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# Quantifying Urban form: A Case Study of Rajshahi City

**Md. Shakil Bin Kashem**[*]
**Tufayel Ahmed Chowdhury**[**]
**Joydip Majumder**[***], **Md. Asif Rahman**[****]

## Abstract

The urban areas comprise complex systems of activities, so the study of its form in terms of a few statistical measures is quite taxing. This paper attempts to employ such measures to define the urban form of Rajshahi city in Bangladesh. It evaluated some of the measures to quantify urban form and selected two indices, namely, Gini coefficient and Moran coefficient to quantify the urban form of the study area. Residential floor area and floor area for employment was computed in a tessellated form for quantifying the urban form of the study area. GeoDa software was employed to calculate Moran for both of the residential and employment floor space. From Moran and Gini value it was found that both of these land uses are highly clustered in a few locations of the study area. The two indices together give intuitive results, which is, residences are generally more dispersed and continuous than that of employment. Although this kind of analysis of urban form is better applied in comparative analysis, the present study provides the take off point for further research of urban form in Bangladesh.

## Introduction

The study on urban form has been of growing interest in international research arena for past few decades. Such studies provide a set of significant benefits to the urban authorities. Firstly, the activity and dwelling pattern within the urban or metropolitan area can be well-conceived; secondly, this can be linked to the intra-urban travel behavior and thirdly, the nature of urban dynamics can be comprehended. It has been conclusively found that dispersed settlement contribute to larger travel distances (Cervero, 1996; Naess, 2003). Cirilli and Veneri (2008) also found that the commuting-to-work mobility within Italian cities is strongly linked to the urban form. In Bangladesh, however, we lack theoretical and empirical works to address quantitative analysis of urban structure. The lack of sound knowledge of urban form can often lead to flawed decisions on urban transportation, growth strategy and infrastructural development. This paper quantified the urban form at city level. For this analysis, the Rajshahi City Corporation area has been taken as a case study. The measures and indices of urban form, as discussed in the subsequent sections, are developed for comparative analyses of urban forms, in particular, the sprawling nature of urban areas. But the analysis of urban form of a particular area, as is in this paper, can undermine the efficacy of these measures. Due to the paucity of comparable data of other cities in Bangladesh, this paper only analyzed a particular urban area. 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 study.

[*] Lecturer, Department of Urban and Regional Planning, Bangladesh University of Engineering and Technology (BUET), Email: shakilkashem@gmail.com, shakil_kashem@urp.buet.ac.bd

[**] Planning & Research Department, Sheltech (Pvt.) Ltd. Email: tufayel.chowdhury@gmail.com

[***] Research Assistant, Sustainable Accessibility for the Urban Poor Project, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET) Email: imjoydip@gmail.com

[****] Project Assistant in Dhaka, Urban Livelihoods and Functionality of the City Project, Technical University Dortmund, Germany, Email: asif0236@gmail.com

## Literature Review

Researches on urban form till now have mostly focused on defining and quantifying urban sprwal as it has been generally accepted that spwraling pattern of urbanization is undesirable. Urban sprawl is so widely used a term that it has become as ambiguous as 'compactness' or 'sustainable urban form'. However, the definition provided by Ewing (1997) is accepted by many researchers. It states that sprawl is 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, by defintion, is a condition (some researchers prefer 'process') of urban form, so this paper considered the measures and indices developed in to quantify urban sprawl as a representative of urban form. It should be kept in mind that there has been very limited attempts to analyze and quantify the urban form *per se*, 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 to the overall three dimensional structure of the urban area (sattlement size and density) and the latter looks into the spatial pattern within the urban area. Urban form can be viewed from different geographical scales- regional (Fina and Siedentop, 2008), country (Cirilli and Veneri, 2008), metropolitan (Bertaud and Malpezzi, 1999), city (Tsai, 2005) or neighborhood (Song and Knaap, 2004).

To date, significant number 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 types- those who identify the sprawl as a 'process' and those recognizing sprawl as a 'condition' of urban form (see Table 1). The present study is about quantifying and analyzing a particular urban area, so it considered the second set of studies. The most widely used measure of urban form is density, measured by the land consumption per capita. Torrens and Alberti (2000) have done a pioneer work on density who 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. Galster *et al.* (2000) suggested seven other measures, in addition to density, to quantify the compactness of urban form at the disaggregate level. These include- continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. Many other researches also employed one or more of these indicators to explain the urban form. Tsai (2005) suggests Gini coefficient and Moran coefficient (also called Moran's I) to measure the distribution and clustering respectively. Interestingly, Moran's I can also measure 'continuity' and 'nuclearity' of Galster *et al.* (2000). So this study selected the Gini and Moran co-efficients to quantify the urban form. Centrality and Proximity are closely linked. Although Proximity to work is a widely used measure of urban form (Table 1), this study could not measure this due to the paucity of transport data (origin-destination). Fractal dimension (Terzi and Kaya, 2008) and total core area index (Fina and Siedentop, 2008) refer to the geometric aspects of urban form, not the activity or land use distribution, so they were also excluded from this analysis.

This study has selected the Gini and Moran coefficient considering the effectiveness of these indices to explain the distribution, clustering, continuity and nuclearity of development. The Gini coefficient is a popular statistic used to measure the discrimination of income, poverty, literacy rate or such other socio-economic indicators of disparity. In the case of urban form, Gini represents the degree to which the development is concentrated or dispersed over the urban area. The following equation can be used to measure Gini.

$$Gini = \frac{\sum_{i=1}^{N} \left| X_i - Y_i \right|}{2}$$

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 population or employment in the sub-area $i$ (Tsai, 2005). The values of Gini range from 0 to 1. The higher the Gini, the more the development is dispersed and *vice-versa*.

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 |

*Table 1 continued*

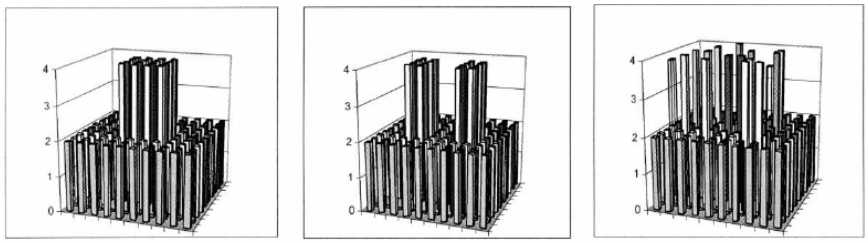
| | Dimensions of urban form | Description | Source |
|---|---|---|---|
| | Proximity | The degree to which diferent land uses are placed with respect to one another (typically the average distance of residential neighborhoods from one or more sub-centers). | Galster *et al.* 2000, Ewing *et al.* 2002, 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 |

But the measure of spatial distribution cannot describe whether concentration of development occurs in one or two places or dispersed over the whole area. To measure the degree of clustering, spatial auto-correlation, measured by Moran's I can be used. The following is the expression of calculating Moran's I (Tsai, 2005).

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

Here, $N$ is the number of sub-areas; $X_i$ is the population or employment in sub-area $i$, $X_j$ is the population or employment 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 location will cause similar observations nearby it. That is, if the value tends to be +1, the development is highly clustered monocentric, a value closed to zero means a random scattering and a high negative value represents a chessboard like pattern (Tsai, 2005). 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.



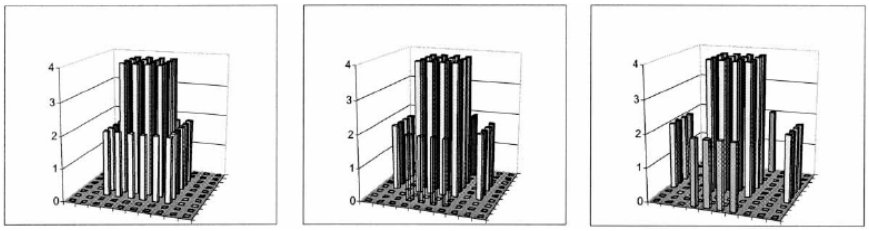
Moran: 0.13
Gini: 0.12
**A. Monocentric form**

Moran: 0.06
Gini: 0.12
**B. Polycentric form**

Moran: -0.01
Gini: 0.12
**C. Decentralised form**

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

As to the 'continuity' of development, Tsai (2005) runs a simulation test that examined the Moran value for continuous and discontinuous patterns of development (Figure 2). It showed that Moran value drops dramatically for a discontinuous form of development from 0.13 in A to 0.06 in B.



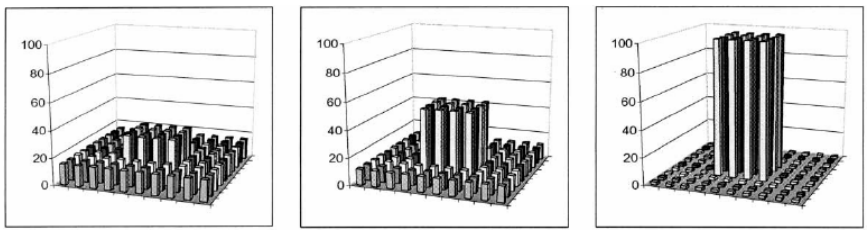
Moran: 0.13
Gini: 0.12
**A. Continuous form**

Moran: 0.06
Gini: 0.12
**B. Moderately discontinuous**

Moran: -0.01
Gini: 0.12
**C. Highly discontinuous**

Fig. 2: Moran's I for continuous and discontinuous forms of development (Adapted from Tsai, 2005)

Although spatial auto-correlation can explain several dimensions of urban form, Moran alone can lead to flawed observations if Gini is not taken into consideration alongside. Figure 3 outlines such scenerio. In these cases, the Moran values may seem to be same because the clustering pattern is the same, but since the distributions of development are different, there are different forms of development. Tsai (2005) also reports that Moran's I cannot differentiate certain leapfrog development pattern if the Gini coefficient is not applied. It is thus imperative to consider both these indicators in case of analyzing the spatial distribution of development.



Moran: 0.13
Gini: 0.27
**A. More equal distribution**

Moran: 0.13
Gini: 0.5
**B. Modarate equal distribution**

Moran: 0.13
Gini: 0.75
**C. Least equal distribution**

Fig. 3: Varied degrees of distribution at the same degree of clustering (same Moran value) (Adapted from Tsai, 2005)

## Study Methodology

This study utilized the GIS database of Rajshahi City prepared for the Rajshahi Metropolitan Development Plan (RMDP) project. The study area was first divided into 250 meter × 250 meter grids. 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, such division will be useful if further studies are to be carried out to compare the urban form (or sprawl) of different cities. Two variables were computed for this analysis: total residential floor space and total employment floor space (obtained by summing the floor area used in employment generating activities, such as, commercial, industrial or institutional uses). These two variables were considered as the proxy of the population and employment, since the population and employment data are not available at the required disaggregate level.

Residential and employment floor spaces in each of the cells of the tessellated study area were computed by GIS tools. Gini coefficients were calculated for each of the variables using the Microsoft Excel software. Moran values were calculated using GeoDa software (developed by Professor Luc Anselin and the Regents of the University of Illinois). As to the calculation of weight matrix, there are commonly two methods- contiguity method and inverse-distance-based weighting. The first method counts zero for discontinuous cells and 1 for contiguous ones while the second method calculates the weights by taking the inverse of the distances from the center of gravity. This study took the latter for analysis because it has been proved to be more sensitive and accurate (Tsai, 2005).

The study area of this analysis is the Rajshahi City Corporation area, so the analysis refers to the urban form in 'city scale'. Rajshahi city, the divisional headquarter of Rajshahi Division, is located in the north-west region of Bangladesh. It has a total area of about 48.06 square kilometers.

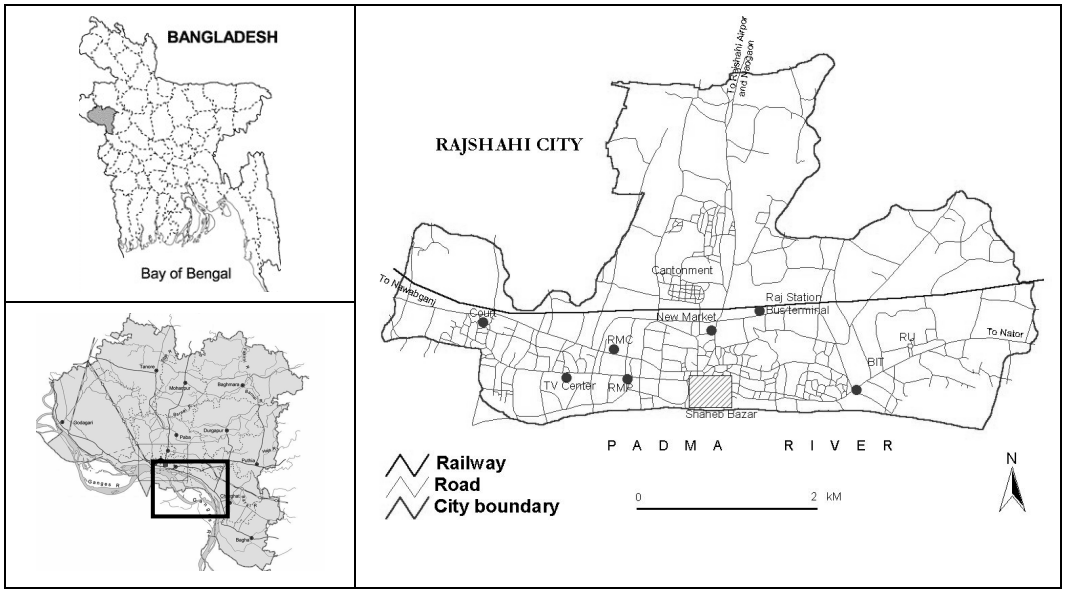



Fig. 4: Study area, Rajshahi City

## Analysis of Study Results

From the discussions in the previous sections, a clear picture can be depicted about the efficiency of Moran's I and Gini coefficient in quantifying the urban form. This study considered the residential and employment spaces as two variables to quantify the shape and spatial arrangement of the urban form as they play the pivotal role in urban dynamics. Considering the residential and employment spaces in the study area, the Moran coefficients were found as 0.749 and 0.607 respectively (Figure 5). The high positive values confirm the tendency of the high attribute values 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 mono-centric in nature displaying high degrees of spatial autocorrelation. In this regard, LISA Cluster map (Figure 6 and 7) at 95% significance level also illustrates high level of clustering.

Gini coefficients for residential and employment spaces in the study area were found as 0.548 and 0.674 respectively. These high values of Gini coefficient indicate the inequality of the distribution of residential and employment spaces in the study area. Therefore, it can be concluded that an uneven distribution of facilities exist in the city, and residential and employment spaces were higher in the fewer areas.

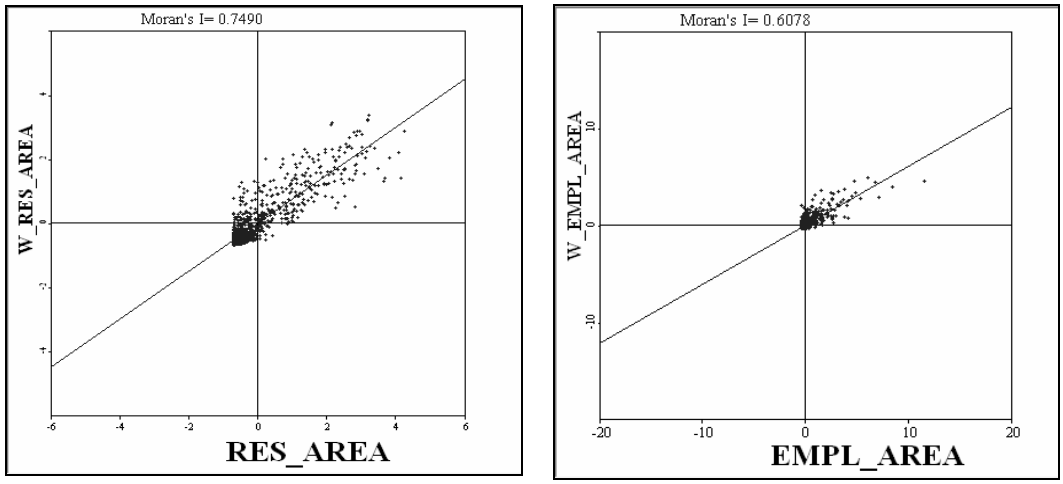



Fig. 5: Moran scatter plot for the residential and employment space

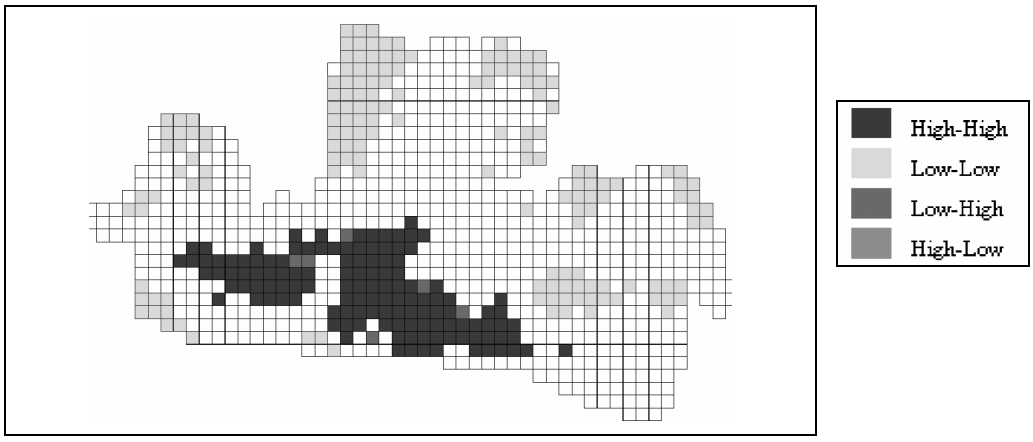



Fig. 6: LISA cluster map considering the residential space

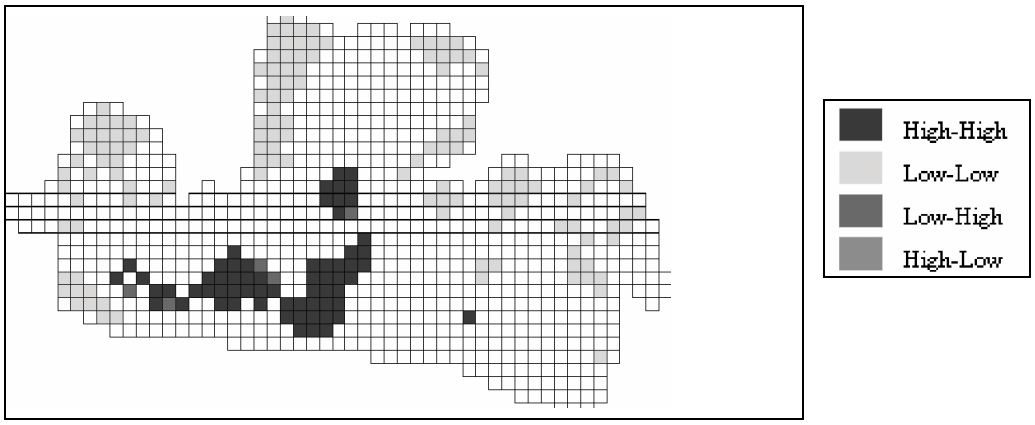



Fig. 7: LISA cluster map considering the employment space

Another interesting observation is that although the Moran's I for the residential space distribution (0.749) is greater than that of employment space (0.607), the opposite scenario is evident for the respective Gini coefficient values. This confirms that overall distribution of residential spaces is more even throughout the area compared to that of employment spaces. As to higher Moran of residential pattern, they have more continuity than that of employment distribution. The LISA cluster map at 95% significance level (Figure 6 and 7) shows that the residential spaces are more concentrated and continuous compared with the employment spaces. 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.

From Gini and Univariate Moran values, a general scenario about the distribution and pattern of residential and employment spaces in Rajshahi city is obtained. But the relationship between these two variables is also necessary to obtain the picture of land use mix. In order to link the two variables and estimate their influence on one another, a multivariate analysis was performed. Considering both the employment area versus lagged residential area and residential area versus lagged employment area, the Moran coefficients were found as 0.317 and 0.318 respectively. Both the values represent a positive and moderate spatial relationship between the residential and employment spaces. This scenario can be better understood by the Bivariate LISA Cluster map.

When similar observations (both high and low) are located closed to each other, the Moran displays positive values. As it can be seen from the Bivariate LISA Cluster map, some portions of the area with low attribute values tend to be located beside the high values. This kind of scenario produces negative local Moran value. As the global Moran value is the average of the entire local Moran's I values, the Bivariate Moran's I value has reduced to a significant level indicating to moderate positive relationships between the variables (Figure 8).

In terms of spatial arrangement, both residential and employment spaces show significantly high Morans when considered separately. When combined, they display lower values of Moran indicating to some degrees of land use segregation over the urban area. However, the bivariate cluster map confirms the existence of a concentration of both dwelling units and activities at some areas of the study area (Figure 9). This complies with our observations from the two univariate cluster maps which show the concentration of both of residences and employments at these areas.

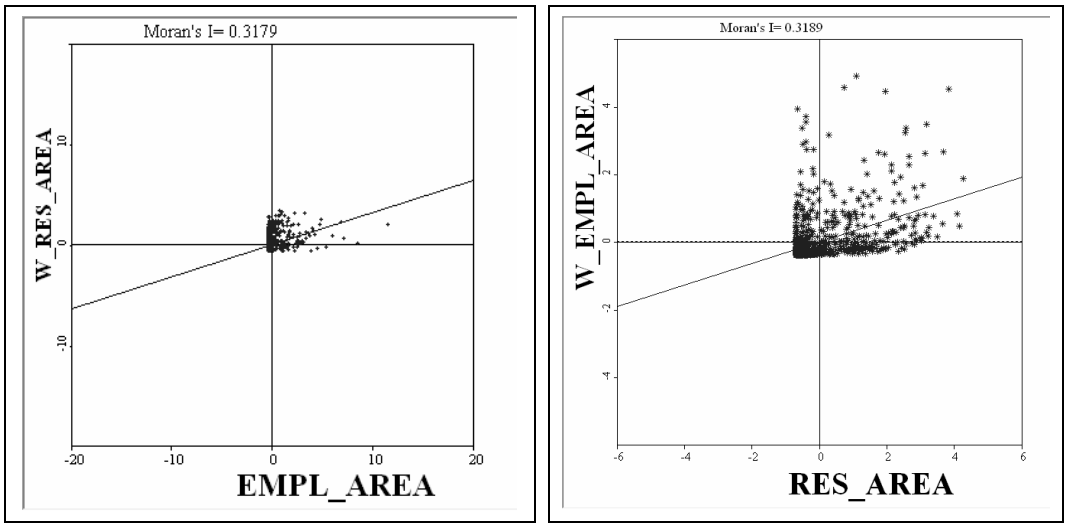



Fig. 8: Bivariate relationship between the employment and residential space

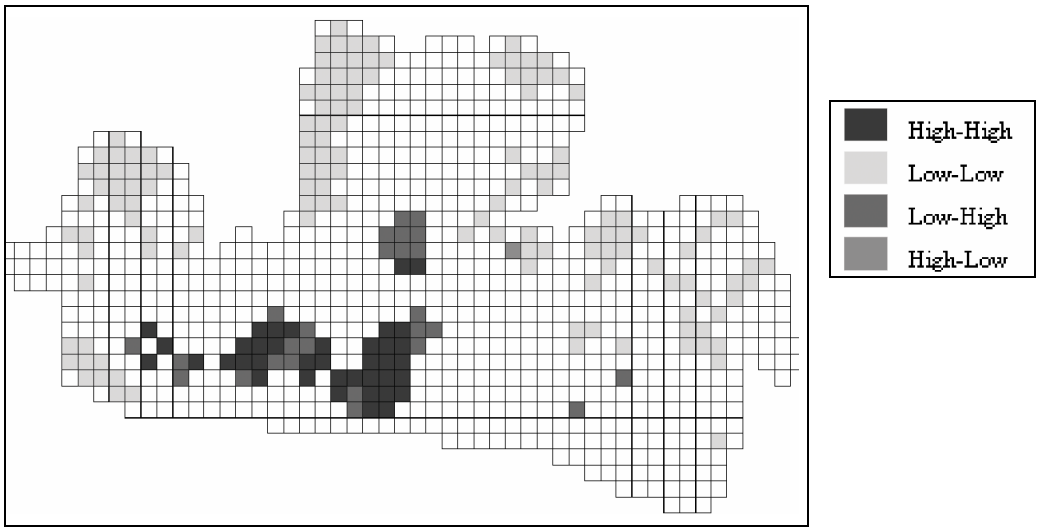



Fig. 9: Bivariate cluster map considering the employment and residential space

## Conclusion

The two indices that have been applied in this study can explain several dimensions of urban form: distribution, clustering, continuity, nuclearity and mixed uses. As it is pointed out in earlier discussions, such analysis can be best employed in comparative analysis of different urban areas. In the case of a single urban area, the problem remains to combine two or more indices to come up with a composite result. Comparative analyses also found this problem during standardizing and combining different measures of urban form. However, this paper provides a basic ground for quantitative analysis of urban structure. Once data is available for large and medium size urban areas in Bangladesh, a comparative study can be conducted and the suitability of the two indices that has been used in this study can be thoroughly examined. In addition, travel behavior within Rajshahi city area can also be linked to its urban form which has been one of the most common concerns in the study of urban form in many countries.

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