Using DMSP/OLS to Calculate Urban Sprawl of Bangladesh

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Abstract

Urban areas comprise composite systems of activities, so the study of their form in terms of a few statistical measures is challenging. Bangladesh is still a moderately truncated urbanized country compared to other Asian countries. However, the country experienced a remarkable rate of urban growth both in terms of urban population and urban centers immediately after its independence in 1971. This paper analyses the urban pattern in Bangladesh to have an in-depth understanding about them. But the problem is reliable data on urban issues of Bangladesh. Nightlight satellite images are appealing alternative data in this case. The present study provides the stepping stone 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 regional level of Bangladesh. Due to the paucity of the reliable urban data this study was fully based on nightlight satellite images data. The basic idea behind this is that there is a strong correlation with night-time imagery with urban extent. This relationship was first investigated by Elvidge et al. (1997). Moreover, the this idea has been successfully utilized by many urban studies (Ebener et al. 2005; Sutton et al. 2007; Ghosh et al. 2009; Henderson et al. 2009).

Literature Review

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. The term "urban sprawl" has been used to describe a variety of urban forms, including contiguous suburban growth, linear patterns of strip development, and leapfrog or scattered development. These forms are typically associated with patterns of clustered, non-traditional centers based on out of town malls, edge cities, and new towns and communities (Ewing 1994; Pendall 1999; Razin and Rosentraub 2000; Peiser 2001). These various urban forms are often presented in the literature as poorer, less sustainable or less economically efficient alternatives to the compact ideal of urban development. In practice sprawling forms can be considered to lie along a continuum from fairly compact to completely dispersed developments.

A variety of urban forms can be described using a typology based on two continuous dimensions, which here are made discrete for explanatory purposes: settlement density (high and low) and physical configuration (ranging from contiguous and compact to scattered and discontiguous). Galster et al. (2001) have also classified the physical forms associated with urban sprawl into types -Compact, Scattered, Linear Strip, Poly nucleated and Leapfrogging. -This classification also accommodates considerations of physical configuration and density and the patterns of urban sprawl are analyzed according to eight components: *density, continuity, concentration, clustering, centrality, nuclearity, land use mix* and *proximity*. These measures are demonstrably useful to identify the major dimensions of sprawl.

At the more compact end of the scale, the traditional pattern of suburban growth has been identified as sprawl. Suburban growth is defined as the contiguous expansion of existing development from a central core. Scattered or leapfrog development lies at the other end of the spectrum (Harvey and Clark 1965). The leapfrog form characteristically exhibits discontinuous development some way from a historic central core, with the intervening areas interspersed with vacant land. This is generally described as sprawl in the literature, although less extreme forms are also included under the term. Other forms that are classified as sprawl include compact growth around a number of smaller centers (poly nucleated growth), and linear urban forms, such as strip developments, along major transport routes.

To date, significant number of studies has 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 (Table 1).

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
Static	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
	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).	Cirilli and Veneri 2008, Tsai 2005
Dynamic	City size	Measures the total metropolitan/urban area/population	Ewing *et al.* 2002
	Density	Measures the gross/net population/employment density. Household/employment units are also used as proxies.	Cirilli and Veneri 2008
	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
	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, discontinuous or leapfrog pattern.	Galster *et al.* 2000
	Centrality	The degree to which the residential or nonresidential or both are concentrated/diffused around the CBD.	Galster *et al.* 2000, Ewing *et al.* 2002
	Nuclearity	Measures whether the development is monocentric, polycentric or dispersed.	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, Song and Knaap 2004
	Proximity	The degree to which different land uses are placed with respect to one another (typically the average distance of residential neighborhoods from one or more subcenters).	Galster *et al.* 2000, Ewing *et al.* 2002,
	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

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. 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 Moran co-efficient 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 Moran coefficient considering the effectiveness of these indices to explain the distribution, clustering, continuity and nuclearity of development.The following is the expression of calculating Moran's I (Tsai, 2005).

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ji}} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum\left(x_i - \bar{x}\right)^2} \tag{1}$$

Where n is the number of spatial units indexed by i and j. x is the variable of interest; $\bar{x}$ is the mean of x; and W_{ij} and W_{ji} are matrices of spatial weights. The expected value of Moran's I is

$$E(1) = \frac{-1}{N-1} \tag{2}$$

Its variance equals

$$Var(I) = \frac{\left\{n\left[\left(n^2 - 3n + 3\right)S_1 + nS_2 + 3S_0\right]\right\} - \left\{k\left[\left(n^2 - n\right)S_1 - 2nS_2 + 6{S_0}^2\right]\right\}}{(n-1)(n-2)(n-3){S_0}^2} - E(1)^2 \tag{3}$$

Where $S_0 = \sum_{i=1}^{n}\sum_{j}^{n} W_{ij}$ (4)

$$S_1 = \sum_{i=1}^{n}\sum_{j=1}^{n}\left(W_{ij} + W_{ji}\right)^2 \Big/ 2 \tag{5}$$

$$S_3 = \sum_{i=1}^{n}\left(Wi. + W.i\right)^2 \tag{6}$$

($W_{i.}$ and $W_{.i}$ mean *i* row and *i* column of the related matrix.)

$$k = \frac{\left[\sum_{i=1}^{n}\left(x - \bar{x}\right)^4 \Big/ n\right]}{\left[\sum_{j=1}^{n}\left(x - \bar{x}\right)^2 \Big/ n\right]} \tag{7}$$

According to the steps talked above, the Moran's I will be between -1 and 1, if the index is greater than 1, it means that the correlation is positive; if less than 0, it means negative, and the more, the larger of the correlation, and vice versa. And if the value is near to 0, it represents random distribution.

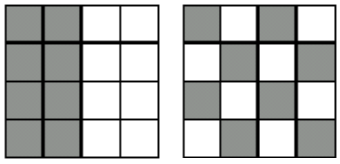

Figure 1: The *Moran's I* = (+1) *Moran's I* = (-1)

Data and Study area

The study area is Bangladesh, which is located in South Asia and consisting of more than 160 million people. In this study nightlight satellite data of the country were used (Figure 2). The National Geophysical Data Center (NGDC) of the National Oceanic and Atmospheric Administration (NOAA) provides Defense Meteorological Satellite Program -Operational Linescan System (DMSP-OLS) data since 1994. Each OLS has a swath width of 3000 Km and 14 orbits per day and therefore is able to cover the globe in a 24 h period. The night-time imagery (night time pass: 20.30 - 21.30 local time each night) is available in a number of different products (Elvidge, 2002). The nighttime lights product for 2011 named "VIIRS" was used for the purposes of this study. This product, which has been already processed, is derived from the average visible band digital number (DN) of cloud-free light detections multiplied by the percent frequency of light detection. The percent frequency of light detection normalizes the DN.

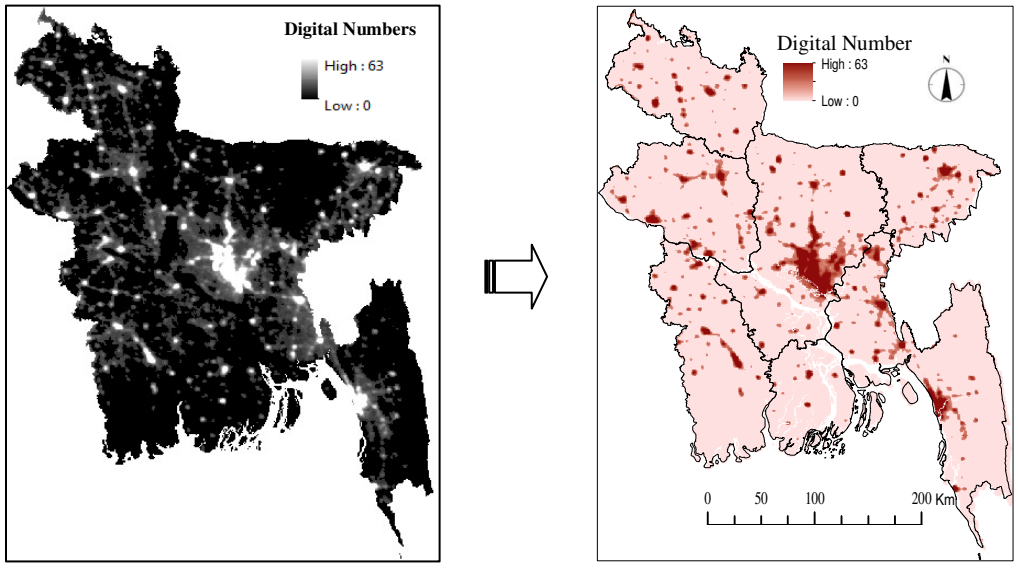

Figure 2: The night-time imagery of the year 2011of Bangladesh

The spatial resolution of the original night-time lights data is 2.7 Km. After geolocation to 30 arc-second grids, the resolution becomes approximately 1 km at the equator. Night-time light imagery has been used in numerous applications. Among them, most common application is the mapping of urban areas (Doll, 2008). The nightlight satellite image data were collected and the urban areas for each seven divisions were extracted based on its DN value (DN value > 6). Moran I indices found are shown in Table 2.

Table 2: Division wise Moran's Index from the year (1992-2012)

Year	Rajshahi	Rangpur	Chittagong	Khulna	Sylhet	Dhaka	Barisal
1992	0.966333	0.966144	0.963619	0.963019	0.959867	0.951801	0.843402
1993	0.966378	0.966167	0.963642	0.962998	0.959838	0.951789	0.843415
1994	0.966364	0.966044	0.963635	0.962943	0.959791	0.951923	0.843293
1995	0.96634	0.966086	0.96358	0.962947	0.959842	0.951967	0.843235
1996	0.966381	0.966121	0.963719	0.962991	0.959901	0.951922	0.843289
1998	0.966435	0.966281	0.963639	0.963109	0.959941	0.951731	0.843431
1999	0.966264	0.966058	0.963686	0.962911	0.959835	0.9519	0.84317
2000	0.966338	0.966057	0.963698	0.962939	0.959778	0.951861	0.843178
2001	0.966342	0.966067	0.963668	0.962977	0.95986	0.951789	0.843168
2002	0.966368	0.966077	0.963665	0.962997	0.959827	0.951892	0.843202
2003	0.966447	0.966247	0.963686	0.963131	0.959891	0.95197	0.843375
2004	0.966412	0.966156	0.963723	0.96307	0.959777	0.952049	0.843324
2005	0.966439	0.966324	0.963676	0.963179	0.959904	0.951889	0.843455
2006	0.966464	0.966342	0.963717	0.963189	0.959899	0.951879	0.843489
2007	0.966342	0.966446	0.963718	0.963162	0.959815	0.951831	0.84341
2008	0.966369	0.966312	0.96374	0.963146	0.959818	0.951787	0.843445
2011	0.966189	0.966555	0.96376	0.963177	0.959575	0.951597	0.843208
2012	0.965917	0.966853	0.963786	0.963095	0.960062	0.951723	0.843115

From the above output Table 2, it is clear that in all 07 divisions the urban areas or more or less compact. The *Moran's I* index range is from 0.84 to 0.96. Among them Rajshahi and Rangpur regions' urban growth are more clustered than other regions of Bangladesh. Chittagong, Khulna, Dhaka and Barisal gradually follow them. From the graph we can get some interesting findings:

1) As in all the regions, the number of non-motorized vehicle is dominant compared to motorized vehicle and the average travel distance is very less. So, urban growth is compacted or concentered within main urban areas' walking distance in most of the regions. Especially Rangpur and Rajshai regions are little bit underdeveloped in terms of industry, education, business and commerce, quality of life than other regions. So, here the urban growths are fewer and little bit condensed.

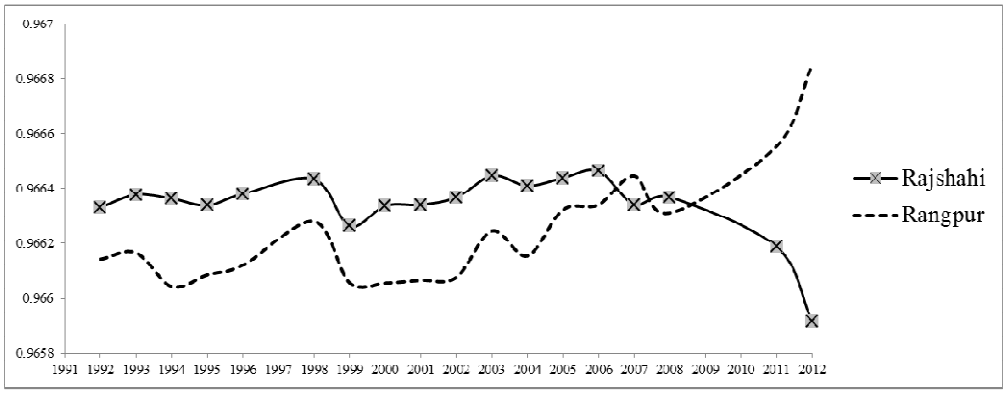

Figure 3: *Moran's I* of Rajshahi and Rangpur regions of Bangladesh from 1992 to 2012

Once Rangpur region is included within Rajshahi region. Very recently it is declared as new division and 'Rangpur Municipality' is declared as city corporation. Anyway some urban centers are rapidly developing within this Rangpur region from 2009 onward consequently *Moran's I* is decreasing here (Figure 3).

2) In terms of urban status in Bangladesh Chittagong and Khulna regions are 2nd and 3rd respectively after Dhaka city. There are many industries, factories, business and commercial activities in these two regions. Chittagong is called the business capital of Bangladesh. Though Chittagong and Khulna have the same pattern of urban growth Chittagong is comparatively clustered (Figure 4).

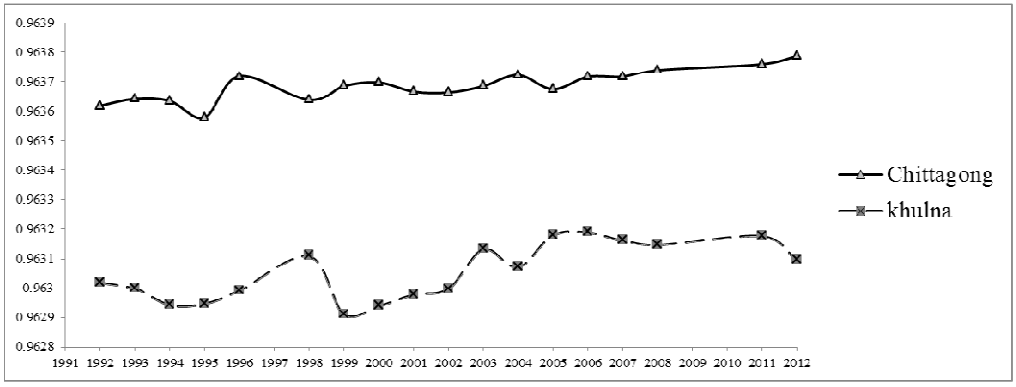

Figure 4: *Moran's I* of Chittagong and Khulna regions of Bangladesh from 1992 to 2012

The main reason behind this is that in Chittagong region there are some hilly areas. In Bangladesh most of the land is little bit flat except Chittagong region. Especially the districts named Rangamai, Bandarban and Khagrachori of Chittagong region are completely hilly area. So, urban areas here are destined to concentred into main core urban areas, haphazard urban expansion is not developed because of its topography. On the other hand Khulna is the third old region city of Bangladesh. This area is little bit flat and many industries, sea port, fish exporting industry are here.

3) Sylhet region is comparatively smaller than other regions of Bangladesh. Here urban centers are more than other regions. Average income of the people here are comparatively high. Many people of this area live in United Kingdom and send lot of remittance to the region. Most of the natural resources of Bangladesh like natural gas, oil, stone etc. are here. The area is also tea producing and exporting region. In all this aspect, the region is more urbanized and developed than other regions. So, urban centres largely developed here and consequently *Moran's I* is 0.95 to 0.96 (Figure 5).

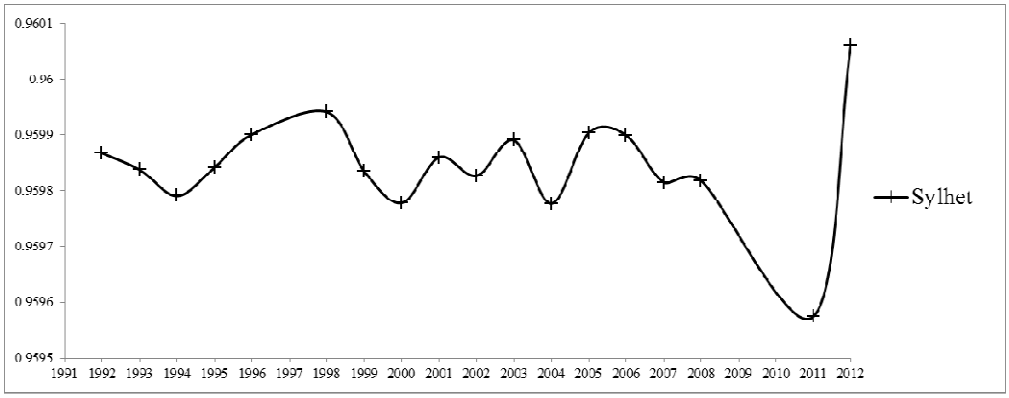

Figure 5: *Moran's I* of Sylhet region of Bangladesh from 1992 to 2012

4) Dhaka region is more urbanized than other regions of Bangladesh. The capital of Bangladesh, Dhaka city is here. Most of the economic activities, business functions, educational institutions, medical colleges, administrative functions, international offices, markets, stadiums, export processing zones all are not only in Dhaka city but its surrounding distiricts like Gazipur, Narayangonj, Munsigonj, Manikgonj, Tangail etc. So, urban centres are developed in all the districts of Dhaka region resulting *Moran's I* 0.95 (Figure 6).

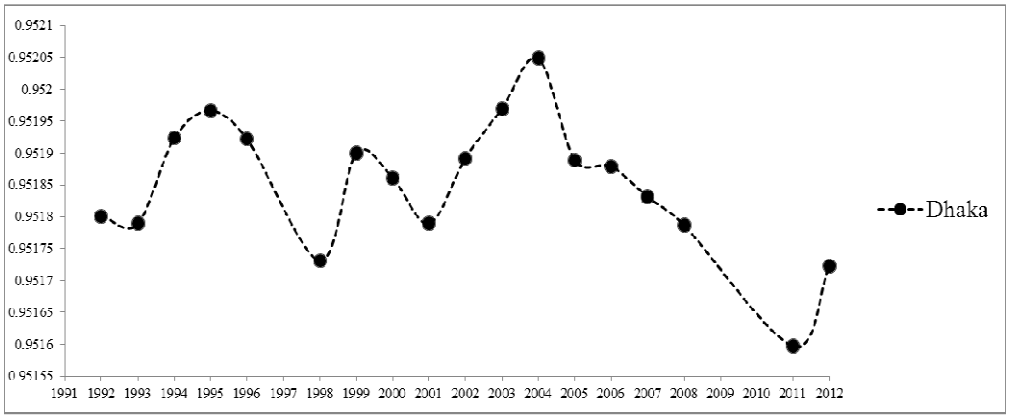

Figure 6: *Moran's I* of Dhaka region of Bangladesh from 1992 to 2012

5) Very interestingly, Barisal Region's *Moran's I* is around 0.84. The logic behind this is the region is not only enclosed by many rivers but within the region there are many rivers and canals. So, the districts are here separated from one another by water ways. So, the urban centres are bounded here to develop with in the districts resulting Moran's I 0.84 (Figure 7).

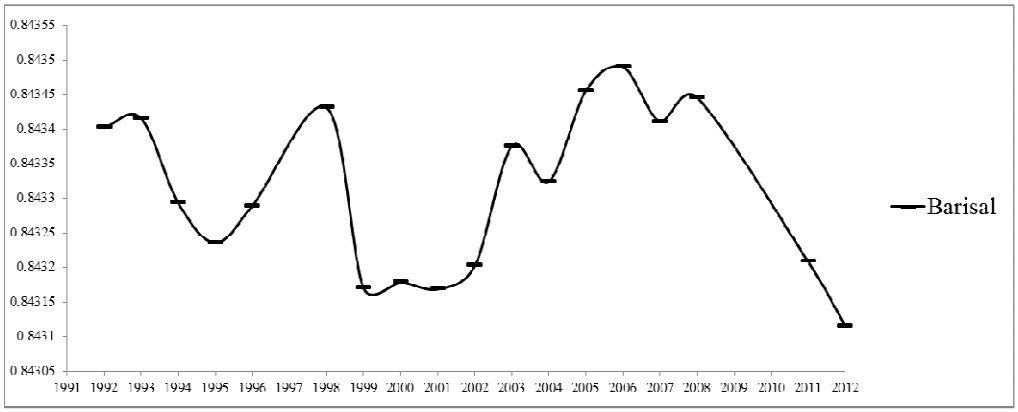

Figure 7: *Moran's I* of Barisal region of Bangladesh from 1992 to 2012

There is no central city or core urban area here, the entire district are little bit same in terms of urban status. So, the Region is not developed or urbanized but because of river network here the urban centres are equally developed within every district. So Moran I index comes to less than other regions of Bangladesh.

Conclusion

As it is pointed out in earlier discussions, such analysis can be best employed in comparative analysis of different methods. 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 in other methods can be conducted and the suitability of the indices that has been used in this study can be thoroughly examined. In addition, travel behavior within 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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