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Compactness of Neighborhood Spatial Structure: A Case Study of Selected Neighborhoods of DNCC and DSCC Area

Md. Hamidur Rahman*, Md. Hedaetul Islam, Meher Nigar Neema

Department of Urban and Regional Planning, BUET, Dhaka-1000, Bangladesh
*Corresponding author's E-mail: rahman.sumon.buet@gmail.com

Abstract

*The popularization of sustainable development has contributed to the promotion of the urban compactness idea. Since the 1990s, research has generally led to the advocacy of cities that are spatially compact, with a mix of uses. Dhaka has been dealing with some burning issues mainly related to land use management, which gives rise to the shortage of livable space along with environmental degradation and economic instability. Sustainable land use management requires proper study of existing spatial structures. Majority of the previous research focused on indicators that measured compactness or the sprawling nature of urban area at City or Metropolitan scale. This research has quantified neighborhood level spatial structures to study the compactness of the development. For measuring the spatial distribution of the development, the study has taken five variables- density in terms of floor use, residential to employment ratio, the percentage of the built-up area by buildings, the degree of equal distribution measured by Gini Coefficient, and the degree of clustering measured by Moran's I Coefficient. In the case of spatial structure, the Gini represents the degree to which the distribution of the development is concentrated or dispersed over the urban area while Moran's I will measure the degree of clustering or the three-dimensional pattern of the development. Each of the studied neighborhoods (ward) has been divided into 100*100 square grid cells which defines the sub-area for analysis, where each grid cell contains the information of total floor space available for residential and employment use used as a proxy variable of the population. The study found that residential spaces in the wards have more even distribution, with more continuous or random scattering behavior, while employment spaces are clustered in a few sub areas producing monocentric urban form in Neighborhood scale. The study focused mainly on two wards, similar study covering all the wards would give the spatial structure of the whole city, which will be the ultimate need of the policymakers or planners to prepare better land use control plans as well as land use development plans.*

Keywords: Spatial Structure, Sustainability, Density, Evenness, Clustering

1. INTRODUCTION

As per the UN Sustainable Development Goal 11, it suggests that cities and communities should be inclusive, safe, resilient and sustainable. For which, the target has been set as the development of an integrated and sustainable human settlement planning and management by 2030 for sustainable urbanization. For many planners and scholars, compactness is the crucial typology to be implemented to achieve sustainability. For example, Dumreicher et al. (2000) argue that a sustainable city should be compact, dense, diverse, and highly integrated. Sustainability in urban spatial structure has been a key concern of policymakers for the last few decades (Rahman, 2012). The understanding of city structures is important for efficient management and development of a city and it is obvious that the development of a city is closely associated with its structure. The degree of spatial concentration of urban population and employment are the factors to know how a city is structured (Anas et al., 1998). Compactness is one of the most accepted, widely used and most promising options toward the idea of sustainable urban spatial

structure (Islam et al., 2009). The concept of compactness in city development incorporates higher density, centralized activities, and a good mix of different land uses in built structures. As Dhaka city is distinctive in all its existing urban dynamics, an appropriate measure needs to be developed which would help understand its urban form. Because far less knowledge exists on urban form at the neighborhood level than at metropolitan and intermediate geographical levels, this research primarily focuses on neighborhood spatial structure. Urban spatial structure is defined as the physical characteristics that makes up built-up areas, including the shape, size, density, and configuration of settlements (Williams, 2014). Brotchie et al., (1985) expressed it as "the pattern of residential and non-residential urban activities and their interactions as expressed by the built environment which accommodates them". Spatial Structure can be viewed from aggregate and disaggregate standpoints. To date, significant numbers of studies have been conducted to find out the measures and indices of quantifying spatial structure. Bertaud (2001) measured the spatial distribution of the population and trip pattern of the people for characterizing the spatial structure of the city. Galster et al. (2001) proposed eight distinct dimensions focusing on spatial geometry: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. Ewing et al. (2002) developed sprawl indices using four indicators of urban form: residential density; neighborhood mix of homes, jobs, and services; the strength of activity centers and downtowns; accessibility of the street network. Tsai (2005) developed four quantitative variables to measure the dimensions of urban form at the metropolitan level: size (population), density, the degree of equal distribution (Gini coefficient) and degree of clustering (Moran coefficient). Islam et al. (2009) determined the urban form of Dhaka City from sustainability perspective by determining the average land consumption per capita, average distance per capita to the CBD, density profile, dispersion index, eccentricity index, land price index, land use index, relative entropy, Gini and Moran Coefficient. Kashem et al. (2009) studied the urban form of Rajshahi Metropolitan using few static indicators like spatial distribution and pattern of spatial development using Gini Index and Moran's *I*, while Rahman (2012) studied the same for Chittagong and Sylhet Metropolitan with an additional entropy index variable. Measuring compactness or sustainability of urban form is the key research topic developed by most of the studies. Urban development in the form of compact development has long been in the focus of the sustainable urban form debate. The relationship between compact development and sustainability has been questioned (Breheny, 1995, 1997; Thomas & Cousins, 1996) as well as opposed (Gordon and Richardson, 1997). Nevertheless, the supporters of compact development as a more sustainable urban form are many (McLaren, 1992) and to them, the concept of the Compact City is the most promising option to achieve this goal.

The nature of the spatial development measured by density, built-up land, the ratio of housing to employment spaces, evenness and clustering help to get directives for compactness measure of the areas; what kind of spatial structure is more appreciable for the neighborhood to be more compact is one of the key aspect of the study. As polices of compact development suggest more concentration of residential or employment space around the transit stops along with the greater level of mixing, the study is focused on spatial development pattern at neighborhood scale. However, as the neighborhood is considered as a fixed geographic unit, the concentration of development in few sub-areas may lead to greater travel time and distance. Hence, more even distribution with a high-decentralized distribution of floor spaces inside the ward can produce greater compactness in neighborhood scale. The study would check these notions from a more disaggregate level study of spatial structure indicators.

2. DATA AND METHODS

Depending on the relevant context of the studies, urban form measurements at the city (aggregate) scale and the neighborhood (disaggregate) scale are available. However, this study has considered the neighborhood scale and has taken two representative neighborhoods-one is DNCC Ward-13 (Mirpur) and other is DSCC Ward 13 (New Paltan). These two wards are representative as they are selected in terms of spatial location, socioeconomic characteristics of the neighborhood, and the street layout pattern of the area. The basic data required for the study were collected from the Detail Area Plan 2015 database. This study focuses on GIS datasets of all the buildings of the neighborhoods, which had the information of building's nature and the type of structure, locality name, floor-wise use of structure, year of establishment, holding number with spatial location and shape of buildings recorded as a polygon shapefile. Square grids (100m*100m) over the neighborhood's boundary defines the subarea of analysis.

Preparation of grids is useful to avoid the disproportionate division of sub-areas that occurs if administrative units are considered. Here, the studied neighborhoods are of different sizes and shapes, so calculating the indicators of the spatial structure need to be in a proportionate way. The Polygon Structure shapefile from DAP 2015 included numerous floor uses. From these uses, six major uses were created which were- Residential, Commercial, Industrial, Institutional, Recreational, and Mixed Use. The newly reclassified categories Polygon Structure shape file included- Structures with use of service activities like banks, hospitals, public office buildings, cinema halls, hotels are treated as commercial. Structures with use of all religious activities like mosques, temples, and other local religious institutes, hotels, community centers, educational institutes are considered institutional. Structures with residential, industrial, and mixed uses remain the same. Here, mixed-use spaces have been divided equally to residential and employment floor use. All the structure use except residential uses were added up and termed as employment use in the study. The total floor space for each category of the polygon shapefile was calculated by multiplying the floor area with the total number of floors. Final grid was produced with adequate information for calculating Gini and Moran coefficient. The Gini index is used to measure the inequality of the distribution by the following formula -

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

Here, N = the number of sub-areas i.e. each of the grid cell of (100*100m) is considered as sub area, Xi = Proportion of land area in sub-area i, Yi = Proportion of residential or employment space in sub-area i, Gini index varies between 0 and 1; whereas 0, means even distribution and, 1 means maximum discrepancy in distribution. The background calculation for the Moran's I is given below

$$I = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij}(X_i - X)(X_j - X)}{(\sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij}))(X_i - \bar{X})^2} \quad (2)$$

Here, N is the number of sub-areas; Xi is the floor space in sub-area i, X j is the floor space in sub-area j, X bar is the average floor space and Wij is the relative weights between sub-area i and j. Zone of Indifference has been used where the features within the distance band or threshold distance are included in analyses for the target feature. For the selection of the distance band, an Incremental Spatial Autocorrelation was performed which produced a summary of Global Moran's *I* by distance.

3. RESULTS AND DISCUSSION

Density affects sustainability through differences in the consumption of energy; materials; and land for housing, transportation, and urban infrastructure (Walker and Rees, 1997). High density and integrated land use not only conserves resources but also provide for compactness, which encourages social interaction. Density can give an aggregate measure of spatial structure. Population density is a popular measure of urban density calculation, but this study focused on floor space density of an area, which will help to understand the intensity of building use. As the floors used by the users may not necessarily include the actual residents of the ward, hence average of day and night time population has been taken for gross density calculation in terms of floor use. As per the Private Residential Land Development Rules (2004) suggest 350 (person per acre) as gross density for residential development, it can be said that both the study area has a greater intensity of floor use, as her an acre of floor space accommodates nearly 550 people in both the neighborhoods (Table-1). Hence, both the neighborhood is compact in terms of floor use.

Measures	Neighborhood	
	Mirpur	**Paltan**
Grid Area (Acres)	714.13	392.90
Ground Coverage by Structures(Acres)	299.52	110.33
Percentage of Developed Area by Structures (%)	41.94	28.08
Density (Population Per Acre Floor Space)	525	541
Total Residential Floor Space (Acres)	619.63	289.18
Total Employment Floor Space (Acres)	79.40	242.36
Ratio of Residential to Employment Floor Space	7.80	1.19

Table 1: Comparison of floor space information of the two study areas

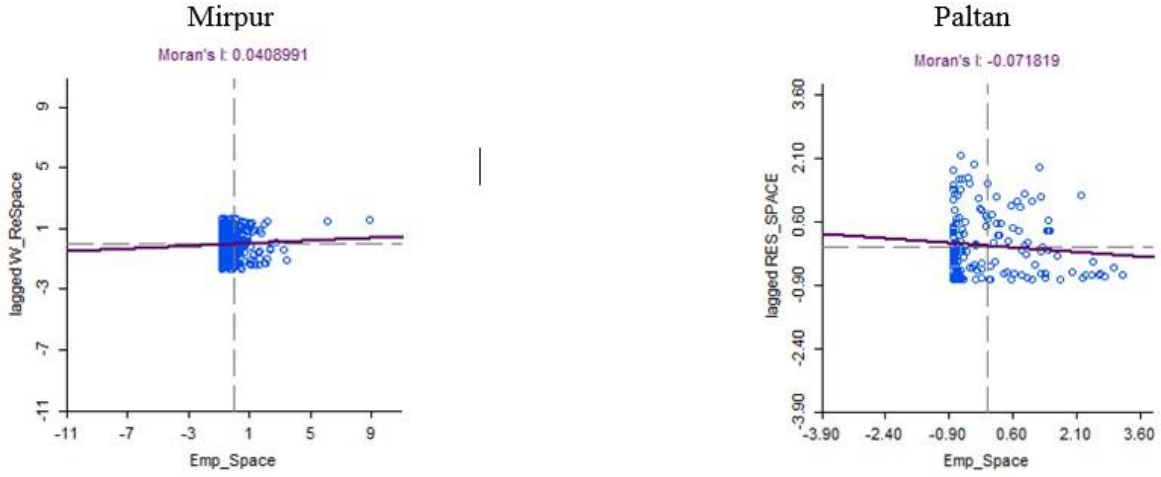
The study used building footprint area for measuring the developed land in each grid cell. By summation of structure area for all the cells of a particular neighborhood, it can be seen that Mirpur area has around 42% of its land covered by buildings while Paltan area has 28% in use (Table-1). As highly sealed areas would increase the temperature of urban areas, the city would face the Urban Heat Island (UHI) effect more acutely. Besides, the increased sealed surface would decrease the percolation rate, which would affect the stormwater drainage. Hence, it can be said that the neighborhood of Paltan is more compact hence sustainable as it has a lower percentage of built-up land by buildings. Besides, Paltan area is more balanced in terms of space distribution than Mirpur area, as for Mirpur the ratio of residential to employment space is higher on a greater margin than Paltan. This ratio value defines the degree of job-housing balance in the neighborhood scale. From the lower value of employment space of Mirpur area, it can be perceived that the distribution of commercial, institutional or industrial facilities is not adequate for being an area to be compact with a different use. Greater imbalances would lead to increased rate of driving, congestion, and air pollution as per the literature suggests. For a sustainable neighborhood, there should be proper mixing of different types of compatible land use. As the sustainability of a compact neighborhood depends on the balance between residential and employment spaces, proper land use distribution for meeting the biocapacity is necessary in this regard. Besides, for the ecological sustainability of an area, there is a certain percentage of land required for ecological purposes i.e. cropland, grazing land, forestland, fishing grounds etc. The higher amount of hard surfaces will lead to less amount of porous land available for maintaining the bio-capacity of an area. The study has used only building footprint areas and no other land use like roads, water bodies, and open spaces. The developable land area along with information of land consumption for other uses like roads, open spaces, water bodies etc. of these two neighborhoods would give a clearer picture of land consumption of the areas, which would help to measure the sustainability. Likewise, neighborhood density is linked to energy consumption. Newman and Kenworthy (1989) found a strong inverse relationship between urban density and energy consumption. As the density of the two neighborhood is comparatively high, it is expected that the energy consumption of the areas would be less than those areas where density is lower.

For being a compact neighborhood, residential and employment spaces should be evenly distributed, as it would increase the accessibility of the service facilities of that area. Besides, the even distribution of residential and employment space would increase the diversity of a neighborhood, which would ultimately increase the sustainability of the area. This study used the Gini coefficient for measuring the evenness of development of residential and employment spaces of the neighborhood. From residential Gini coefficient values, Mirpur shows more even distribution (Gini coefficient of .129) than Paltan Area does (Gini coefficient of .318). The lower value of Residential Gini for Mirpur area can be explained from the predominant residential floor space value of the areas as stated earlier. A similar scenario can be seen from the employment Gini values of the two area where Paltan (Gini coefficient of .572) has a more uneven distribution of employment spaces than Mirpur area (Gini coefficient of .207). The higher value of employment Gini coefficient indicates that the distribution of employment spaces in the wards is more uneven than the residential areas. In Metropolitan scale Kashem (2010), Rahman (2012), Israt et al. (2009) showed that the larger the metropolitan is, the higher the uneven distribution of land-use. However, the notion is not true for neighborhood scale. This uneven distribution may be the result of several reasons. Zoning regulation, distribution of community facilities and utilities, amount of space dedicated to roads, the presence of open space and water bodies of the area etc. need to be studied to understand the reason for such distribution. However, such study is outside the scope of this research. One of the key aspects of the Gini coefficient is that it cannot describe the spatial relationship of high-density sub-areas. Hence, it fails to explain whether studied geographical unit (i.e. neighborhood) is

monocentric, polycentric, or decentralized. Therefore, the degree of clustering of the development needs to be studied to measure the extent to which high-density areas are clustered or randomly distributed. The inequality of distribution reckoned by the Gini index is well complemented by the Moran's I index in this regard.

The Moran coefficients for residential and employment land-uses in Mirpur is 0.01 and -0.002 respectively. Higher Moran values for residential spaces indicate that the residential spaces are more concentrated and continuous than the employment spaces. However, Paltan has a higher Moran value for both uses (residential use: 0.229 and employment use: 0.328) than Mirpur. High positive values of Moran coefficient confirm that the tendency of the sub-areas (100m * 100m) with high attribute value (residential space or employment space) to be located near one another and low attribute values to be located near one another. In other words, both residential and employment land-uses are concentrated and clustered in few areas.
It further indicates that both the residential and employment space arrangements tend to be monocentric in nature, displaying high degrees of spatial autocorrelation. It, therefore, leads to the finding that neighborhood of Paltan area is more monocentric than Mirpur.

So far, the analysis considered two variables (e.g. Gini coefficient and Moran' I) separately. However, to get a clear idea about the pattern and distribution of residential and employment spaces over the study areas, multivariate analysis linking the two variables have been done. While univariate Moran's I show the clustering of one land use variable, the bivariate analysis shows the influence of one land use over the other. Here, employment floor space of each neighborhood is compared with the predefined weighted value for the residential spaces. The Bivariate Moran's I is positive when similar values (both high and low) of both the land uses i.e. the residential and the employment are located in close proximity to each other. The Bivariate Moran's I is negative when the opposite occurs i.e. low values of one land use category tend to be close to the high value of another category.



(a) (b)

Figure 1: Bivariate Relationship between the Employment and Residential Space of two Neighborhoods: (a) Mirpur (DNCC 13) and (b) Paltan (DSCC 13)

In Figure-1, the scatter plot shows the original values of original variables (employment floor space) on the horizontal axis and spatial lag of the variable (residential floor space) on the vertical axis. The slope of the regression line is Moran's I. Scatter plot matrix has been prepared to visualize the relationship between the two variables. Moran values for univariate analysis differs from that of the bivariate analysis as univariate analysis deals with single-use; there are high chances that these would be found more clustered or dispersed than the case when two uses are considered.

Variation of bivariate Moran's I is supported by the Bivariate Lisa Cluster map, which visually shows the

pattern of distribution (Figure- 2). For the ward of Mirpur (DNCC 13), the Bivariate Moran's I coefficient is 0.0408 which means there is a very low tendency of locating similar land use values in close proximity. For the ward of Paltan (DSCC 13), the Bivariate Moran's I coefficient is -0.0718 which indicates that there is a negative tendency of the similar land use values of both categories to be in close proximity. Moran coefficient suggests that in the Mirpur neighborhood, the high value of residential space is in close proximity to high value of employment space and vice versa. Whereas, in Paltan opposite scenario can be observed where the high value of residential space is associated with the low value of employment space and hence, resulted in negative Moran coefficient value. For both the cases, the neighborhoods are monocentric and have spatial segregation of concentration of the residential and employment floor spaces.

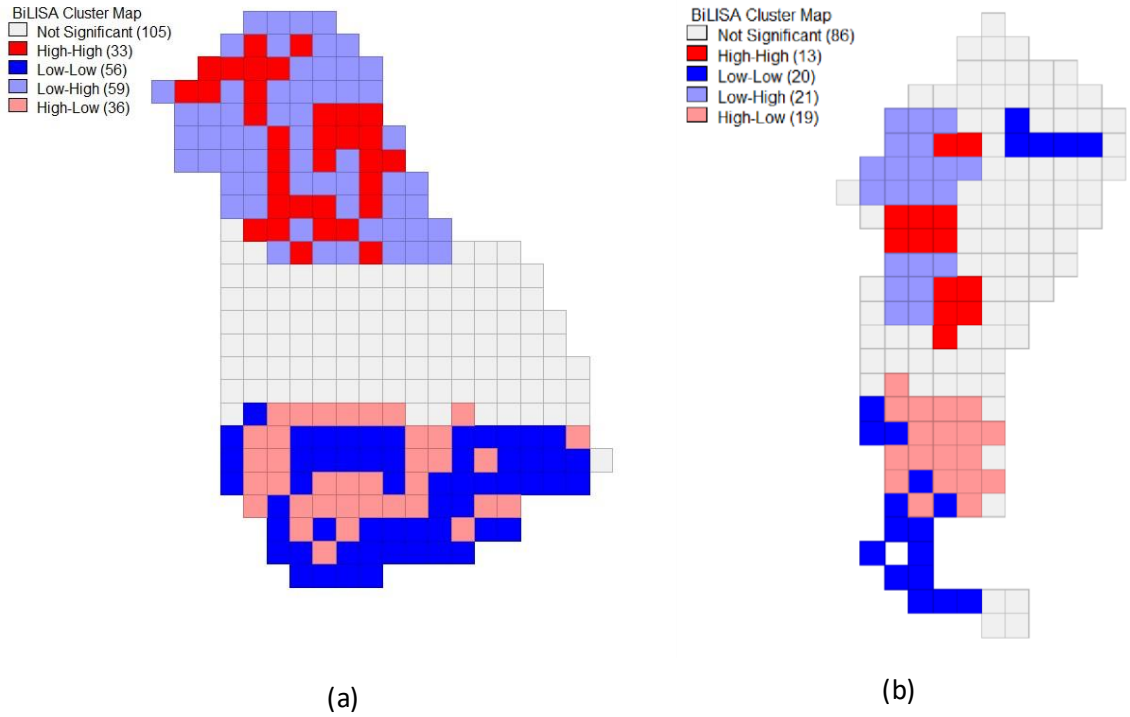


Figure 2: Bivariate Cluster Map considering Residential and Employment Space: (a) Mirpur (DNCC 13) and (b) Paltan (DSCC 13)

Reducing the need for travel is on the agenda of achieving sustainable urban form. Works of literature of neo-traditional planning and the "new urbanism" often argue that car use will decline in the neighborhoods designed with high enough densities and by closely grouping some commercial and residential developments. This monocentric form of development in both neighborhoods would create an imbalance, which would create greater travel time and distance for the residents of the neighborhoods to meet the trip requirements for both work and non-work purpose. Sustainability would be ensured if the number and length of trips by modes of transportation can be reduced which would minimize greenhouse gas emissions.

4. CONCLUSIONS

To ensure sustainability of the city, it's neighborhoods should be more compact through which sustainability would be ensured. This study depicted the scenario of only two neighborhoods, the analytical framework used in the study would help to measure and compare the urban spatial structure at the city scale in the future for effective development regulations. The study attempted to quantify the spatial structure of the city at neighborhood scale to measure the compactness in terms of its density, distribution, and clustering of development. Study results showed that floor use density is comparatively high in both the neighborhoods, of which Mirpur has a greater percentage of built-up area. Evenness of spatial distribution measured by the Gini coefficient indicates that residential spaces in the two neighborhoods are more evenly distributed than the employment spaces. Gini coefficient values for both employment and residential land-use were higher in Paltan, therefore, more unevenly distributed than in

Mirpur. While, the degree of clustering measured by Moran's coefficient suggests that the residential spaces are randomly distributed or more continuous in nature, but employment spaces are clustered in a few sub areas producing monocentric urban form. However, bivariate analysis showed positive spatial auto-correlation between residential space and employment space in Mirpur, indicating close proximity of these two land uses. According to three indicators, these two neighborhoods showed a different degree of compactness. Overall, Paltan area is compact in terms of density and balance between residential and employment spaces but Mirpur is comparatively more compact by all the three indicators except for the balance the two land uses. These three measures are under the domain of environmental sustainability as they have a direct impact on travel mode choice and travel distance of the residents, as well as on urban temperature. Further studies including indicators of environmental, social, and economic aspects of compactness should be carried out to measure the level of sustainability of the urban form.

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