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Research Article

GIS-based compactness measurement of urban form at neighborhood scale: The case of Dhaka, Bangladesh

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ABSTRACT

Compact development is broadly professed for making significant contributions to achieve sustainable growth of cities. Therefore, evaluation of the existing compactness of urban areas is crucial for guiding future urban development. Previous studies measured urban areas' compactness at a city or metropolitan scale in a developed country context. Hence, a considerable research gap exists in studying compactness at the neighborhood scale, especially in urban areas from a developing country. This paper aims to evaluate and compare compactness level of neighborhoods in the GIS environment through broadly six indicators-population density, evenness of development, clustering nature of development, land-use diversity, floor use mix, and road network connectivity in eight neighborhoods of Dhaka city, Bangladesh. For this, the study developed a Composite Compactness Index (CCI) based on a multi-criteria decision-making (MCDM) approach. Study results classified four neighborhood as low compact, three as moderately compact, and one as high compact neighborhood. Travel behavior analysis through modal share, travel time, and travel distance validated compact neighborhoods' tenability. Here, identified low and moderate compact neighborhoods require immediate planning interventions for improving their compactness level. Results from this study can work as a preliminary guideline for planners, policymakers, and development agencies for designing a more sustainable and efficient urban form through compact urban development on neighborhood scale. The developed methodology presented here can be applied to other areas with refinements necessary for corresponding geographic location.

1. Introduction

1.1. Compact urban development

Due to the rapid increase in the global urban population, it is projected that urban space needs to be doubled in developed countries and be expanded by 326% in developing countries between 2000 and 2050 (Angel et al., 2011). Unplanned urban growth creates urban sprawl characterized by low density, single-use, scattered, or leapfrog development (Galster et al., 2001; Hamidi & Ewing, 2014). Sprawl development is posing adverse effects on urban sustainability through higher carbon emission (Hamidi & Ewing, 2014), agricultural land reduction (Lo, 2004), increased expenditures on infrastructural facilities provision (Burchell & Mukherji, 2003), negative impact on public health (Sturm & Cohen, 2004), and also creating social problems (Zhang et al., 2014). Hence, there is growing concern among researchers, city planners, and policymakers for compact urban development as means of sustainable urban development (Geurs & Van

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Wee, 2006; Dieleman & Wegener, 2004; Burton et al., 2013; Sachs, 2015; Lan et al., 2021). For a long time, the United Nations have been espoused the idea of sustainable urban form at a more disaggregated level (Annex, 1992). As most of the new developments occur at the neighborhood level; hence, the city's sustainability largely depends on its neighborhood's sustainability (Choguill, 2008; Williams, 2014).

As compact development significantly contributes to the idea of ecological and environmental sustainability, it has been popularized as a policy tool (Friedman, 2007). However, the unanimous definition of a compact city is still lacking (Zhao et al., 2020). Compact urban deployment is popularly termed as high density, mixed-use development with greater accessibility, concentrated development around public transportation facilities (Burton, 2000; Zhao et al., 2020). Against unplanned horizontal development, compact development encourages densification of the existing population and built environment in vertical direction for future growth accommodation (Koziatek & Dragičević, 2019). This type of development has a significant positive impact on energy consumption (Schläpfer et al., 2015; OECD, 2012), environmental condition (Bechle et al., 2011), transport mode choice (Neuman, 2005; Li et al., 2018), access to employment opportunities (Neuman, 2005), social equity (Burton et al., 2003), public health (Burton, 2000) and overall quality of life, (WHO, 2011). Developed countries like the USA, Japan, and Australia, and many European Cities are considering compact urban development for decades (Burgess, 2000, pp. 9–24; Koziatek & Dragičević, 2019). Also, few Asian Cities like Shanghai, Hong Kong followed compact urban development policies (Chen et al., 2008).

1.2. Review of literature

Urban form can be defined as city elements that are fixed in geographical scale, including the spatial pattern of land uses and their densities and the spatial design of transport infrastructure (Anderson et al., 1996). So far, urban form has been studied by multiple disciplines at varying geographical scales, i.e., regional level (Siedentop & Fina, 2010), metropolitan level (Bertaud & Malpezzi, 1999), city-level (Tsai, 2005; Chhetri et al., 2013; Lee et al., 2015; Abdullahi, Pradhan, & Jebur, 2015; Abdullahi, Pradhan, Mansor, & Shariff, 2015), building level (Ding, 2005), Block or Street level (Cao et al., 2007). To quantify urban form, different studies adopted different indicators among which popular measures included indicators like, i.e., population density (Galster et al., 2001; Lowry & Lowry, 2014); floor space density (Rahman et al., 2019; Kashem et al., 2009; Rahman, 2012); development's evenness (Tsai, 2005); development's clustering nature (Galster et al., 2001; Tsai, 2005); land use mix (Abdullahi, Pradhan, Mansor, & Shariff, 2015); proximity (Galster et al., 2000; Bertaud & Malpezzi, 1999); street design and circulation systems (Tresidder, 2005); land consumption (Siedentop and Fina, 2010); passive solar design and ecological design (Jabareen, 2006), and many others.

There is a crucial distinction between the concept of “compact city” and “compact urban development.” According to the OECD (2012), a “compact city” is considered a metropolitan-level policy. While “compact urban development” indicates development on a neighborhood scale (OECD, 2012; Geurs & Van Wee, 2006; Burton et al., 2003). Previous literature has focused on studying characteristics, feasibility, and compact development functions at city scale (Anderson et al., 1996; Burton, 2000, OECD, 2012; Abdullahi, Pradhan, & Jebur, 2015; Zhao et al., 2020). The very first compactness index (CI) was initially proposed by Thinh et al. (2002), who derived urban physical compactness based on a gravitation approach. Before that, there was a compactness measure like Cole Compactness (Cole, 1964) and Richardson Compactness (Richardson, 1973), which measured urban space's physical compactness. With improved technologies like Geographic Information System (GIS) and Remote Sensing, many recent studies derived compactness index at city scale through various spatial indicators (Abdullahi, Pradhan, & Jebur, 2015; Lee et al., 2015; Koziatek & Dragičević, 2019; Zhao et al., 2020; Lan et al., 2021). From a city-scale, one can get a broader understanding of the spatial location of different uses and their interaction; a more detailed understanding needs to disaggregate level analysis. For which, a community or neighborhood can be a practical geographical unit to study the city's compactness as a whole (Lee et al., 2015). Nevertheless, in the context of a developing country, neighborhood compactness measure as intermediate geographic scale has received a very insignificant amount of concentration by researchers around the world.

1.3. Need for research

This research paper would contribute to several crucial research gaps identified in compactness assessment literature in developed and developing countries, considering different geographic scales. First, among the numerous studies, little research has quantified neighborhood compactness from urban form measuring variables in developing country context where significant difference exists in terms of socio-demographic and city form elements compared to developed ones (Cervero, 2013). The proposed method would enable municipal governments of developing countries to compare the current compactness of neighborhoods, leading to the motivation to improve their policies. Second, although different studies identified the effects of compact development (Ahlfedlt & Pietrostefani, 2017; Chen et al., 2008), what makes compactness different in different places has been rarely quantitatively discussed. For this, there is a need to develop an easy and legible methodological approach to quantify the existing compactness to realize the current situations. This study has developed a Composite Compactness Index (CCI) for making a consistent and standard approach to compactness evaluation. Third, some of the scholars used remotely sensed data to identify shape features (Song et al., 2018) of urban form, some used socio-economic data (Chen et al., 2008; Turskis et al., 2006) for evaluating compactness level. However, vector-type geospatial data is advantageous over satellite data-based raster data or statistical data that can calculate geometric and geographic details of an area more precisely and accurately (Crooks, 2010; Zhao et al., 2020). Vector-type geospatial data used for this research would be more effective to evaluate the compactness level of the existing urban form. Fourth, unlike previous research that counts horizontal mixed-use development, this study counts vertical mixed land use development information of an area that effectively captured existing mixed-use development scenarios of interest. Lastly, selecting the appropriate scale to conceptualize the neighborhood urban form has not been addressed adequately in

the literature (Clark & Scott, 2014). Regular grid base computation in geographical information system (GIS) software is identified as an effective way to analyze urban structure patterns or growth patterns in previous studies (Ahmed & Bramley, 2015; Yeh & Li, 2002). Hence, this study considered grid-based analysis for extracting few urban form variables and aggregated for each neighborhood unit.

Against this identified research gap, this paper aims to propose a quantitative approach of compactness level measurement in a neighborhood-scale based on urban form variables. Multi-criteria Decision Making Approach (MCDM) coupled with Geographic information Science (GIS) based geospatial analysis was applied for deriving Composite Compactness Index (CCI) on eight neighborhoods selected from Bangladesh's capital city, Dhaka, as a representative of developing countries. The primary rationale behind developing a composite index is to develop a consistent methodology for compactness evaluation of neighborhoods so that planners, policymakers can perform the analysis while making decisions.

This section gives the background and brief literature with research gaps accommodated through this study. Section 2 introduces data sources, study area, and detailed analytical methods used for compactness derivation. Section 3 presents the results of compactness measurement. Results of compactness measure of Dhaka city neighborhoods, policy recommendation, limitations, and future work scope are presented in Section 4. Lastly, in section 5, conclusion section summarizes the whole work.

2. Materials and methods

2.1. Study area

Dhaka city has 38% of Bangladesh's urban population and is expected to become the world's third-largest megacity by 2020 (DTCA, 2015; BBS, 2011). After independence in 1971, Dhaka experienced rapid urbanization with home of 1.6 million people (Kabir & Parolin, 2012). It has a population of around 17.6 million within its 1528 sq.km. area, and it is expected that Dhaka would have near 26 million people by 2035 (RAJUK, 2015). The two municipalities- Dhaka North City Corporation and Dhaka South City Corporation have a population density of around 28,748 per sq. km. (Ahmed et al., 2018). The city expanded towards a north-ward direction over time. With an unequal distribution of urban services, the spread of population and employment made sprawling development patterns in the peripheral areas of Dhaka city. As part of planning intervention, the first Master Plan was prepared in 1959 by Dhaka Development (Rajdhani Unnayan Kartripakkhya' – RAJUK), previously named as Dhaka Improvement Trust (DIT) in 1959 (RAJUK, 2015). After that, Dhaka Metropolitan Development Plan (DMDP) was formulated in 1995, and later, Dhaka Structure Plan is the latest planning documents with a strategic vision to develop this city for the period of 2016–2035 (RAJUK, 2015).

Although its population growth trend is similar to other global south mega-cities, such as Rio de Janeiro and Mumbai, the interplay of local politics, power, and policies shaped it is unique and dynamic as suggested by Ahemd et al. (2018). Dhaka city contributes 36% of the national GDP and 31.8% of total national employment, making it an administrative and political hub of the country (RAJUK, 2015). With rapid urbanization, a substantial decrease in natural vegetation cover, water bodies, and agricultural land happened as a built-up area increased significantly from 1980 to 2015 (Morshed et al., 2017). Rural to urban migration along with uncontrolled land conversion worked as contributing factors for rapid urbanization resulting in urban sprawl development in Dhaka City (Islam et al., 2009).

This rapid urbanization rate in the capital city also brought social, cultural, political, and institutional change in Dhaka city (Siddiqui et al., 2016). A significant number of migrated people are poor people involved in informal sectors in Dhaka city for employment purposes (Rashid, 2009). This informal employment is unregulated by the city's legal institutions, for which they are the most vulnerable groups stricken by urban poverty and deprived of basic urban service facilities like housing, education, healthcare, sanitation, water, etc. (Hossain, 2013). Thus over the last two decades, although there is a rise in real income of people, this increase couldn't minimize the social inequalities in this capital city, i.e., only 2% of the city's population lives in 15–20% of its residential neighborhoods, while 50% of the poor and middle-income people live in only 6% of its residential neighborhood areas (Siddiqui, 2004). So the state or local level policies resulted in the accumulation of capital to a small segment of society (Hossain, 2013). Besides, the role of different city management authorities, i.e., two City Corporations- DNCC and DSCC, Dhaka Metropolitan Police (DMP), Capital Development Authority (RAJUK) have shared institutional responsibilities, which resulted in uncoordinated and overlapping interventions (Talukder & Newman, 2003). As a result of the city's entrenched weak formal governance structure and process for shared delivery of city-level services and land management, informal governance structures further divide the city (Ahmed et al., 2018). Hence, consideration of Dhaka city Neighborhoods as compactness derivation is crucial for the city authority to evaluate its development status locally.

Two City Corporations currently govern Dhaka city, Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC), with around 8.9 million population within 306 sq. km. of urban area (Dhaka, 2021). This study considered eight neighborhoods delineated following the ward boundary, the lowest administrative unit for the City Corporations (Fig. 1). The selection of these neighborhoods was based on their variation in development patterns. Studied neighborhoods vary with a locational attribute-the neighborhood's location within the city, i.e., central part, newly developed area, and old part, the difference in socio-economic characteristics-median income, size and shape, street layout pattern. Table-2 summarized the general overview of the study neighborhoods.

2.2. Data

This study considered spatial data set, i.e., structure, land use data of Draft Dhaka Structure Plan (DSP, 2016–2035), the latest urban development plan for Dhaka City. Road network data were acquired from Open Street Map. As mentioned earlier, grid-based analysis was considered for urban form analysis. Grid-level population or employment information was not available. Hence, floor use information was considered a proxy variable of the actual population and employment in this study. To validate the performance of compact neighborhoods, the Revised Strategic Transport Plan's (RSTP-2015) database was considered. RSTP-2015 is the latest and

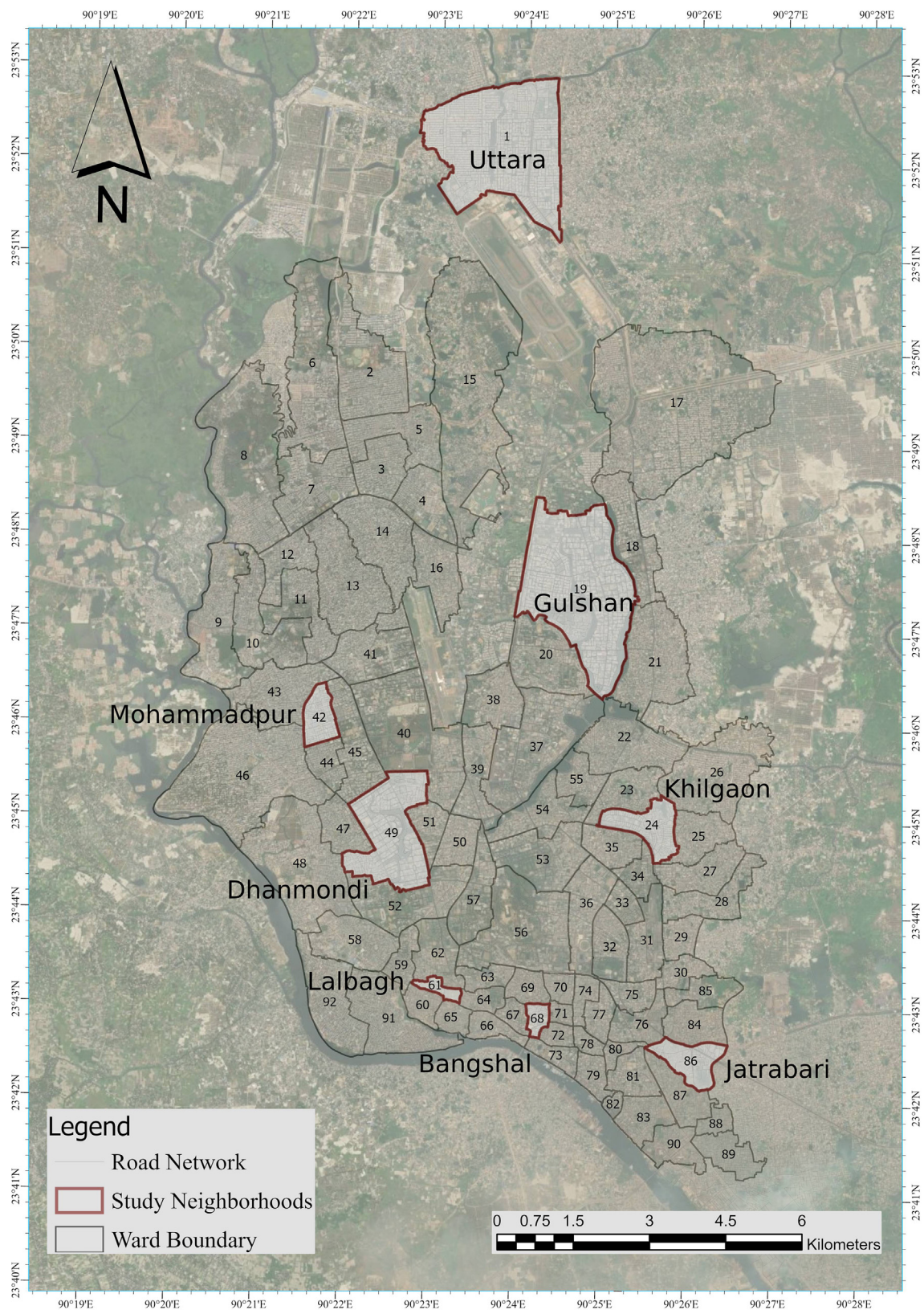


Fig. 1. Map showing geographical location and boundary of study neighborhoods.

comprehensive study on the transportation for Dhaka city conducted under Dhaka Transport Coordination Authority (DTCA) initiative. Table 1 summarized the urban form indicators used for deriving compactness of neighborhoods along with their description.

2.3. Method

2.3.1. Spatial data processing

All the urban form measuring variables were processed in ArcGIS. Few indicators like evenness of development, clustering of development, and land use mix involved grid level analysis. For that, grid cell size was determined as 100m × 100m size, following the application and adaption of literature (Yeh & Li, 2002; Rahman, 2012; Kahsem et al., 2009). The grid-based method divided each neighborhood into a continuous square grid of cells with unique cell-ID. Grid preparation was done using the Fishnet tool of ArcGIS. Overlay operation of grid cells with building structures created two distinct geographical settings- (1) features entirely inside the cell; (2) features divided by the grid cell boundary, therefore falling between grid cells. These two sets were addressed during building floor space estimation for distributing space proportionately to each grid cells.

2.3.2. Reclassification of floor use data

Indicators considered for measuring compactness included density, spatial distribution, and clustering analysis of residential and workplace space. Hence, reclassification of structure use and land use data into these two major categories was absolute necessity. Table-3 illustrates how different types of structure use were reclassified and aggregated.

2.3.3. Building floor space estimation

Building floor spaces were derived by multiplying each building's floor area with its height or number of floors. The features that fell between multiple cells were divided following the grid boundary line. The final grid dataset contained the total amount of residential and workplace floor space in each grid cells.

2.3.4. Computation of urban form indicators

2.3.4.1. Density. Population density has been calculated by analyzing people accommodated per sq. km. of floor space. The average neighborhood population (day and night time) was used for population estimation.

$$\text{Population Density} = P_i / A_i \quad (1)$$

Where P_i = Population of the neighborhood; A_i = Total floor area of the neighborhood i.

2.3.4.2. Evenness of development. To measure residential and workplace space distribution inequality in each neighborhood, the study used the Gini index, which economists popularly use to measure income or wealth inequality. But, now Gini Index is used in various disciplines to measure inequality or evenness of any feature distribution (Penfold, 2001; Tsai, 2005). The formula for Gini index is as follows-

$$\text{Gini} = \frac{\sum_{i=1}^N (X_i - Y_i)}{2} \quad (2)$$

Here, N = number of grid cells (100m × 100m) in each neighborhood; X_i = proportion of floor space in grid cell i; Y_i = portion of specific category floor space in the grid cell i. This index shows the added-up inequalities of all the grid cells.

2.3.4.3. Clustering nature of development. Spatial autocorrelation analysis were done for analyzing the “clustering of development”

Table 1

Dataset used for urban form analysis with their description.

Indicators	Dataset	Variable	Description	Data Source
Density	Building	Population Density	Population per sq.km. of floor space	Draft Dhaka Structure Plan, 2016-35
Evenness of Distribution	Floor Space	Residential and Workplace Gini	Degree of equal distribution of development in the neighborhoods	Authors Calculation in GIS and SPSS
Clustering nature of Development	Floor Space	Residential and Workplace Moran's I; Bivariate Local Moran's I	Degree of clustering of development in the neighborhoods	Draft Dhaka Structure Plan, 2016-35
Diversity	Land use	Land use Diversity	To measure the heterogeneity of land use	Authors Calculation in GIS and SPSS
Floor use mix	Building	Degree of Parcel Use	To measure vertical land use diversity	Open Street Map Data-2018
Connectivity	Physical Road Network	Connected Node Ratio Link Node Ratio Percentage of 4 way intersection Percentage of Cul-de-Sacs	To measure the connectivity of road network	

measure for each of the studied neighborhoods. Global Moran's I is one of the most commonly used measures which identifies whether the spatial pattern is clustered, dispersed, or random. Univariate Moran's I value for each neighborhood was derived in ArcGIS, while multivariate Moran's I value was calculated using GeoDa software. Global Moran's I formula is as follows (Cliff & Ord, 1972):

$$\text{Moran's } I = \frac{N \sum_{i=1}^N \sum_{j=1}^N W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\left(\sum_{i=1}^N \sum_{j=1}^N W_{ij} \right) (X_i - \bar{X})^2} \quad (3)$$

Here, N = number of grid cells; X_i = amount of residential or workplace floor space in grid cell i , X_j = amount of residential or workplace floor space in grid cell j , \bar{X} = average residential or workplace floor space, and W_{ij} = relative weights between grid cell i and j .

Moran's I value ranges from a negative one to a positive one. For monocentric-clustered spatial structure, this value tends to be a positive one. While, for random scattering spatial structure, value usually tends to be zero. Negative Moran's I mean that development pattern is like chessboard (Tsai, 2005). For selecting the distance band, an "Incremental Spatial Autocorrelation" was performed in ArcGIS environment as threshold distance is crucial while running Global Moran's I statistics.

For mapping the location local clusters and local spatial outliers, a local indicator of spatial association (LISA) was carried out on GeoDa software through local Moran statistics suggested by Anselin (1995). It produced a bivariate LISA cluster map examining the relationship between residential floor space and workplace floor space for each neighborhood. For conceptualizing the spatial relationships, "Zone of indifference" options were chosen while mapping the clusters. We used bivariate models to address a closely related and pertinent question-whether the geographic location of high-density residential space is also highly dense with workplace space and vice versa.

2.3.4.4. Diversity. Entropy index is the most commonly used index for land-use diversity study (Boarnet, 2011). The resulting value of the entropy index varies from 0 to 1. Where 0 means maximum specialization or total homogeneity, and 1 means maximum diversification or heterogeneity. The mathematical expression of the entropy index is as follows (Shannon, 1948)-

$$\text{Entropy Index} = - \sum_{i=1}^N P_i \frac{\ln(P_i)}{\ln(N)} \quad (4)$$

Here, P_i = proportion of land use category j within a specified buffer zone (service area), in the study, the neighborhood boundary is the buffer area; And N = number of land-use categories. The exact process was followed for reclassification of the land use described in floor space estimation.

2.3.4.5. Floor use mix. After connecting floor use information in each grid cell, several different uses found in each grid cell defined floor use mix scenario of the selected neighborhoods. For each cell, the number of uses of the structure was categorized as - a) single-use, b) combination of two types, c) combination of three types, d) combination of four types, e) combination of five types of floor uses. Floor use mix analysis provided a basis to quantify vertical land use mix scenarios of the study units.

2.3.4.6. Connectivity of road network. Road network connectivity was measured using network data set created through ArcGIS Network Analyst Tool. Network dataset produced edges and nodes for the whole road network inside a neighborhood. To overcome the MAUP problem, the study produced nodes and edges through complete network data instead of taking clipped networks for each network. Earlier studies showed that clipped road network creates dangle nodes that incorrectly identify node degree (Tresidder, 2005). For analysis purposes, we classified nodes as cul-de-sacs, three legs, and four legs intersection. The indices measure for connectivity calculation is as follows (Tresidder, 2005)-

$$\text{Percentage of Cul-de-Sac} = \left(\frac{\text{Number of the Cul-de-Sacs}}{\text{Number of the Nodes}} \right) * 100 \quad (5)$$

Table 2
Study Area information.

Area (Ward No.)	Area (Sq.km.)	Household	Population	Median Income (BDT)	Development Typology	Street Pattern	Code Used
Bangshal (68)	0.22	2556	13,531	32,000	Traditional-Old	Irregular	A1
Dhanmondi (49)	2.34	14,735	72,449	50,000	Planned- Central	Grid	A2
Gulshan (19)	6.94	22,936	159,907	40,000	Planned-Central	Grid	A3
Jatrabari (86)	0.86	11,941	56,766	18,000	Traditional-Old	Irregular	A4
Khilgaon (24)	0.83	15,532	68,931	25,000	Traditional-Old	Irregular	A5
Lalbagh (61)	0.36	6193	29,832		Traditional-Mixed	Irregular	A6
Mohammadpur (42)	0.71	12,080	54,739	40,000	Planned-Central	Grid	A7
Uttara (1)	15.05	39,922	183,298	40,000	Planned-Fringe	Grid	A8

(Source: RAJUK, 2015)

Table 3

Reclassification of building use information.

Structure Use	Reclassified Name
Bank, hospital, hotel, cinema hall,	Commercial
Religious institutes (mosques, temples), hotels, community centers, educational institutes, public office building	Institutional
Residential	Residential
Industrial	Industrial
Mixed uses	Distributed as Residential and Workplace

$$\text{Percentage of Four Leg Intersections} = \left(\frac{\text{Number of the Four Leg Intersections}}{\text{Number of the Nodes}} \right) * 100 \quad (6)$$

$$\text{Link Node Ratio} = \left(\frac{\text{Links per unit of the area}}{\text{Nodes per unit of the area}} \right) * 100 \quad (7)$$

$$\text{Connected Road Ratio} = \left(\frac{\text{Actual Nodes}}{\text{Actual Nodes} + \text{Cul-de-Sacs}} \right) \quad (8)$$

2.3.5. Assumptions for formulating Composite Compactness Index (CCI)

For developing CCI, each urban form indicator was critically analyzed to capture its effect on urban compactness. Authors considered a rule-based approach to concisely presenting assumptions for the measured variables. All the assumptions were checked through adequate literature to make them consistent and for broader acceptance. Table-4 is showing the key questions and associated rules used for developing CCI in this study.

2.3.6. Multiple criteria decision making (MCDM) method for compactness index derivation

After calculating the indicators for compactness measurement, a Multiple-criteria analysis was carried out to calculate CCI for the studied neighborhoods. Simple Additive Weighting (SAW) is one of the simplest MCDM methods used for comprehensive assessment of multiple spatial indicators with different measurement units (Afshari et al., 2010). Other MCDM approaches like Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) or Artificial Intelligence techniques were not used here due to computational complexities. The concept of SAW is to find the summation of the weighted performance value of each neighborhood or alternatives taken for evaluation (Afshari et al., 2010). In MCDM evaluation, each criterion has been identified as either benefit or cost criteria through evaluating how their value effect compactness. Cost criteria put a higher score to the alternative which performance rating is lower, while benefit criteria work the opposite. Among all the criteria- Gini index, univariate Moran's I , single-use parcels, percentage of cul-de-sacs, are cost criteria as high value of these indicators would reduce compactness of a neighborhood. All other indicators identified as benefit criteria as they positively contribute to compactness of neighborhood.

2.3.6.1. Weight determination of indicators. Previous studies have used different techniques like AHP, Public Opinion, and Score Card while identifying weight for composite index derivation. However, for simplicity, this study used an equal weight approach following the work of Burton (2002) on a similar study.

2.3.6.2. Data normalization. As the criteria were in different scales, data normalization was done to make them comparable. Among different normalization techniques, this study used proportion-based normalization, alternatively termed as Max-Min Method, due to its advance of constructing benefit and cost criteria (Saaty, 1977; Tzeng & Huang, 2011). A decision matrix was constructed where urban form indicators were in one dimension and neighborhoods were in another dimension. Following formulas were used for normalizing each cost and benefit criterion. For beneficial criteria-

$$r_{ij} = \frac{x_{ij}}{\max(x_{ij})} \quad (9)$$

For non-beneficial or cost criteria-

$$r_{ij} = \frac{\min(x_{ij})}{x_{ij}} \quad (10)$$

x_{ij} = the original value of j th criterion of i th neighborhood; r_{ij} = is the normalized value of i th neighborhood for the j th criterion.

2.3.6.3. Normalized decision matrix. After normalizing the decision matrix, each dimensionless indicator's values multiplied with their corresponding weight for constructing a weighted normalized decision matrix. The overall score for each neighborhood was calculated through equation (Saaty, 1977)-

$$CCI_i = \sum_{j=1}^M w_j r_{ij} \quad (11)$$

Where CCI_i = is the overall score of the i th neighborhood; W_j = is the weight of the j th criterion; r_{ij} = is the normalized value of i th neighborhood for the j th criterion; N = Number of neighborhoods, M = is the number of urban form indicators.

2.3.7. Classification of neighborhoods

For the current study, CCI scores were categorized into three classes using the equal class interval method. Compact neighborhoods have more equality in floor space distribution, creating several residential and workplace use clusters, increased diversity, and functional connectivity, with opposite scenarios for low compact ones.

3. Results

3.1. Density

High density is one of the significant variables for a neighborhood being compact. The population density variable suggests that, on average, 56 thousand people occupy per square kilometer of floor area, which indicated selected neighborhoods are immensely dense. Table 5 presents descriptive statistics of each urban form variable considered for this study.

Neighborhoods located in the old part of Dhaka City, i.e., Lalbagh, have the highest population density: more than a million people per sq.km. of floor area. Whereas, comparatively newly developed areas like Dhanmondi, Gulshan, and Uttara have a low level, i.e., around thirty thousand population persons per sq.km. of floor area (Table 6), which indicates that intensity of floor uses significantly low compared to neighborhoods of older parts of the city.

The ratio of residential and workplace floor space was considered to access the degree of job-housing balance in terms of floor use distribution. For five neighborhoods, residential space is four times higher than the workplace space (Appendix Table 1), indicating predominant nature of residential use in neighborhoods. There is no such threshold on how much population or employment should present in a neighborhood to be compact. But the jobs-housing balance literature suggests that these two should be in balance (Rahman & Ashik, 2020). That is, the ratio should be close to one.

3.2. Evenness of development

Table 5 shows that the range of Gini index of workplace space (0.172–0.572) is larger than the range of the residential space (0.114–0.318). For all the neighborhoods, residential Gini is less than the workplace one (Table 6). The high value of the workplace Gini index indicates the more uneven distribution of workplace spaces in the neighborhoods than the residential spaces. It is expected that workplace spaces (i.e., commercial, institutional) spaces usually developed following road networks. Hence, this kind of spatial concentration decreases the value of evenness for workplace space distribution. It is evident that traditional or old neighborhoods, i.e., Lalbagh, Bangshal of Dhaka, have more evenness in distribution of residential and workplace floor space than planned new neighborhoods, i.e., Gulshan, Uttara.

Table 4
Attributes of compactness measurement indicators and their description.

Indicators of Urban Form	Key questions	Rules Used for Compactness Index Preparation	Source
Density	What is the overall activity intensity of an area?	Higher the densities of an area, the greater the level of compactness.	Galster et al., 2001; Dieleman & Wegener, 2004; Neuman, 2005; Burton et al., 2003; Chhetri et al., 2013
Evenness of Development	To what degree population and employment are evenly or equally distributed in sub-areas?	Higher the equality or evenness (Lower Gini index) in the distribution of population and employment, the greater the area's compactness or less sprawling.	Yeh and Li, 2002; Tsai, 2005; Kashem et al., 2009; Rahman, 2012; Rahman et al., 2019
Clustering nature of Development	To what degree existing high-density sub-areas are clustered or randomly distributed?	Lower Univariate Moran coefficients suggest polycentric clustering of population and employment, which positively affects an area's compactness. In contrast, higher bivariate Moran Coefficients suggest that residential workplace space is clustered closely, which positively affects compactness.	Yeh and Li, 2002; Tsai, 2005; Kashem et al., 2009; Rahman, 2012; Li et al., 2018; Chhetri et al., 2013
Diversity	What is the condition of horizontal mixed land use development in an area?	Greater Entropy index value measuring heterogeneity of land uses means greater degree of intensity of use, which increases compactness level of an area	Rahman, 2012; Burton et al., 2003
Floor Use Mix	What is the scenario of vertical mixed land use development in an area?	Different uses in a single structure increase the likelihood of balance in residential and non-residential use, which positively influence compactness of an area	Hoppenbrouwer and Louw (2005)
Connectivity	To what degree existing road network is connected inside the area of analysis?	Higher 4 leg intersection, link node ratio, and connected node ratio values and lower cul-de-sacs, higher degrees of accessibility positively influence compactness level.	Tresidder, 2005; Ewing & Cervero, 2010; Chhetri et al., 2013

3.3. Clustering nature of the development

From Table 6, it is observed that the univariate Moran coefficient is overall low (below 0.2) and positive for most of the neighborhoods, which indicated that positive spatial autocorrelation exists among the values of residential and workplace floor space. Hence, for both residential space and workplace space, high-density settlements are separated from low-density. Also, Moran coefficient values are higher for residential space (Table 6), which indicated that residential spaces are more concentrated and continuous than workplace space.

Table 6 shows that the values of the univariate Moran coefficients differ from that of the bivariate Moran. As univariate analysis concerns the single-use (either residential or workplace), there is a high possibility that these would be found more clustered than the case when two uses were considered simultaneously. The variation of bivariate Moran is supported by the bivariate Lisa cluster map, which visually shows the pattern of distribution (Fig. 2). Seven out of eight neighborhoods have bivariate Moran's I ranging from 0.0 to 0.15, indicating the likelihood of similar land use values of both categories to be in close proximity forming polycentric form, which is favorable for compact development (Li et al., 2018).

3.4. Diversity

The entropy index measured the heterogeneity in six major land-use types. Mean entropy index value (0.68) for the selected neighborhoods indicated diversified land use supportive for compact development (Table 5). Neighborhoods from old parts of city are more diverse than newly developed ones. Entropy-based measures provided horizontal land-use heterogeneity levels for which vertical mix-use scenarios were analyzed through parcel-level diversity analysis.

3.5. Floor use mix

This study measured the total number of different floor use types in each grid cells. Higher the number of floor use types in a particular grid cell, the higher the degree intensity of uses. Studied neighborhoods showed a significant degree of floor use mix as only 14.06% grid cells were of single-use, whereas around 64% of cells have three to five types of uses on comparatively smaller zones of 1-ha size. This implies that a significant portion of each neighborhood is diverse in terms of vertical uses. Fig. 3 depicted the floor use mix scenario of each neighborhood visually.

3.6. Connectivity of road network

In a relatively well-planned area, each node or intersection would be accessible from various directions. For that, literature suggests that higher link-node ratio, connected node ratio, four-leg intersections with less amount of cul-de-sacs in an area showed better road network connectivity, positively influencing compactness of an area. Among the eight neighborhoods, traditional neighborhoods like Lalbagh, Jatrabari have a greater percentage of cul-de-sacs hence a lower value of link-node, connected node ratio, and 4 leg intersection. While, neighborhoods relatively new and planned areas like Gulshan, Uttara, and Mohammadpur have a greater value of link-node ratio and connected node ratio with a lower percentage of dead ends. Also, none of the studied neighborhoods have a perfect grid pattern of the road network as the link-node ratio value is very much less than 2.5.

3.7. Composite Compactness Index (CCI)

Overall compactness of each neighborhood was derived through the SAW-based MCDM approach. Following the assumptions of

Table 5
Descriptive statistics of the urban form variables.

Indicators	Variable	Min	Max	Mean	STDEV
Density	Population Density	21,533	123,561	56,395	36,629
Evenness of Development	Residential (Gini)	.114	.318	.1968	.06120
	Workplace (Gini)	.172	.572	.3372	.1127
Clustering of Development	Residential Moran's I	−0.018	0.229	.0962	.0911
	Workplace Moran's I	−0.002	0.328	.0775	.1046
	Bivariate Local Moran's I	−0.072	0.151	0.0437	0.0606
Diversity	Entropy Index	0.227	0.905	.6759	.1930
Floor Use Mix	Single use parcels	6.92	35.82	14.06	7.83
	Combination of two types of uses	10.81	32.26	21.822	7.24
	Combination of three types of uses	21.69	45.76	33.495	7.79
	Combination of four types of uses	11.09	40	26.484	8.83
	Combination of five types of uses	0	11.43	4.144	3.70
Connectivity	Link Node Ratio	.900	1.46	1.162	.1783
	Connected Node Ratio	.630	.900	.7420	.0928
	Percentage of Cul-de-Sacs	10.10	37.03	25.73	8.74
	Percentage of 4 leg intersections	1.03	6.84	4.026	2.046

each urban form variable's effect on compactness, variables were segregated either into cost or benefits criteria. For instance, Gini index and univariate Moran's I were taken as cost criteria as for greater compactness and equity, the distribution of the residential or workplace use should be even and polycentric or decentralized. However, the bivariate Moran coefficient value was considered a benefit criterion as the higher value of this variable suggests that high-density residential areas in close proximity to high-density workplace areas positively impact compactness on neighborhood scale (Anderson et al., 1996; Gordon & Richardson, 1997). All other variables except single-use parcels were taken as benefit criteria as they were positively affecting compactness level. SAW steps required preparation of decision matrix (Table 6), data normalization (Table 7), and a weighted normalized matrix (Table 8) preparation for deriving final CCI scores for each study unit.

CCI suggests that neighborhoods with more equality in the distribution of floor space with closer proximity of residential and workplace use, increased diversity, and functional connectivity resulted in identifying a neighborhood as the compact one. Here, the classification of neighborhoods is based on the equal class interval method (Table 9). Lalbagh got highest CCI score and was classified as high compact neighborhood correlating with greater population density, polycentric clustered space distribution, diversified land use, and a well-connected road network.

3.8. Validation of compactness characters of the identified clusters

This study examined compact neighborhoods' tenability by examining modal share, commuting time, and distance data. It is widely accepted that compact development can reduce travel distance and travel time, hence positively impacting the city environment through reduced carbon emissions in developed and developing countries. The study used daily trip data of the residents collected in RSTP-2015 for Dhaka city. Here, different degree of compactness level of neighborhoods has been compared with their travel behavior information (Table 10).

Modal share data showing high compact neighborhoods have the largest share of active mode and lowest private mode share. In contrast, low compact neighborhoods experiencing greater private mode use, comparatively lower active mode use compared to other two categories. Table 9 also shows that there is a significant difference in travel distance and time of commuters among the neighborhood types. Commuters living in compact neighborhoods make shorter trips in terms of travel time and distance. Therefore, it can be said that a compact neighborhood has the efficacy of reducing commuting time and distance, which conforms to the previous study (Cao et al., 2007; Cervero, 2013).

4. Discussion

There is a lack of methodological study that comprises numerous indicators to quantify an area's overall compactness. This research provides a tool to compare the compactness level of eight residential neighborhoods. Study results showed that older parts of the city had grown with more compact settings than newly developed areas. Neighborhoods of old Dhaka developed with high densities of population and buildings; diversified land uses for which existing areas are comparatively more compact found by previous studies (Ashik et al., 2019; Rahman et al., 2019). In addition, these areas have connected road networks though their pattern is more irregular in nature than traditional grid-based structures. Another critical observation is that the clustering of development variables showed multiple clusters or polycentric development inside the neighborhoods. These findings comply with the literature that polycentric structure offers a more desirable form of urban development at a city scale (Li et al., 2018). Polycentric urban development was found to lower commuting distance and time (Gordon & Richardson, 1997; Li et al., 2018), which conforms to current study findings.

Table 6
Neighborhood wise measurement of Urban Form Variables (Decision Matrix).

Code	Variables	Neighborhoods							
		A1	A2	A3	A4	A5	A6	A7	A8
V1	Density (Population/sq.km. of Floor Space)	26250	21532	24527	94274	43887	123560	85788	31338
V2	Residential (Gini)	0.16	0.178	0.213	0.265	0.114	0.187	0.222	0.182
V3	Workplace (Gini)	0.207	0.391	0.572	0.34	0.31	0.172	0.256	0.383
V4	Residential Morans' I	−0.018	0.029	0.096	0.212	0.135	−0.008	0.176	0.101
V5	Workplace Morans' I	0.012	0.016	0.19	0.096	0.016	0.051	0.043	0.025
V6	Bivariate Local Moran's I	−0.042	0.059	0.017	0.074	0.111	0.079	0.151	0.019
V7	Single-use parcels	8.11	10	35.82	18.07	8.73	14.29	8.14	6.92
V8	Combination of two types of uses (%)	10.81	27.1	28.36	22.89	12.7	11.43	19.77	22.1
V9	Combination of three types of uses (%)	43.24	40.97	24.36	21.69	34.92	22.86	37.21	45.76
V10	Combination of four types of uses (%)	37.84	20.65	11.09	32.53	37.3	40	24.42	21.88
V11	Combination of five types of uses (%)	0	1.29	0.36	4.82	6.35	11.43	10.47	3.35
V12	Entropy Index	0.896	0.693	0.73	0.784	0.632	0.711	0.578	0.603
V13	Link Node Ratio	1.12	0.96	1.22	0.9	1.39	1.02	1.46	1.26
V14	Connected Node Ratio	0.81	0.69	0.79	0.65	0.83	0.63	0.90	0.79
V15	Percentage of Cul-de-Sacs	18.87	31.25	20.83	34.48	17.24	37.04	10.10	20.83
V16	Percentage of 4 leg intersections	2.5	4.58	6.21	1.44	6.84	5.96	2.11	5.87

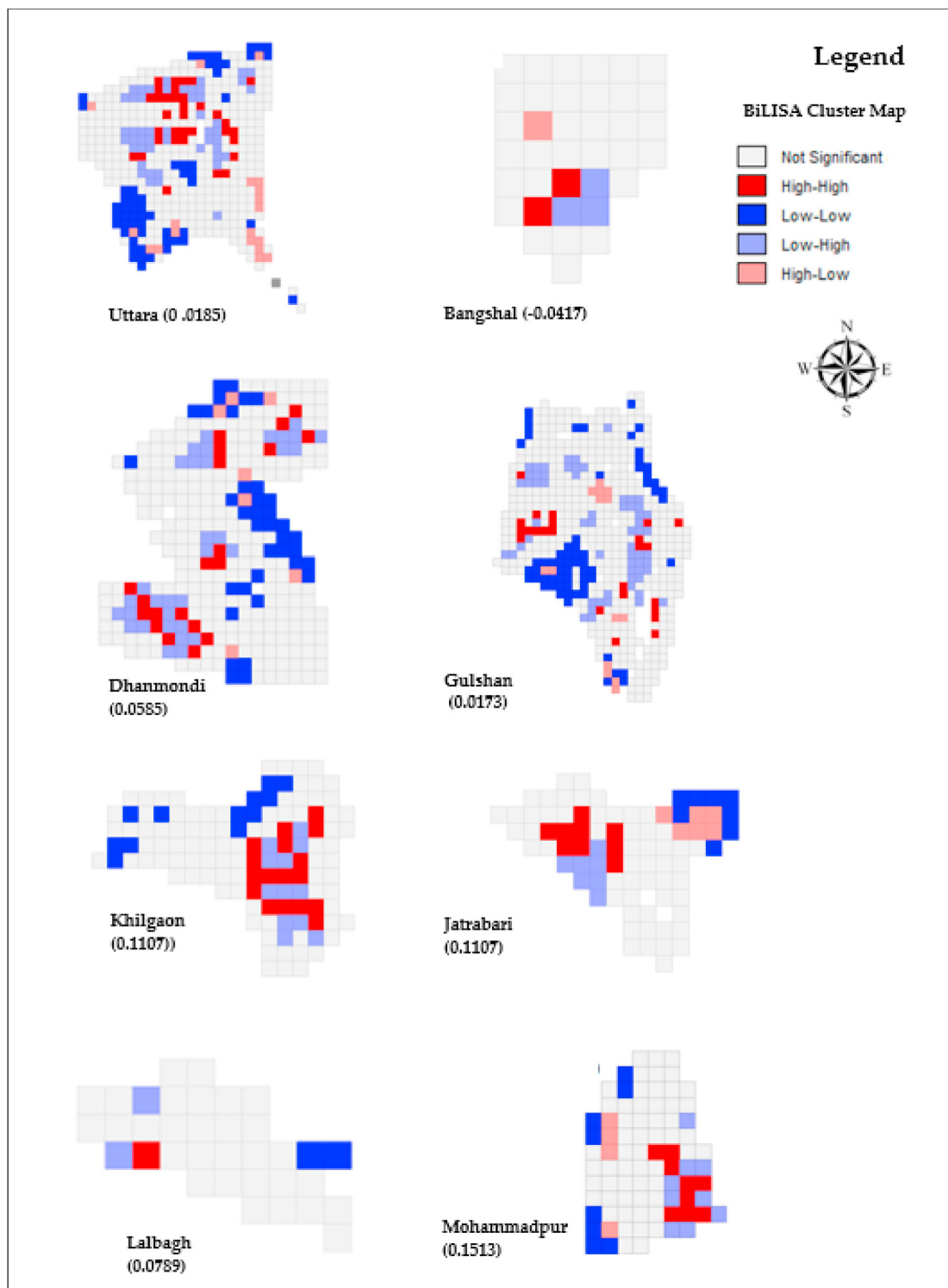


Fig. 2. Bivariate relationship between the Workplace and Residential Space among the studied neighborhoods.

4.1. Reasoning behind compactness level variability in local context

Besides urban form elements, several other factors might be influencing compactness level as a confounding factor. In the case of Dhaka city, rapid urbanization has taken place over the last few decades, affecting different parts of the city differently. Core city areas

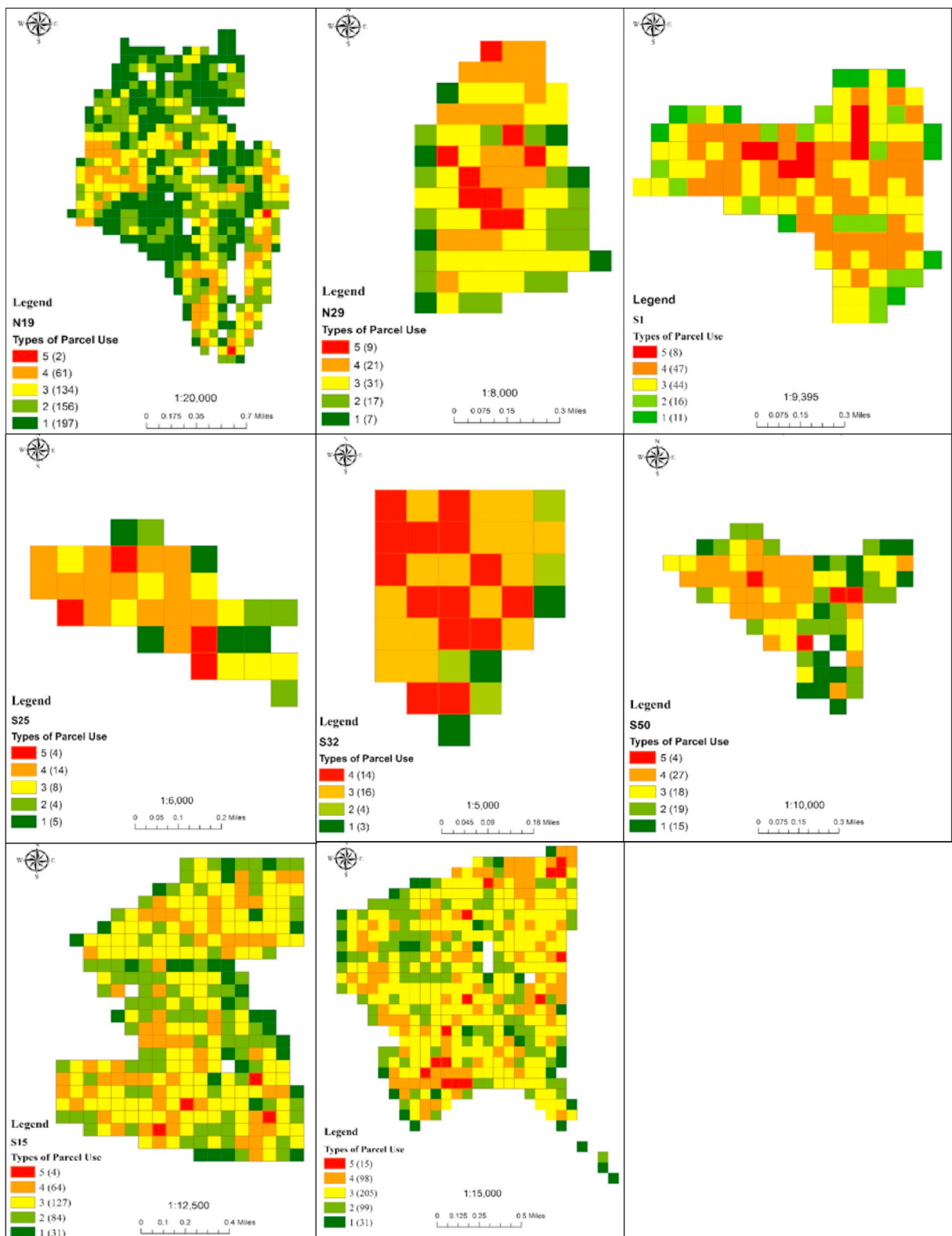


Fig. 3. Variation of floor use mix of the studied neighborhoods.

experienced vertical development, whereas peripheral areas experienced horizontal expansion. Here, residential land use is more evenly distributed than non-residential use because of the predominant nature of the capital city itself, i.e., Dhaka city is predominantly using its larger portion of the land for residential purposes for accommodating ongoing demand for housing (Labib et al., 2013). Major force towards uneven strip development of non-residential uses is due to the high demand for lands for commercial, institutional, and industrial development on both sides of arterial or sub-arterial roads. Also, few neighborhoods are experiencing sprawl development due to slum or squatter development in neighborhoods located in fringe areas. Increased living costs in dense urban cores and high rural-urban migration contributing to gentrification and triggers generate low-income settlements like slums or squatter in neighborhoods (Ahmed et al., 2014; Hossain, 2007). Besides, factors like existing development regulation, inequity in public facility distribution water body and open space distribution, contributing compactness level of neighborhood areas of the city (Mahtab-uz-Zaman & Lau, 2000; Rahman, 2012).

4.2. Need for comprehensive study on compact development

Researchers from developed countries promoted the idea of compact development on a city scale (Zhao et al., 2020). In contrast, many developing countries are already compact with existing spatial structures (Richardson et al., 2000, pp. 25–36). But many find this spontaneous compactness results from the lax planned land use policy of developing countries (Richardson et al., 2000, pp. 25–36). But, the effect of compactness needs to be measured as previous research found that high density in developing country cities is frequently associated with high levels of environmental degradation, i.e., high congestion in core city results increase vehicular emission, inadequate solid waste management systems (Richardson et al., 2000, pp. 25–36), and catalyzed the spread of COVID-19 (Rahman et al., 2021). Although compact urban form at the neighborhood scale provides higher accessibility of urban facilities within walking distance, neighborhood safety, neighborhood satisfaction, social networking, and public engagement need to be accounted for (Shirazi, 2020). Hence, the effects of compact neighborhoods on the environment, economy, and society as a whole need to be analyzed comprehensively.

4.3. Policy implications

The compactness evaluation created for the present study would help planners and policymakers effectively identify areas where compactness levels should be improved and which elements should be considered. The index also acts as a surrogate value for the positive impact of dense, connected, and densified neighborhood environments. Based on the current results, several policy initiatives are recommended to improve Dhaka city's overall physical urban environment.

4.3.1. Job-housing balance

From the CCI values, moderate to low compact neighborhoods should be considered for compactness improvement through changing existing spatial structures in a planned way. Policy like jobs-housing balance might help improving compactness level significantly. From the neighborhood residential to workplace floor space ratio values (Appendix Table- 1), it can be observed that there is still scope to allow more workplace-generating land uses to a controllable extent where the residence to workplace ratio is comparatively high.

4.3.2. Densification of existing areas

Study results showed the scope of further densification of few neighborhoods, i.e., Uttara, Gulshan, Dhanmondi, and Mohammadpur, to become more compact. Residential use and further densification of institutional, office, and commercial use should be encouraged to

Table 7
Normalized Decision matrix.

Variables	Criteria (Cost/Benefit)	Neighborhoods							
		A1	A2	A3	A4	A5	A6	A7	A8
V1	B	0.87	0.22	0.18	0.76	0.49	1.00	0.60	0.18
V2	C	0.71	0.64	0.54	0.43	1.00	0.61	0.51	0.63
V3	C	0.83	0.44	0.30	0.51	0.55	1.00	0.67	0.45
V4	C	1.00	−0.62	−0.19	−0.08	−0.13	2.25	−0.10	−0.18
V5	C	1.00	0.75	0.06	0.13	0.75	0.24	0.28	0.48
V6	B	−0.28	0.39	0.11	0.49	0.74	0.52	1.00	0.13
V7	C	0.85	0.69	0.19	0.38	0.79	0.48	0.85	1.00
V8	B	0.38	0.96	1.00	0.81	0.45	0.40	0.70	0.78
V9	B	0.94	0.90	0.53	0.47	0.76	0.50	0.81	1.00
V10	B	0.83	0.45	0.24	0.71	0.82	0.87	0.53	0.48
V11	B	0.00	0.11	0.03	0.42	0.56	1.00	0.92	0.29
V12	B	1.00	0.77	0.81	0.88	0.71	0.79	0.65	0.67
V13	B	0.77	0.66	0.84	0.62	0.95	0.70	1.00	0.86
V14	B	0.90	0.77	0.88	0.72	0.92	0.70	1.00	0.88
V15	C	0.51	0.84	0.56	0.93	0.47	1.00	0.27	0.56
V16	B	0.37	0.67	0.91	0.21	1.00	0.87	0.31	0.86

Table 8

Weighted normalized decision matrix.

Variables	Criteria (Cost/Benefit)	Neighborhoods							
		A1	A2	A3	A4	A5	A6	A7	A8
V1	B	0.05	0.01	0.01	0.05	0.03	0.06	0.04	0.01
V2	C	0.04	0.04	0.03	0.03	0.06	0.04	0.03	0.04
V3	C	0.05	0.03	0.02	0.03	0.03	0.06	0.04	0.03
V4	C	0.06	−0.04	−0.01	−0.01	−0.01	0.14	−0.01	−0.01
V5	C	0.06	0.05	0.00	0.01	0.05	0.01	0.02	0.03
V6	B	−0.02	0.02	0.01	0.03	0.05	0.03	0.06	0.01
V7	C	0.05	0.04	0.01	0.02	0.05	0.03	0.05	0.06
V8	B	0.02	0.06	0.06	0.05	0.03	0.03	0.04	0.05
V9	B	0.06	0.06	0.03	0.03	0.05	0.03	0.05	0.06
V10	B	0.05	0.03	0.02	0.04	0.05	0.05	0.03	0.03
V11	B	0.00	0.01	0.00	0.03	0.03	0.06	0.06	0.02
V12	B	0.06	0.05	0.05	0.05	0.04	0.05	0.04	0.04
V13	B	0.05	0.04	0.05	0.04	0.06	0.04	0.06	0.05
V14	B	0.06	0.05	0.05	0.05	0.06	0.04	0.06	0.05
V15	C	0.03	0.05	0.04	0.06	0.03	0.06	0.02	0.04
V16	B	0.02	0.04	0.06	0.01	0.06	0.05	0.02	0.05
Composite Score		0.67	0.54	0.44	0.52	0.68	0.81	0.62	0.57

Table 9

Neighborhood categorization based on CCI score.

Neighborhood Code	Neighborhoods (Ward No.)	CCI Score	Status
A3	Gulshan (19)	0.44 to 0.56	Low Compact
A4	Jatrabari (86)		
A2	Dhanmondi (49)		
A8	Uttara (1)	0.56 to 0.69	Moderate Compact
A7	Mohammadpur (42)		
A1	Bangshal (68)		
A5	Khilgaon (24)	0.69 to 0.81	High Compact
A6	Lalbagh (61)		

Table 10

Difference in travel distance and time of commuters living in different types of neighborhoods.

Types of neighborhoods	^a Modal share (in %)			Average work trip travel time (min.)	Travel Distance (km.)
	Active	Transit	Private		
High Compact	79.67	8.72	7.30	26.55	4.01
Moderate Compact	64.43	19.78	7.83	29.23	7.40
Low Compact	44.05	29.38	17.88	38.93	7.93

^a Modal share data doesn't present all modes; hence added-up percentage is not 100%.

allow smart growth. Besides, there should be standards for a minimum number of housing units per land parcel, limiting the sprawl development in peripheral areas.

4.3.3. Infill or brownfield development

Infill or brownfield development should be carried out to low to moderate compact neighborhoods as infill developments provide opportunities to reuse both the land and the existing infrastructure. Development authorities need to locate and evaluate the development suitability of these sites.

4.3.4. Transit-oriented development

High-density housing developments near transit corridors should be constructed to reduce dependence on the automobile. For minimizing the negative consequences of compaction, the government should implement development concepts, such as mixed-use and transit-oriented development, to create walkable and eco-friendly neighborhoods.

4.3.5. Concentrated decentralization

On a neighborhood scale, the development pattern should be polycentric to break down their mono functionality. This policy would densify selected areas for the benefit of agglomeration of residential and non-residential use. Also, selected sub-centers need to be connected by transport and development corridors for enhancing accessibility and mobility.

4.4. Limitations and way forward

The CCI index framework of this study has notable limitations. First, urban form characteristics defining the compactness level might not cover compactness indicators comprehensively. Several other factors, i.e., accessibility to urban facilities, neighborhood safety, social interaction, environmental indicators, can be incorporated with refined validation (i.e., Delphi) and scoring techniques. Second, assumptions considered for formulating the composite index need to be checked in different settlement contexts and geographic scales before application.

5. Conclusion

The paper contributes to the body of literature by providing rare empirical evidence of compactness evaluation in the South Asia context. It presents a comprehensive index specifically created for compactness level evaluation at neighborhood scale. The spatial index was derived from six urban form indicators-population density, evenness and clustering nature of development, land use diversity, floor use mix, and road network connectivity. For each urban form indicator, rule-based assumptions were made following previous literature. Finally, Simple Additive Weighting (SAW) based multi-criteria decision-making approach (MCDM) was used for developing the Composite Compactness Index (CCI) score. As there were no threshold values urban form indicators to be identified as the ideal of the compact development, CCI provided an opportunity to compare compactness levels of city neighborhoods. The proposed method would enable municipal governments of both developed and developing countries to compare the current compactness of neighborhoods, leading to the motivation to improve their policies.

According to their CCI value, neighborhoods were classified as high compact, moderately compact, and low compact. Population density measure showed a significant population occupying existing residential floor spaces. The evenness of space distribution measured by Gini index indicated more even or continuous distribution of residential space with the opposite outcome for workplace space distribution in studied neighborhoods. Bivariate Moran coefficient found positive spatial autocorrelation between residential and workplace floor use, indicating proximity to each other forming polycentric urban form. Entropy indexed-based diversity measure confirmed that most of the neighborhoods are diverse in terms of different land-use types in close proximity. Floor use mix variable also conforms to the issues of intensive land use development. Lastly, connectivity measuring variables depicted network connectedness inside the study areas.

The existing spatial structure's focus would help identify areas where more significant effort might be needed to develop a neighborhood in a more compact setting. Changes in the urban form elements would impact compactness level, allowing policymakers to grasp the effect of changes through cost-benefit analysis easily. Hence, the empirical evidence found in this study would help local level planning. City authorities around the world are planning to reduce the sprawling of urban areas and increasing compactness. In this scenario, this study showed that how different urban form elements can affect the overall compactness of neighborhoods which would be directive for planners working in development authorities.

Furthermore, the case study of compactness measurement in developing country context would help compare developed countries results in the future. The result of this study can be generalized to another study context as the urban form indicators, and measurement techniques used in this research are transferrable. It is evaluated that the performance of compact neighborhoods is sustainable in terms of the transportation system for which cities around the world should focus on creating more balanced, diversified, clustered, mixed-use, and connected development in neighborhoods. However, the study conducted in different geographical settings should determine the threshold value of different indicators in terms of their socio-demographic context for better application.

Declaration of competing interest

We declared no conflict of interest regarding this manuscript.

Appendix

Table 1
Distribution of the residential and workplace floor spaces in the neighborhoods

Neighborhood	Residential FS (%)	Workplace FS (%)	Total Floor Area (Sq.Km.)	Ratio Residential/Workplace
Bangshal	(47.2)	(52.8)	0.52	2.45
Dhanmondi	(61.5)	(38.5)	3.36	4.3
Gulshan	(58.8)	(41.2)	6.52	3.59
Jatrabari	(58.7)	(41.3)	0.60	2.67
Khilgaon	(69.8)	(30.2)	1.57	5.37
Lalbagh	(57.0)	(43.0)	0.24	3.18
Mohammadpur	(76.0)	(24.0)	0.64	5.33
Uttara	(71.0)	(29.0)	5.85	5.22

References

- Abdullahi, S., Pradhan, B., & Jebur, M. N. (2015). GIS-based sustainable city compactness assessment using integration of MCDM, Bayes theorem and RADAR technology. *Geocarto International*, 30(4), 365–387.
- Abdullahi, S., Pradhan, B., Mansor, S., & Shariff, A. R. M. (2015). GIS-based modeling for the spatial measurement and evaluation of mixed land use development for a compact city. *GIScience and Remote Sensing*, 52(1), 18–39.
- Afshari, A., Mojahed, M., & Yusuff, R. M. (2010). Simple additive weighting approach to personnel selection problem. *International Journal of Innovation, Management and Technology*, 1(5), 511.
- Ahlfeldt, G., & Pietrostefani, E. (2017). *The effects of compact urban form: A qualitative and quantitative evidence review*. London and Washington, DC: Coalition for Urban Transitions. Retrieved from <http://newclimateeconomy.net/content/cities-working-papers>.
- Ahmed, S., & Bramley, G. (2015). How will Dhaka grow spatially in future? Modelling its urban growth with a near-future planning scenario perspective. *International Journal of Sustainable Built Environment*, 4(2), 359–377.
- Ahmed, S. J., Nahiduzzaman, K. M., & Bramley, G. (2014). From a town to a megacity: 400 years of growth. In *Dhaka megacity* (pp. 23–43). Dordrecht: Springer.
- Ahmed, S., Nahiduzzaman, K. M., & Hasan, M. M. U. (2018). Dhaka, Bangladesh: Unpacking challenges and reflecting on unjust transitions. *Cities*, 77, 142–157.
- Anderson, W. P., Kanaroglou, P. S., & Miller, E. J. (1996). Urban form, energy, and the environment: A review of issues, evidence, and policy. *Urban Studies*, 33, 7–35 (CC).
- Angel, S., Parent, J., Civco, D., & Blei, A. (2011, January 1). *Making room for a planet of cities making room for a planet of cities*. Retrieved from https://www.researchgate.net/publication/267418628_Making_Room_for_a_Planet_of_cities.
- Annex, I. (1992, August). Report of the United Nations conference on environment and development. In *Rio de Janeiro (3–14 June 1992) A/CONF* (Vol. 151, p. 12), 26.
- Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical Analysis*, 27(2), 93–115.
- Ashik, F. R., Mim, S. A., & Neema, M. N. (2020). Towards vertical spatial equity of urban facilities: An integration of spatial and aspatial accessibility. *Journal of Urban Management*, 9(1), 77–92.
- Bangladesh Bureau of Statistics (BBS). (2011). *Population and housing census, 2011: Urban area report*. Dhaka, Bangladesh: Planning Division, Ministry of Planning.
- Bechle, M. J., Millet, D. B., & Marshall, J. D. (2011). Effects of income and urban form on urban NO₂: Global evidence from satellites. *Environmental Science and Technology*, 45(11), 4914–4919.
- Bertaud, A., & Malpezzi, S. (1999). The spatial distribution of population in 35 world cities: The role of markets, planning and topography. *The Center for urban land and economic research, The University of Wisconsin*.
- Boarnet, M. G. (2011). A broader context for land use and travel behavior, and a research agenda. *Journal of the American Planning Association*, 77, 197–213.
- Burchell, R. W., & Mukherji, S. (2003). Conventional development versus managed growth: The costs of sprawl. *American Journal of Public Health*, 93(9), 1534–1540.
- Burgess, R. (2000). *The compact city debate: A global perspective*. Compact cities: Sustainable urban forms for developing countries.
- Burton, E. (2000). The compact city: Just or just compact? A preliminary analysis. *Urban Studies*, 37(11), 1969–2006.
- Burton, E., Jenks, M., & Williams, K. (2003). *The compact city: A sustainable urban form?* London, England: Routledge.
- Burton, E., Jenks, M., & Williams, K. (2013). *Achieving sustainable urban form*. London, NY: Routledge.
- Cao, X., Mokhtarian, P. L., & Handy, S. L. (2007). Do changes in neighborhood characteristics lead to changes in travel behavior? A structural equation modeling approach. *Transportation*, 34(5), 535–556.
- Cervero, R. (2013). Linking urban transport and land use in developing countries. *Journal of transport and land use*, 6(1), 7–24.
- Chen, H., Jia, B., & Lau, S. S. Y. (2008). Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. *Habitat International*, 32(1), 28–40.
- Chhetri, P., Han, J. H., Chandra, S., & Corcoran, J. (2013). Mapping urban residential density patterns: Compact city model in Melbourne, Australia. *City, Culture and Society*, 4(2), 77–85.
- Choguill, C. L. (2008). Developing sustainable neighbourhoods. *Habitat International*, 32(1), 41–48.
- Clark, A., & Scott, D. (2014). Understanding the impact of the modifiable areal unit problem on the relationship between active travel and the built environment. *Urban Studies*, 51(2), 284–299.
- Cliff, A., & Ord, K. (1972). Testing for spatial autocorrelation among regression residuals. *Geographical Analysis*, 4(3), 267–284.
- Cole, J. P. (1964, July). Study of major and minor civil divisions in political geography. In *The 20th international geographical congress*.
- Crooks, A. T. (2010). Constructing and implementing an agent-based model of residential segregation through vector GIS. *International Journal of Geographical Information Science*, 24(5), 661–675.
- Dhaka. (2021, March 27). Wikipedia.
- Dhaka Transport Co-ordination Authority. (2015). Revised strategic transport plan (2015–2031), Dhaka, Bangladesh. Retrieved from [https://dtca.portal.gov.bd/sites/default/files/files/dtca.portal.gov.bd/page/2c9ed98b_602a_468b_84bc_6b4858449313/DFR_UrbanTransport%20Policy%20\(Edited\).pdf](https://dtca.portal.gov.bd/sites/default/files/files/dtca.portal.gov.bd/page/2c9ed98b_602a_468b_84bc_6b4858449313/DFR_UrbanTransport%20Policy%20(Edited).pdf).
- Dieleman, F., & Wegener, M. (2004). Compact city and urban sprawl. *Built Environment*, 30(4), 308–323.
- Ding, G. K. (2005). Developing a multi-criteria approach for the measurement of sustainable performance. *Building Research & Information*, 33(1), 3–16. <https://doi.org/10.1080/0961321042000322618>
- Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. *Journal of the American Planning Association*, 76(3), 265–294.
- Friedman, A. (2007). *Sustainable residential development: Planning and design for green neighborhoods*. New York, NY: McGraw Hill Professional.
- Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: Defining and measuring an elusive concept. *Housing policy debate*, 12(4), 681–717.
- Geurs, K. T., & Van Wee, B. (2006). Ex-post evaluation of thirty years of compact urban development in The Netherlands. *Urban Studies*, 43(1), 139–160.
- Gordon, P., & Richardson, W. (1997). Are compact cities a desirable goal? *Journal of the American Planning Association*, 63(1), 95–106.
- Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. *Landscape and Urban Planning*, 128, 72–82.
- Hoppenbrouwer, E., & Louw, E. (2005). Mixed-use development: Theory and practice in amsterdam's eastern docklands. *European Planning Studies*, 13(7), 967–983.
- Hossain, S. (2007). Poverty and vulnerability in urban Bangladesh: The case of slum communities in Dhaka city. *International Journal of Development Issues*, 6(1), 50–62. <https://en.wikipedia.org/wiki/Dhaka>.
- Hossain, S. (2013). *Social formations of the megacity of Dhaka: A review essay*.
- Islam, I., Adnan, M. S. G., Rahman, M., & Sayed, M. (2009, August). An analysis of spatial structure of Dhaka: Associated problems and issues. In *10th Asian urbanization conference, Hong Kong*.
- Jabareen, Y. R. (2006). Sustainable urban forms: Their typologies, models, and concepts. *Journal of Planning Education and Research*, 26(1), 38–52.
- Kabir, A., & Parolin, B. (2012, July). Planning and development of Dhaka—a story of 400 years. In *15th international planning history society conference* (pp. 1–20).
- Kashem, S. B., Chowdhury, T. A., Majumder, J., & Rahman, A. M. (2009). Quantifying urban form: A case study of rajshahi city. *Journal of Bangladesh Institute of Planners*, 2, 39–48.
- Koziatek, O., & Dragičević, S. (2019). A local and regional spatial index for measuring three-dimensional urban compactness growth. *Environment and Planning B: Urban Analytics and City Science*, 46(1), 143–164.
- Labib, S. M., Bhuiya, M. M. R., & Rahaman, M. Z. (2013). Location and size preference for apartments in Dhaka and prospect of real estate market. *Bangladesh Research Publications Journal*, 9(2), 87–96.
- Lan, T., Shao, G., Xu, Z., Tang, L., & Sun, L. (2021). Measuring urban compactness based on functional characterization and human activity intensity by integrating multiple geospatial data sources. *Ecological Indicators*, 121, 107177.
- Lee, J., Kurisu, K., An, K., & Hanaki, K. (2015). Development of the compact city index and its application to Japanese cities. *Urban Studies*, 52(6), 1054–1070.

- Li, X., Mou, Y., Wang, H., Yin, C., & He, Q. (2018). How does polycentric urban form affect urban commuting? Quantitative measurement using geographical big data of 100 cities in China. *Sustainability*, 10(12), 4566.
- Lo, C. P. (2004). Testing urban theories using remote sensing. *GIScience and Remote Sensing*, 41(2), 95–115.
- Lowry, J. H., & Lowry, M. B. (2014). Comparing spatial metrics that quantify urban form. *Computers, Environment and Urban Systems*, 44, 59–67.
- Mahtab-uz-Zaman, Q. M., & Lau, S. S. (2000). City expansion policy versus compact city demand: The case of Dhaka. In M. Jenks, & R. Burgess (Eds.), *The compact cities: Sustainable urban form for developing countries* (pp. 141–1152).
- Morshed, N., Yorke, C., & Zhang, Q. (2017). Urban expansion pattern and land use dynamics in Dhaka, 1989–2014. *The Professional Geographer*, 69(3), 396–411.
- Neuman, M. (2005). The compact city fallacy. *Journal of Planning Education and Research*, 25(1), 11–26.
- OECD. (2012). *Compact city policies: A comparative assessment*. Retrieved from OECD Publishing website. <https://www.oecd.org/greengrowth/compact-city-policies-9789264167865-en.htm>.
- Penfold, R. (2001). *Lecture note for elementary statistics*. Retrieved from <http://www.cquest.toronto.edu/geog/ggr270y/notes/not04c.html>.
- Rahman, S. (2012). Quantifying urban form - compactness versus sprawl: An analysis of chittagong and sylhet metropolitan cities. *Jahangirnagar University Planning Review*, 10, 39–50.
- Rahman, M. H., & Ashik, F. R. (2020). Is neighborhood level jobs-housing balance associated with travel behavior of commuters?: A case study on Dhaka city, Bangladesh. *GeoScape*, 14(2).
- Rahman, M. H., Islam, M. H., & Neema, M. N. (2019). Compactness of neighborhood spatial structure: A case study of selected neighborhoods of DNCC and DSCC area. In *Paper presented at the 1st International conference on sustainability in natural and built environment (iCSNBE 2019)* (pp. 19–22). Dhaka, Bangladesh: GSTMR. Retrieved from http://www.icsnbe.net.au/proceedings/2019/iCSNBE2019_Proceedings.pdf.
- Rahman, M. H., Zafri, N. M., Ashik, F. R., Waliullah, M., & Khan, A. (2021). Identification of risk factors contributing to COVID-19 incidence rates in Bangladesh: A GIS-based spatial modeling approach. *Heliyon*, 7(2), Article e06260.
- Rajdhani Unnayan Katrapakkha (RAJUK). (2015). *Dhaka structure plan 2016–2035 (draft)*. Dhaka: *Rajdhani Unnayan Katrapakkha*, Government of the People's Republic of Bangladesh.
- Rashid, S. F. (2009). Strategies to reduce exclusion among populations living in urban slum settlements in Bangladesh. *Journal of Health, Population, and Nutrition*, 27(4), 574.
- Richardson, H. W. (1973). *The economics of urban size*. Lexington, MA: DC Heath.
- Richardson, H. W., Bae, C. C., & Baxamusa, M. H. (2000). Compact cities in developing countries: Assessment and implications. *Compact cities: Sustainable urban forms for developing countries*.
- Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3), 234–281.
- Sachs, J. D. (2015). *The age of sustainable development*. NY, USA: New York: Columbia University Press.
- Schl  pfer, M., Lee, J., & Bettencourt, L. (2015). *Urban skylines: Building heights and shapes as measures of city size*. arXiv preprint arXiv:1512.00946.
- Shannon, C. E. (1948). A mathematical theory of communication. *The Bell system technical journal*, 27(3), 379–423.
- Shirazi, M. R. (2020). Compact urban form: Neighbouring and social activity. *Sustainability*, 12(5), 1987.
- Siddiqui, K. (2004). *Megacity governance in South Asia: A comparative study*. University Press.
- Siddiqui, K., Ahmed, J., Siddique, K., Huq, S., Hossain, A., Nazimud-Doula, S., & Rezawana, N. (2016). *Social formation in Dhaka, 1985–2005: A longitudinal study of society in a third world megacity*. Routledge.
- Siedentop, S., & Fina, S. (2010). Monitoring urban sprawl in Germany: Towards a GIS-based measurement and assessment approach. *Journal of Land Use Science*, 5(2), 73–104.
- Song, J., Lin, T., Li, X., & Prishchepov, A. V. (2018). Mapping urban functional zones by integrating very high spatial resolution remote sensing imagery and points of interest: A case study of xiamen, China. *Remote Sensing*, 10(11), 1737.
- Sturm, R., & Cohen, D. A. (2004). Suburban sprawl and physical and mental health. *Public Health*, 118(7), 488–496.
- Talukder, S. H., & Newman, P. (2003). *Search of sustainable governance and development management setting for a Megacity and its Extended Metropolitan Region (EMR): The case study of Dhaka-capital of Bangladesh*.
- Tresidder, M. (2005). *Using GIS to measure connectivity: An exploration of issues*. Portland State University (Field Area Paper).
- Tsai, Y. H. (2005). Quantifying urban form: Compactness versus 'sprawl'. *Urban Studies*, 42(1), 141–161.
- Turskis, Z., Zavadskas, E. K., & Zagorskas, J. (2006). Sustainable city compactness evaluation on the basis of GIS and Bayes rule. *International Journal of Strategic Property Management*, 10(3), 185–207.
- Tzeng, G. H., & Huang, J. J. (2011). *Multiple attribute decision making: Methods and applications*. CRC press.
- Who. (2011). *Health co-benefits of climate change mitigation-Transport sector: Health in the green economy*. Geneva: World Health Organization.
- Williams, K. (2014). *Urban form and infrastructure: A morphological review*. Technical Report. Government Office for Science. Retrieved from: <http://eprints.uwe.ac.uk/24989>.
- Yeh, A. G., & Li, X. (2002). A cellular automata model to simulate development density for urban planning. *Environment and Planning B: Planning and Design*, 29(3), 431–450.
- Zhang, Q., He, C., & Liu, Z. (2014). Studying urban development and change in the contiguous United States using two scaled measures derived from nighttime lights data and population census. *GIScience and Remote Sensing*, 51(1), 63–82.
- Zhao, F., Tang, L., Qiu, Q., & Wu, G. (2020). The compactness of spatial structure in Chinese cities: Measurement, clustering patterns and influencing factors. *Ecosystem Health and Sustainability*, 6(1), 1743763.