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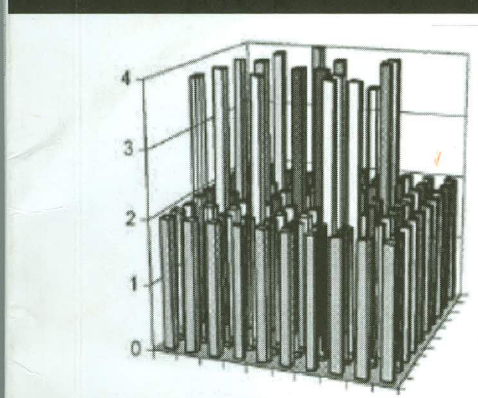

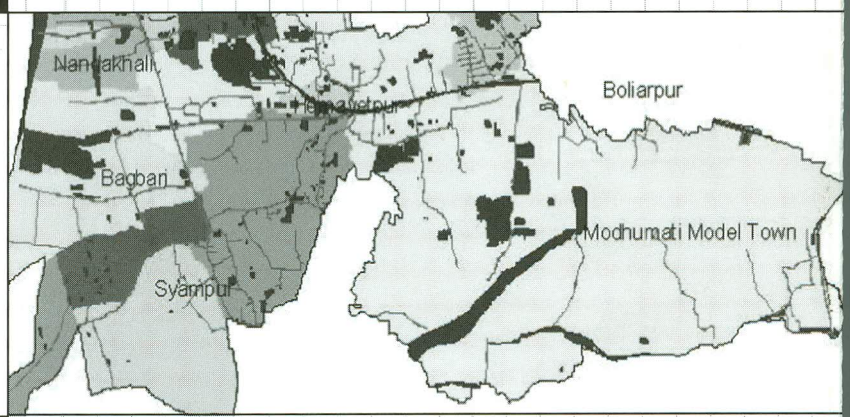

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Quantifying Urban Form - Compactness versus Sprawl: An Analysis of Chittagong and Sylhet Metropolitan Cities

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Abstract

Metropolitan area is characterized by the complex activity system. Compactness is an alternative urban form of urban sprawl focusing on sustainable development. This study is inspired from the necessity of urban form quantification to achieve sustainable urban form and support planner and policy maker to look in depth of city problem from the need and demand point of view rather than supply point of view (traditional master plan and land use plan). This paper is intended to look into the spatial structure of a very large and a comparatively small metropolitan area in Bangladesh based on some selected static indicators of urban sprawl and compactness. The indicators considered include population density, land-use distribution pattern, clustering, nuclearity and mixed uses. Besides quantification of the urban form, a comparison is made between the two case cities to understand the relationship of the indicators and the degree of differences in their form. Unlike the 'number of employment' and 'residential unit' that have traditionally been used to measure urban form, the use of 'employment space' and 'residential space' in the quantification of urban form made this study very unique. From Moran and Gini value it was found that both of these land uses are highly clustered in a few locations in both study areas. Residential space and employment space in large metropolitan with low density is found to be unequally distributed than smaller metropolitan with high density.

Introduction

Sustainable urban development in consideration with land use and infrastructure has been a key concern of policy makers for the last few decades. In recent years, city planners, researchers, developers and policymakers have turned their focus on designing a more compact city for a sustainable urban form. Thus quantifying urban sprawl and compactness becomes major concerns of research among urban researchers.

Unplanned and haphazard urbanization is a common phenomenon in Bangladesh (Alam *et al.* 2006). The capital of the country is called Mega City Dhaka. Six other major cities have the status of City Corporation. However, there is no research in place to quantify urban form in Bangladesh and these kinds of studies provide a perfect ground for showing the need for such research to the urban authorities. Firstly, inhabitants living patterns in relations to the residences and their movement to and from work within the urban area can be well-conceived; secondly, the study can be linked to the intra-urban travel behaviour and thirdly, the nature of urban dynamics, like growth pattern, urban development, activity concentration, land use orientation etc. can be comprehended. Dispersed settlement, for example, contributes to larger travel distances (Cervero, 1996; Naess, 2003) while commuting-to-work mobility in cities is strongly linked to the urban form (Cirilli and Veneri 2008).

The absence of sound knowledge of urban form leads to flawed decisions on urban transportation, growth strategy and infrastructural development in Bangladesh. The purpose of this paper is to quantify the urban form of two cities in Bangladesh on the basis of land use mix, degree of equal distribution and degree of clustering. The measures and indices of urban form, as discussed in the subsequent sections, are developed for comparative analysis of urban forms in general and the sprawling nature of urban areas in specific. This study is unique in its kind in quantifying urban forms and their pattern in Bangladesh. This study avoids the capital city, Dhaka primarily for two reasons. Firstly is the unavailability of suitable data. Secondly, there is no other city in Bangladesh that can be compared with the characteristics and dynamics of the capital city. Due to the scarcity

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of comparable data of other cities in Bangladesh this paper intends to analyse only two particular urban areas. Nevertheless, this can provide, to some extent, the basic grasp of the techniques to quantify urban form and will also give a premise for further comparative studies.

Theoritical Framework

Definition of the concept of sprawl and the measuring indicators are the two broad issues that are often considered seperately in the contemporary study on urban form. There are a number of researches that are primarily on conceptual level (Hansson, J. 2007, *Galster et al. 2000,* Terzi, F. and Kaya, H. S. 2008), which require to be translated to numerical expressions for better application in the planning process. Urban sprawl is so widely used as a term that it has become as ambiguous as 'compactness' or 'sustainable urban form'. Ewing (1997) provided one of the mostly used definitions of urban sprawl. He defines sprawl as a condition of urban form or land uses, which is characterized by low-density, scattered development; commercial strip development, and leapfrog (i.e. discontinuous) development. Sprawl is, therefore, a condition whereas some researchers prefer to call a process of urban form. In this connection, this paper considers the idea of sprawl as a condition and the measures and indices developed to quantify urban sprawl as a representation of urban form. It should be kept in mind that there have been very limited attempts to analyse and quantify the urban form *per se*, and most of the studies have been carried out to quantify the sprawling and compactness of urban form.

Before the discussion on the quantitative measures of urban form, it is necessary to clarify its meaning. Generally, urban form refers to the physical structure of an urban area. It has also been indicated as the spatial pattern of human activities at a certain point of time (Anderson *et al.* 1996). Urban form can be viewed from aggregate and disaggregate standpoints. The former indicates the overall three dimensional structure of the urban area (settlement size and density), and the latter looks into the spatial pattern within the urban area. Urban form can be viewed from several different geographical scales - regional (Fina and Siedentop, 2008), country (Cirilli and Veneri, 2008), metropolitan (Bertaud and Malpezzi, 1999), city (Tsai, 2005) or neighbourhood (Song and Knaap, 2004).

In 2008, two separate study in urban form quantification used static and dynamics indicator to quantify urban from. In a popular work done by Stefan Fina and Stefan Siedentop in 2008 on urban sprawl in Europe - Identify the challenge. In their work they look at indicators of urban form quantification from the surface and pattern point of view. They classified it again as static and dynamic indicators for urban form quantification. Another pioneer study in this research arena is wrestling sprawl to the ground: Defining and measuring an elusive concept, done by a group of researchers in 2000. For their background they found that there is no common definition for sprawl. They found only two notable exceptions: one in Torrens and Alberti (2000), and the other in Malpezzi (1999). These two studies offer some multiple aspects of sprawl and precise definitions of several dimensions of sprawl. Thus, on the basis of literature and their observations, they define "Sprawl is a pattern of land use in an urban area that exhibit low level of some combination of eight distinct dimensions." Galster et al. (2000). It is possible to find out the different types of sprawl consisting of different combinations of these suggested dimensions. However, all suggested dimensions are static dimensions of urban form quantification. But, it is also possible to use these indicators to quantify urban sprawl as a process of development by looking the changes in patterns of land use over time at the peripheral level.

To date, significant numbers of studies have been conducted to find out the measures and indices to quantify the sprawl. Still, contentions are in place as to which techniques can best explain the urban compactness or sprawl. Such approaches can be broadly grouped in two categories - those who identify the sprawl as a 'process' and those recognising sprawl as a 'condition' of urban form.

The present study is about quantifying and analysing two particular urban areas with a data set of specific time, so it considered the second set of studies (sprawl as a condition). Metropolitan size can be a distinct dimension to measure urban sprawl. Sprawl causes the more land than compact developments, Hess *et al*; (2001). But without the population dimension, the city size says almost nothing. So when the population is added as the dimension with size, the sprawl pattern can be

Table 1: A summary of different dimensions and measures of urban form as developed or applied in different studies

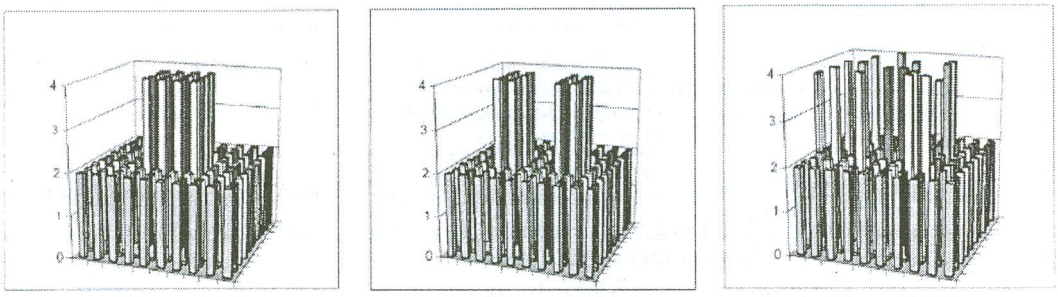
	Dimensions of urban form	Description	Source
Dynamic (as process)	New consumption	Measures the amount of land converted into urban use in a specified time period.	Fina and Siedentop 2008
	Density gradient	Measures the decrease of density with the increase of distance from the CBD.	Torrens and Alberti 2000, Terzi and Kaya 2008
	Openness	Measures integration of new urban areas within existing urban areas (infill development)	Fina and Siedentop 2008
	Conversion of sensitive areas	Proportion of new urban area converted from environmentally sensitive area (forest and semi-natural areas, wetlands and water bodies).	Fina and Siedentop 2008
Static (as condition)	City size	Measures the total metropolitan/urban area/population.	Cirilli and Veneri 2008, Tsai 2005
	Density	Measures the gross/net population/emplyment density. Household/emplyment units are also used as proxies.	Cirilli and Veneri 2008, Tsai 2005, Torrens and Alberti 2000, Terzi and Kaya 2008, Galster *et al.* 2000, Ewing *et al.* 2002, Song and Knaap 2004
	Distribution of development	The degree to which the development is concentrated or distributed across the metropolitan/urban area.	Cirilli and Veneri 2008, Tsai 2005, Galster *et al.* 2000 (they termned as 'Concentration')
	Clustering of development	The degree to which development is grouped/clustered in a few locations.	Cirilli and Veneri 2008, Tsai 2005, Galster *et al.* 2000
	Continuity	The degree to which the development is connected. Development may be contiguous, discontiguous or leapfrog pattern.	Galster *et al.* 2000
	Centrality	The degree to which the residential or non residential or both are concentrated/diffused around the CBD.	Galster *et al.* 2000, Ewing *et al.* 2002 (strength of activity center and downtown)
	Nuclearity	Measures whether the development is monocentric, polycentric or disparsed.	Galster *et al.* 2000
	Mixed uses	The degree to which two or more different land uses are intermingled in a small area.	Galster *et al.* 2000, Ewing *et al.* 2002, Song and Knaap 2004
	Proximity	The degree to which diferent land uses are placed with respect to one another (typically the average distance of residential neighborhoods from one or more sub-centers).	Galster *et al.* 2000, Ewing *et al.* 2002, Bertaud and Malpezzi 1999 (they termed it as 'Compactness Index'), Terzi and Kaya 2008
	Fractal dimension	Fractal dimension is defined as the ratio of the logarithmic functions of perimeter of space and two dimensional area of the space.	Terzi and Kaya 2008
	Total Core Area Index	The core area is defined by a 500 meter buffer from an urban area's boundaries, i.e. the boundary at a 500 meter offset on the inside of the settlement polygon. The index is measured by summing the proportion of core areas of different sub areas. If the urban area contains discontinuous, scattered, small size development, its Core Area Index is low.	Fina and Siedentop 2008

Source: Kashem et al. 2009

viewed by the density measurement. Thus, the most widely used measure of urban form is density, measured by the land consumption per capita. Torrens and Alberti (2000) have done pioneer work on density, which determines the density level at which the urban form can be considered as

sprawling. But density or settlement size can only provide the aggregate measure of urban form. As Galster *et al.* (2000) suggested seven other measures, in addition to density, to quantify the compactness of urban form at the disaggregate level. Many other researchers have also employed one or more of these indicators to explain the urban form. Thus Tsai (2005) explains the efficiency of four indicators such as metropolitan size, density, degree of equal distribution and degree of clustering to measuring urban form. This study is inspired by the idea of him and considers these indicators to quantify Bangladeshi cities. Tsai (2005) suggests Shannon's relative entropy, Gini coefficient and Moran coefficient (also called Moran's I) to measure the land use mix, distribution and clustering respectively. Interestingly, Moran's I can also measure 'continuity' and 'nuclearity' of Galster *et al.* (2000).

The Gini coefficient is a popular statistical tool used to measure the discrimination of income, poverty, literacy rate or such other socio-economic indicators of disparity. In the case of urban form, the Gini represents the degree to which the development is concentrated or dispersed over the urban area. But the measure of spatial distribution cannot describe whether concentration of development occurs in one or two places or is dispersed over the whole area. To measure the degree of clustering we can take the help of spatial auto-correlation, measured by Moran's I. Thus Moran's I can explain the three-dimensional pattern of development. Figure 1 compares the two measures of dispersion, the Gini and Moran coefficients. While Moran's I can explain the degree of clustering of the development, it can also describe whether the development is monocentric, polycentric or decentralized (Figure 1). A high Moran indicates a higher nuclearity and a negative and low Moran indicates the absence of such nuclei. Moran, however, possesses one fundamental flaw. It cannot determine the sharp boundaries or range of its moderate values to determine the polycentric pattern, i.e. the number of nuclei for a given range of Moran value.



Moran: 0.13 Gini: 0.12	Moran: 0.06 Gini: 0.12	Moran: 0.01 Gini: 0.12
Monocentric form	**Polycentric form**	**Decentralised form**

Note: Values close to +1 mean high clustering; values close to zero mean random scattering; and negative values mean a chessboard pattern (Adapted from Tsai 2005, p149)

Fig. 1: Clustering of different degrees with same degree of distribution (same Gini value).

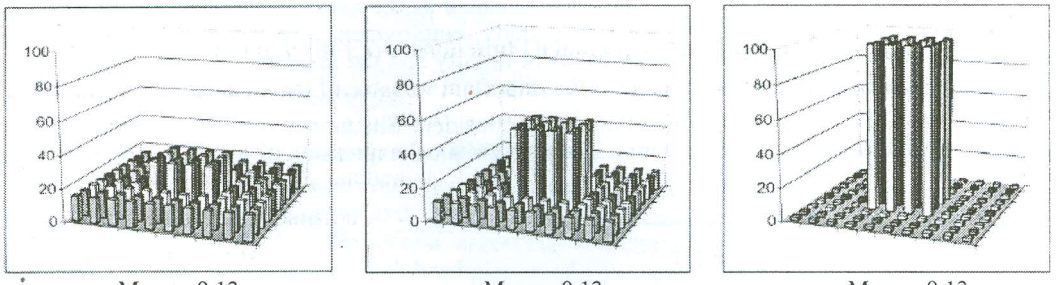
Although spatial auto-correlation can explain several dimensions of urban form, if Gini is not taken into consideration alongside Moran, this can lead to flawed observations. Figure 2 outlines such scenario. In these cases, the Moran values may seem to be the same, because the clustering pattern is the same, but since the distributions of development are different, we have different forms of development. Tsai (2005) also reports that Moran's I cannot differentiate certain leapfrog development patterns, if the Gini coefficient is not applied. It is thus imperative to consider both these indicators in the case of analysing the spatial distribution of development.

Methodology

This study generally finds, perhaps not surprisingly, that many alternative measures exist for urban form quantification and that widely speaking, most produce the same findings. However, these indicators are used to quantify urban form successfully in last two decades.

The basic data for analysis are collected for the database of detailed area plan of two metropolitan cities. This study focuses on GIS data sets for all buildings of the metropolitan areas. The data sets

contain information on buildings, such as the use of the building, the number of floors, and the area of the building. A GIS database includes data about the spatial location and shape of geographic features, recorded as polygons of all the buildings, as well as their attributes (the number of floors and their uses).



Moran: 0.13
Gini: 0.27
More equal distribution

Moran: 0.13
Gini: 0.5
Moderate equal distribution

Moran: 0.13
Gini: 0.75
Least equal distribution

Source: Adapted from Tsai, 2005, p.151

Fig. 2: Varied degrees of distribution at the same degree of clustering (same Moran value)

The square grid over metropolitan area defines the sub-area. The extent of these sub-areas is the analysis unit. Typology of land use and socio-demographic parameters are the main determinants of urban form categorisation. The size of the grid cell should be observed such that variations in urban form characteristics are not lost. "Analysis unit (grid cells) used is smaller than the census zone and larger than a household unit. Therefore, issues related to aggregation and disaggregation need to be addressed" (Narayan, 2009, p 44). The grids were selected as sub-areas instead of administrative units, because grids provide two types of advantages over the polygonal division in the case of administrative units. Firstly, grids avoid the disproportionate division of sub-areas that occurs if administrative units are considered; activities and developments in real world also do not take place following such boundaries. Secondly, in reality, administrative boundaries are of different sizes and different shapes, on the basis of local context. So, it is difficult to compare urban form (or sprawl) of different cities with these disproportionate sub areas. Here, the study area was first divided into 250m × 250m grids. Thus, all output for indicators were then scaled to the polygon layer of square grid for land area.

The main task of the survey data preparation is to redefine and reclassify the land use. The original category of land use is revised for this study. All public office buildings are defined in the survey as government services. All other services, like banks, hospitals, etc. are considered as service activities. This study combines these two kinds of land use with the commercial activity and defined it as commercial. All religious activities like mosques, temples, and other local religious institutes, together with cinema halls, hotels, and community centres are considered as community services in survey. In this study, the cinema halls, hotels, and community services are treated as commercial. All religious institutes are grouped with educational institutes, to be considered as institutional for this study purpose. Residential, industrial and mixed land uses remains the same. Therefore, for the calculation of land use mix this paper grouped all land uses in four categories, namely residential, commercial, institutional and industrial. In addition, for the degree distribution and clustering residential space remains same, but other three categories of land uses again grouped as employment space. It is assumed in this study from the Bangladeshi socio-economic point of view that mixed use is considered to be fifty percent residential and fifty percent employment. Thus residential space and employment space were considered as the proxy of the population and employment, since the population and employment data are not available at the required disaggregate level.

The total building space has been calculated by multiplying the floor area with the total number of floors. Therefore, corresponding value of different uses in a sub area (grid) are calculated. For the analysis of data, each indicator is analysed separately. For a better result of the analysis, this study

excluded all lands that are restricted to development. These restricted lands are mainly reserve hills, tea resorts, rivers and large water bodies, and wetlands. Thus, the remaining lands for the study area are considered as developable land. The city size is very simple, and the gross dimension of urban form. Here, City size is determined by the total number of population and total developable land area. And therefore density calculated as the average number of population per square kilometre of developable land. In this study, employment space per grid and residential space per grid are considered as the employment density and the residential density, respectively. This employment and residential density is the important variable of the analysis.

For the calculation of land use mix, this study considers Shannon's relative entropy, which is commonly used to measure land use mix. The mathematical expression of entropy is given below:

$$\text{Land use mix entropy} = \frac{-\sum[Pn * \ln(Pn)]}{\ln(N)} \quad \ldots\ldots (1)$$

Where,

N = the number of different land uses in the sub area

Pn = the proportion of space of the nth land use within the sub area.

The values of land-uses mix (or entropy) range from 0 to 1, with lower land-use mix buffers (i.e., buffers with more homogeneity in land uses) having values closer to 0 and buffers with greater land use mix having values closer to 1. Thus, the entropy is calculated for all grids (sub area), excluding grids, where the density value zero. An entropy map is produced for each city. The average entropy is calculated for the comparison of the two cities.

The computation of degree of equal distribution, the Gini coefficient is selected as the appropriate method to quantify this indicator. This equation of Gini coefficient is as follows:

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

Here, N is the number of sub-areas, X_i is the proportion of land area in a sub-area i and Y_i is the proportion of residential or employment space in the sub-area i (Tsai, 2005, p146). The values of the Gini range from 0 to 1. The higher the Gini, the more the development is dispersed and *vice-versa*.

This study considered Moran's I based on spatial autocorrelation, as the appropriate method to quantify the degree of clustering of urban area. Univariate Moran and multivariate Moran values are calculated using GeoDa software (developed by Professor Luc Anselin and the Regents of the University of Illinois). The mathematical expression of Moran's I is as follows:

$$I = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij}(X_i - X)(X_j - X)}{\left(\sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij}\right)\left(X_i - \overline{X}\right)^2} \quad \ldots\ldots (3)$$

Here, N is the number of sub-areas; X_i is the population or employment in sub-area i, X_j is the residential or employment space in sub-area j, $\overline{X}$ is the average population or employment and W_{ij} is the relative weights between sub-area i and j. The weights are calculated by forming a weight matrix, the number of rows and columns of which is the equal to the number of sub-areas. The values of Moran's I range from -1 to +1. A high value implies that an observation in a one location will cause similar observations nearby it. That is, if the value tends to be +1, the development is highly clustered monocentric, a value close to zero means a random scattering and a high negative value represents a chessboard like pattern (Tsai, 2005, p.146).

For the calculation of the weight matrix, there are two common methods that are used – the contiguity method, and the inverse-distance-based weighting. The first method counts zero for discontinuous cells and one for contiguous ones while the second method calculates the weights by taking the inverse of the distances of the centre of gravity of two grids. This weight matrix has been used for all calculations. This study used the latter for analysis as it has proved to be more sensitive and accurate (Tsai, 2005, p.147). Univariate LISA cluster map and bivariate LISA cluster map is produced alongside with Moran scatter plot for better understanding of the clustering of both employment and residential space.

Study Area

Bangladesh is a small south Asian country with the highest population density and growth. Among six metropolitan cities, Chittagong and Sylhet metropolitan cities are selected for this study. The Chittagong metropolitan city is the second largest city of Bangladesh based on population size and land area. This city is also divisional headquarter of Chittagong division. According to World Urbanization Prospects Report (2009 revision) Chittagong is 56th urban agglomeration and 10th fast growing city in the world. The busiest sea port of the country makes the city the main international business hub, as well as the commercial capital of the county. Chittagong metropolitan area has the population of 3.83 million (BBS, 2008) in 770 square kilometres of land area (CDA, 2008, Ch1, p.1). The large population size and growth is the main challenge to city planners and policy makers. Unlike Chittagong metropolitan city, Sylhet city is not a business hub of the region. From the earliest times, it has been considered as the important administrative headquarter for the neighbouring regions. The valley of Surma is the origin of this city. Although the jurisdiction of the Sylhet City Corporation covers 26.5 sq. km., the present development trend of the city tends to cover approximately 57.63 sq. km. But the study area (Metropolitan area) is considered 85.63 sq. km. including five growth centres which is merged with the existing City Corporation area. Population growth and continuous migration have been the main factors in the rapid expansion of the city.

Analysis and Discussion of Results

The metropolitan size is an index of sprawl under the understanding that a sprawl city consumes more land than a compact city. The consumption of land, however, gives a wrong indication that population size not be taken into consideration. Per capita land consumption in this case provides a complete scenario and thus explains the compactness of a metropolitan area. In terms of both total area and developable land area, Chittagong has 557 sq. km. developable land that is at least eight times larger than Sylhet with 67.26 sq. km. The population of Chittagong is also about eight times higher than in Sylhet. However, the population density in the developable land of Chittagong is less than in Sylhet. It is, therefore, at the very first hand shows that the developable area of Sylhet is relatively compact than of Chittagong.

The discussion on the degree of distribution requires beforehand, the understanding about how differently land-uses of an area can be mixed with each others. The application of Shannon's relative entropy (see details in the methodology part) shows Chittagong and Sylhet with an average land-use mix value of 0.201 and 0.192, respectively. It therefore marks both cities to have a low degree and low tendency to mix these four types of land use (residential, commercial, institutional and industrial) and thus a low degree of average land use mix in both cases. About one third of the developable area (Chittagong: 30%, Sylhet: 33%) of both cities is absolutely of a single use. Thus the low value of entropy and presence of a single land-use in one third of the developable area leads to conclusion that the urban functions in both cases are differently located in different parts of the cities. Here single land use means entropy value is zero. The sub area with no activity (four categories) is mentioned as density value zero, where there is no land-use. In general, this kind of low degree of land use mix leads to uneven distribution of land uses in the whole city and a high level of clustering. However, this indicator alone is not enough to explain the distribution and clustering of development.

The Gini coefficient for values for Chittagong is found 0.513 and 0.718 for the residential and employment spaces respectively. In the case of Sylhet the values are 0.463 and 0.655 for the

residential and employment spaces respectively. These high values of the Gini coefficient indicate the uneven distribution of residential and employment spaces in the study area. In both cities, the Gini coefficient for employment space is higher than for residential space. It therefore indicates that the residential spaces are intermediately equally distributed and employment spaces are least frequently distributed. The Gini coefficient values for both employment and residential land-use are higher in Chittagong than in Sylhet. The residential and employment land-uses in Chittagong are therefore unevenly distributed than in Sylhet. Thus, the larger the metropolitan is the higher the uneven distribution of land-use. The distribution of urban utilities and facilities and development regulation need to be studies to understand the reason for such distribution of activity. However, such study is outside the scope of this paper.

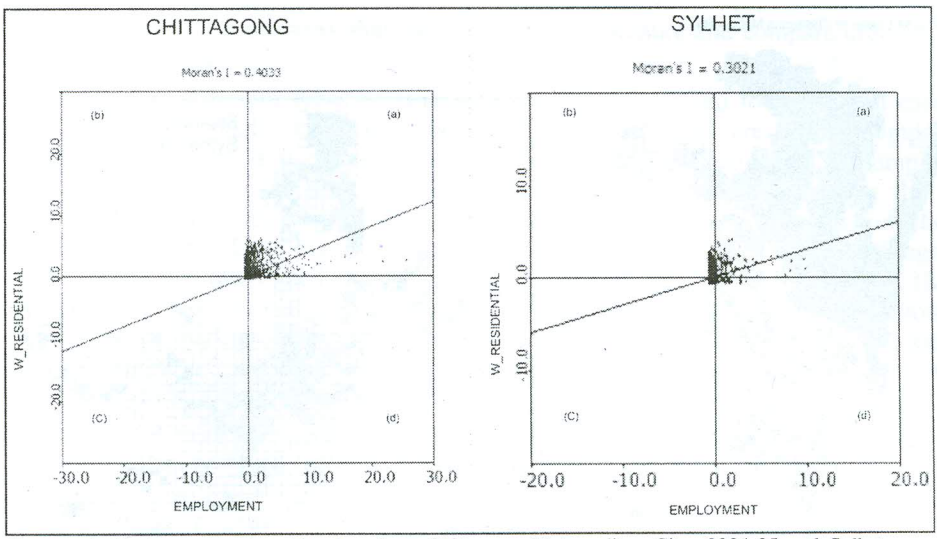
This uneven distribution may the result of several reasons. Hilly topography, tea resort inside city is the main and some other causes that may relate to the segregation of land-use. On the other hand, city centre is highly demanded than other places, thus can lead to the more concentration of land-use inside and near the city centre. Some residential areas are completely residential or industrial zones that are separated from other uses due to the zoning regulation. Thus residential uses are concentrated in residential areas and employment areas are concentrated in commercial areas exclusively in some extent rather than even distribution over the metropolitan. The river passes through both metropolitan cities and Chittagong has a seaport. The existent of water body is the route of water transport that may lead to the concentration of commercial use along the river to get advantage from the river port. Land along both sides of major roads has high demand for commercial strip development. These all factors may be responsible for such kind of highly uneven distribution (high value of Gini coefficient) of land-uses over the metropolitan areas.

The Gini coefficient does not describe the spatial relationship of high density sub-areas. It also fails to explain whether a metropolitan form is more monocentric, polycentric or decentralized sprawl. This paper therefore demands the analysis of the degree of land-use clustering to understand the level of concentration. The degree of clustering explains the extent to which high density areas are clustered or randomly distributed. From the previous discussion, both metropolitans face an unequal distribution of residential and employment spaces; but to know the level of concentration Moran' I is applied to analyse the degree of clustering.

The Moran coefficients for residential and employment land-uses in Chittagong are 0.746 and 0.529 respectively. The high positive values of Moran coefficient confirm that the tendency of the sub areas (250m * 250m) 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. It further indicates that both the residential and employment space arrangements tend to be monocentric in nature, displaying high degrees of spatial autocorrelation. Moreover, this high moran value show that both residential and employment land-uses are concentrated and clustered in few areas. It therefore indicates that the city has a high influential centre of both residential and employment uses. However, the higher Moran value for residential spaces indicates that within this influential centre, residential spaces are more concentrated and continuous than the employment spaces. Employment spaces in Chittagong are, therefore, monocentric but discontinuous.

In the case of Sylhet metropolitan area, the degree of clustering is very similar to that of Chittagong. However, Sylhet has a higher Moran value for both uses (residential use: 0.7803 and employment use: 0.5651) than Chittagong. It therefore leads to the finding that Sylhet metropolitan city is more monocentric than Chittagong metropolitan city.

Compared to employment space, residential space has a higher Moran's I value and a lower Ginii value for both metropolitan areas. It indicates that the distribution of residential space is more clustered and continuous (for higher Moran's I value) and more evenly distributed (for low Gini value) than employment space in both Sylhet and Chittagong. As to the higher Moran of the residential pattern shows, it has more continuity than that of employment distribution. Due to the continuity of the residential spaces, its Gini is less than that of employment space distribution. Likewise, the discontinuous distribution of employment spaces is supported by its lower Moran.



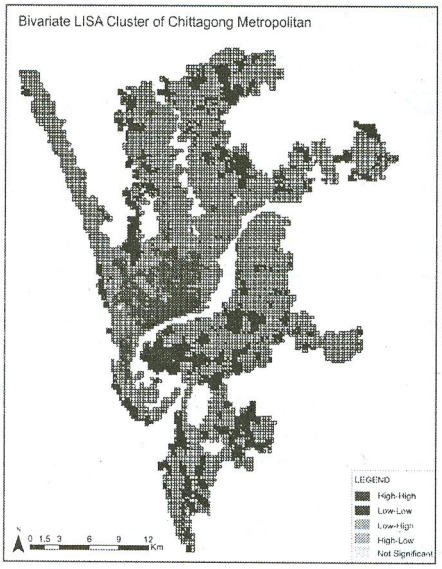
Source: Author's own construction based on Chittagong Metropolitan City, 2004-05 and Sylhet Metropolitan City, 2006-07 Structure Survey Data

Fig. 3: Bivariate relationship between the employment and residential space of two metropolitans

So far the analysis considered two variables (e.g. Gini coefficient and Moran I) separately. However, a general scenario about the distribution and pattern of residential and employment spaces in both study areas can be obtained only when a relationship between the two variables can be established. A multivariate analysis has been administered to link the two variables and estimate their influences on each other.

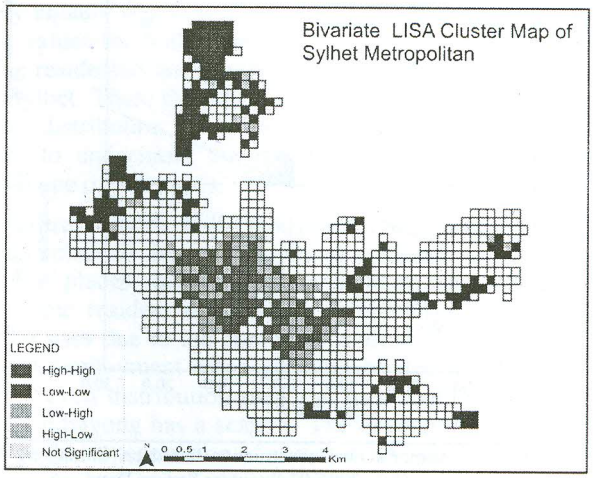
Bivariate Moran coefficients were found to be 0.4033 and 0.3021 for Chittagong and Sylhet, respectively, when the employment area of each city is compared with the predefined weighted value for the residential area (Figure 3). The positive values of bivariant Moran coefficient for both cities indicate a positive and moderate spatial relationship between the residential and employment spaces. The following Bivariate LISA Cluster map (Figures 4 and 5) supports the above finding.

In the Bivariate LISA Cluster map, a high-high relationship means that the sub-area with a higher employment density is linked to high density residential sub-areas. Similarly, a low density employment sub-area surrounded by a low density residential area is termed as a low-low relation. A high density employment sub-area with a low density residential neighbouring sub-area is known as high-low relationship and a low-high relationship is the opposite of that. For the areas surrounding the employment centre, there exists a low-high relationship between the residential and the employment space. It shows that in the peripheral area of the employment centre, comparatively low employment density is prevalent and relatively high density residential areas are located in the central areas. At the same time, it indicates that higher number of people in both cities is residing in the residential areas located in the peripheral area of the employment centre. Similarly, the low-low relationship in both cities indicates low dense residential areas located near to the low dense employment areas (dark black clusters in Figures 4 and 5). For gray colour clusters in the maps, no significant (at 5% level) relationship between residential use and employment use has been observed.



Source: Author's own construction based on Chittagong Metropolitan Structure Survey Data, 2004-2005

Fig. 4: Chittagong bivariate cluster map considering employment and residential space



Source: Author's own construction based on Sylhet Metropolitan Structure Survey Data, 2006-2007

Fig.5: Sylhet bivariate cluster map considering employment and residential space

A difference in Moran's I values has been observed in the univariate and bivariate analyses. Moran's I values in the bivariate analysis have been reduced considerably than in the univariate analysis. As in the case of univariate analysis, a single use is considered (either employment or residential), similarly a high value of Moran's I is observed which means that the individual uses are highly clustered in a place. But when both uses are taken together in the bivariate analysis, the analysis gives a comparatively low Moran's I value and thus shows that highly clustered residential and employment uses are segregated in some degree.

However, the bivariate cluster map confirms the existence of a concentration of both dwelling and activities in some areas of the study area (Figures 4 and 5). This complies with our observations from the two cluster maps, which show the concentration of both of residences and employments in these areas. The concentration of residential activity near employment activity may the result of worse transport system. Because, it is clear that if travel time is so long from living place to working place due to the congestion, travel cost and some other factors, people try to live near the working place to save money and time. Here, it is observed from both case study areas that the residential and the employment activities are highly clustered separately, but are segregated from each other.

Conclusion

The issue of urban sprawl is of crucial importance in urban growth management in urban planning discipline. The patterns of urban spatial development are very complex. After an effective theoretical discussion in previous section, this paper focused on land use mix, degree of equal distribution and degree of clustering to measuring urban form. Following the theoretical discussion, Shannon's relative entropy, Gini coefficient and Moran coefficient (also called Moran's I) are used to measure the land use mix, distribution and clustering respectively. This methodological framework contributes to the analysis of urban sprawl and thus an understanding of sprawl dynamics in two metropolitan cities of Bangladesh. It is not the intension of this paper to generalise the findings of the study for the application in other cities as a whole. However, this

paper gives an analytical framework that can be applied to measure and compare urban forms of other cities of Bangladesh.

The analysis on four different types of land uses that later combined to two broad categories (residential and commercial) shows that the two case study cities are highly compact and monocentric in urban form. It also presents an uneven distribution of residential and employment spaces in cities. However, the low level of average land use mix is found for the whole metropolitan areas. In the case of two case studies, metropolitan size does not have mentionable influence on urban form. Land use in large metropolitan area with low density (Chittagong) is found to be unequally distributed than smaller metropolitan area with high density (Sylhet). Consideration of single land use (either residential or employment) in the analysis shows that smaller city is indicating high degree of clustering than the large city. Analysis with two variables (residential and employment), however, present an opposite result. Degree of land use mix in both cities is also tends to be similar.

This paper is limited from only addressing the quantification of urban form. It is also based on a single time frame data of space use and, therefore, change in urban form over time has not been analyzed. Again, a complete picture of the urban form can only be found when number of employment and residential unit can be considered in the analysis. For absence of necessary data for Bangladeshi cities, such detailed analysis has not been carried out, but only left for future research interpretations. Another important issue is that the impact of different urban forms on urban life is also outside the scope of this paper. The findings of such research can also be related with other crucial urban issues, like travel behaviour, urban growth pattern and spatial segregation, utility services, and housing provision. Thus this research may illuminate important ideas in the future researches on urban forms in Bangladesh.

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References

Alam. J. B., Alam. J. B., Rahman. M. H., Khan. S. K. and Munna. G. M. 2006. Unplanned urbanization: Assessment through calculation of environmental degradation index. *International journal of Environmental Science and Technology,* 3(2) pp. 119-130.

Anderson, W. P., Kanaroglou, P. S. and Miller, E. J. 1996. Urban form, energy and the environment: a review of issues, evidence and policy. *Urban Studies*, 33(1), pp.7–35

Bangladesh Bureau of Statistics, 2009. *Statistical Pocket book of Bangladesh-2008,* Ministry of Planning, Dhaka

Bangladesh Bureau of Statistics (2005). *Statistical Yearbook of Bangladesh-2001,* Ministry of Planning, Dhaka

Bangladesh Bureau of Statistics, 1995. *Statistical Yearbook of Bangladesh-1991,* Ministry of Planning, Dhaka

Bertaud, A. and Malpezzı, S. 1999. The Spatial Distribution of Population in 35 World Cities: The Role of Markets, Planning and Topography. *Centre of Urban Land Economics Research*, the University of Wisconsin, WI, USA

Chittagong Development Authority, 2008. *Chittagong Metropolitan Detail Area Plan,* Chittagong

Cervero, R. 1996. Jobs-housing balance revisited: Trends and impacts in the San Francisco Bay Area. *Journal of the American Planning Association*, 62, pp. 492-511

Cirilli, A. and Veneri, P. 2008. Spatial structure and mobility patterns: towards a taxonomy of the Italian urban systems. *EconPapers*. http://dea.univpm.it/quaderni/pdf/313.pdf (Accessed on February 14, 2010).

Denial, 2001. Polycentric urban structure: The case of Milwaukee Economic perceptive (online) Available at http://www.chicagofed.org/publications/economicperspectives/2001/2qepart2.pdf (Accessed on March 16, 2010).

Ewing, R. 1997. Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association.* http://stuff.mit.edu/afs/athena/course/11/11.951/albacete/Course%20Reader/Transportation/High-Speed%20Tranist %20Literature%20Review/Ewing%201997.pdf. (Accessed on January 16, 2010)

Ewing, R., Pendall, R. and Chen, D. 2002. Measuring Sprawl and Its Impact. *Smart Growth America.* Washington DC. http://www.smartgrowthamerica.org/sprawlindex/MeasuringSprawl.PDF (Accessed on February 11, 2010)

Feng, L. 2009. Applying remote sensing and GIS on monitoring and measuring urban sprawl. A case study of China, *Revista Internacional Sostenibilidad, Tecnología y Humanismo.* N4, pp. 47-56

Fina, S. and Siedentop, S. 2008. Urban sprawl in Europe – identifying the challenge. REALCORP, Vienna. http://programm.corp.at/cdrom2008/papers2008/CORP2008_34.pdf. (Accessed on February 11, 2010)

Galster, G., Hanson, R., Wolman, H., Coleman, S., and Freihage, J. 2001. Wrestling Sprawl to The Ground: Defining And Measuring An Elusive Concept. *Housing Policy Debate* 12, pp. 681-717. www.mi.vt.edu/data/files /hpd%2012(4)/hpd%2012(4)_galster.pdf (Accessed on February 15, 2010)

Galster, G., Hanson, R., Wolman, H., Ratcliffe M., Furdell, K.and Sarzynski, A. (2005). The Fundamental Challenge in Measuring Sprawl: Which Land Should Be Considered? *The Professional Geographer*, 57(1), pp 94–105.

Giuliano, G. and Small, K. A. 1991. Subcenters in the Los Angeles Region, *Regional Science and Urban Economics,* 21, pp. 163-182.

Hansson, J. 2007. Sustainability and the urban form - An assessment of sprawl/compactness indicators in Umeå, Research report, MSc Department of Social and Economic Geography, Umeå university.

Hess, G. R., Daley, S. S., Derrison, B. K. 2001. Just what is sprawl, anyway? *Carolina Planning*, 26(2), pp. 11–26.

Kashem, S. B., Chowdhury, T. A., Majumder, J. and Rahman, A. M. (2009). "Quantifying urban form: a case study of Rajshahi City." Journal of Bangladesh Institute of Planners, 2, 39-48

Lechner, J. and Maier, G. 2009. Sprawl or No Sprawl? A Quantitative Analysis for the City of Vienna, Working paper, Institute of regional development and environment, *Vienna University of Economics and Business, http://epub.wu-wien.ac.at/dyn/virlib/wp/eng/showentry?ID=epub-wu-01_fbb* (Accessed on February 15, 2010)

Malpezzi, S and Guo, W. K. 2001. Measuring "Sprawl:" Alternative measures of urban form in U.S. metropolitan areas. *The Center for Urban Land Economics Research,* the University of Wisconsin

Naess, P. 2003. Urban structures and travel behaviour: Experiences from empirical research in Norway and Denmark. *European Journal of Transport and Infrastructure Research*, 3, pp 155-178

Narayan, S. M. 2009. Quantification of Urban Form Indicators. Research Report, MSc Geo-Information Science and Earth Observation for Environmental Modelling and Management, ITC, The Netherlands

Pan, Q. and Ma, L. n.d. Employment Subcenter Identification: A GIS-Based Method, Research report, School of Public Affairs, Texas Southern University, http://proceedings.esri.com/library/userconf/proc04/docs/pap2074.pdf (Accessed on January 28, 2010)

Ryan, S. and Frank, L .F 2009. Pedestrian Environments and Transit Ridership. *Journal of Public Transportation,* 12(1), pp.48

Song, Y. and Knaap, G. J. 2004. Measuring Urban Form: Is Portland Winning the War on Sprawl? *Journal of the American Planning Association*, 70(2), 210-225. www.smartgrowth.umd.edu/articles/PortlandSprawlPR_ 050404.pdf (Accessed on January 28, 2010)

Terzi, F. and Kaya, H. S. 2008. Analyzing Urban Sprawl Patterns through Fractal Geometry: The Case of Istanbul Metropolitan Area. *Working Paper Series, Paper-144*, CASA: Centre for Advanced Spatial Analysis, University College London, London.

Torrens P. M. and Alberti, M. 2000. *Measuring Sprawl.* Working Paper Series, Paper-27, CASA: Centre for Advanced Spatial Analysis, University College London, London.

Tsai Y. H. 2005. Quantifying urban form: compactness versus 'sprawl'. *Urban Studies*, 42(1). pp.141-161 http://www.webs1.uidaho.edu/ce501-400/resources/tsai.pdf (Accessed on January 8, 2010).