authorities' initiatives to ensure adequate access to urban facilities. In such circumstances, to achieve vertical spatial equity in the distribution of the urban facilities, planners and policymakers must ensure an effective and efficient urban management and governance system including equitable and adaptable land management policies (Cohen, 2006). These policies should stress the mixed-use development, transit-oriented development, improvement of public transit system (Duncan, 2010), minimization of spatial separation between facilities and residences (Kelobonyea et al., 2019).

Urban facilities should be distributed in such a way so that it can facilitate the need of socially disadvantaged people while the distribution should also follow the number of potential users of such facilities. In the case of Dhaka city, higher-social-need areas and higher-demographic-demand areas are spatially correspondents to each other. The higher population growth rate in periphery areas

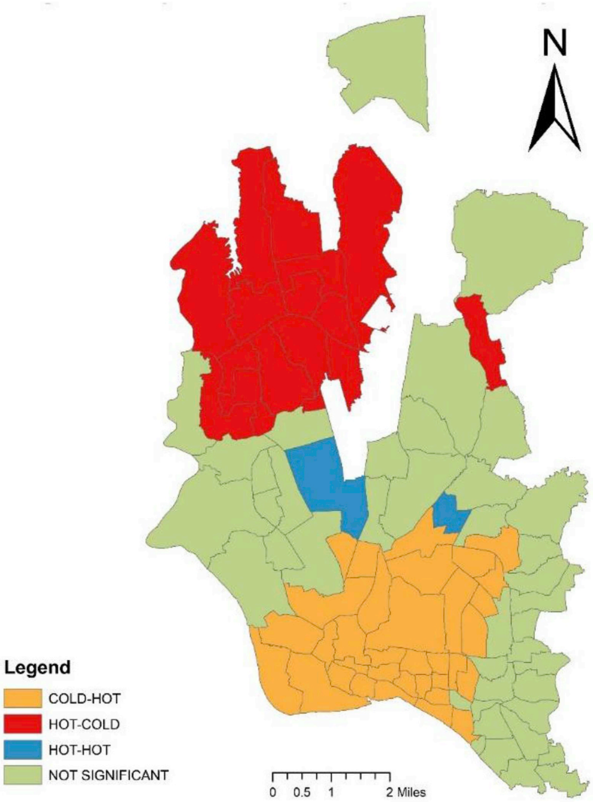

Fig. 11. Geographic extents of integration of significant local patterns between demographic-demand spatial accessibility index values (Source: Author, 2018).

Table 5
Percentages of areas of DCC within specified cluster types.
(Source: Author, 2018)

Cluster types		Hot-Cold	Cold-Hot	Hot-Hot	Not Significant
Percentage of areas	Social-need perspective	25.25	19.35	1.74	53.6
	Demographic-demand perspective	25.25	20.5	3.2	50.97

due to illiteracy and limited knowledge about family planning may be the underlying reason for the spatial correspondence between high-social-need and high-demographic-demand. Therefore, the new allocation of urban facilities in these areas can meet both the social need and demographic demand simultaneously. However, there may be obvious exceptions where there is a possibility of the existence of a spatial mismatch between high-social-need areas and high-demographic-demand areas. In this case, the higher-social-need area should get more priority while distributing urban facilities over space as the quality of life of socially disadvantaged residents is more endangered. Potential users of high-social-need areas have few choices to get access to alternative facilities as they have no access to private cars which in turn hamper active participation of these socially disadvantaged populations in physical activities (Kelobonyea et al., 2019). So it is obvious that the quality of life of these disadvantaged populations can be sufficiently promoted by ensuring adequate access to urban facilities. In addition, unemployment and child labor are common issues in higher-social-need areas. Good access to urban facilities can also inflate the productivity of populations living in the high-social-need areas. These areas are also more vulnerable to natural or manmade hazards (like urban flood, fire, etc.). In such a situation, residents face many difficulties to reach urban facilities resulting deterioration of access to such facilities.

7. Conclusion

The main theme of this paper is that there may exist unequal access of urban residents to urban facilities while this inequality should be in accordance with the 'demand' and 'need' of urban residents to ensure better spatial access to urban facilities of these populations so that they can improve their quality of life. To address this very issue, this study, first, measures an integrated spatial accessibility index for urban facilities in GIS environment, and, then, integrates spatial and aspatial accessibility with a focus on the assessment of vertical spatial equity of urban facilities. This paper shows how consistently, precisely, and flexibly spatial and aspatial accessibility can be integrated using quantitative criteria in the context of vertical spatial equity. Besides, it has demonstrated how GIS technologies can be used for a systematic urban management system. This integrated approach can be a useful decision making reference for urban planners to investigate and adjust the distribution of urban facilities, thereby resulting in equitable access to urban facilities as the integration of spatial and aspatial accessibility not only contributes to grasp equity issues within cities but also allows urban planners to depict under-provisioned areas on the basis of 'need' and 'demand'.

This paper authenticates that within DCC area there exists a variation of spatial accessibility to urban facilities. While this inequality responds neither to the demand of population nor to the need and constraints of socially disadvantaged population. Therefore, according to the vertical equity concept, it can be inferred that the geographical arrangement of urban facilities is substantially inequitable in DCC area. This finding of the paper also supports the assumption that cities in developing countries have a shortage in the supply of urban facilities which are also disproportionately distributed over space, thereby contributing to spatial inequity (Taleai, Sliuzas, & Flacke, 2014).

However, there are some limitations to this study. We measure integrated spatial accessibility index assuming that all residents are concentrated in the centroid of the ward, and have equal accessibility. As residents are not evenly distributed over space, in case of large wards, this can be misleading because, in reality, though some of the facilities can be reached from the origin zone within the access time, others in the same area may not be accessible. Therefore, the findings of the large areas should be interpreted carefully. Furthermore, this study doesn't include the availability of different transport modes required for accessing a facility to keep the method easy and intuitive. But accessibility is profoundly influenced by the availability of transport modes as well as types of transport modes. Therefore, to have a more comprehensive understanding of spatial equity in the geographical disposition of urban facilities, further studies can consider the availability of different transport modes to have access to urban facilities. Besides, analysis of intergenerational spatial equity of urban facilities is paramount important as accessibility can be changed over time due to the increasing level of urbanization.

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