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Analysis of Urban Growth using RS, GIS and Shannon's Entropy in and around Burdwan City, West Bengal, India

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Abstract

Urban landscape has undergone dramatic changes in most of the developing countries as a result of unplanned urban growth which needs to be analyzed and understood for future planning purpose. Such growth has been facilitated by rapid development in transport and communication and new economic opportunities mostly found in the surrounding regions of an urban centre. This kind of growth later on takes different shapes in different directions. It can be effectively mapped and precisely analyzed with the help of statistical, RS and GIS techniques. In this study, satellite images (1980, 1990 and 2000) and Google Map (2010) of Burdwan city and its surroundings (West Bengal, India) have been used to monitor the nature of the pattern of urban growth between 1980 and 2010.

Introduction

Urban growth refers to the process of increasing concentration of population within a town or city. It starts from a point eventually spreading in different directions. The growth pattern varies from one urban place to another and it is necessary to study such phenomenon for appropriate urban planning. Urban growth can be mapped, measured and modeled by using remote sensing data and GIS techniques along with several statistical measures. The application of new techniques has created opportunities to analyse the processes of urban growth which has considerable significance in the understanding of space organization, transformation of landscape and socio-economic structure of the area concerned.

Study Area

The surrounding area of Burdwan City located in Barddhaman C. D. Blocks I and II of Barddhaman district, West Bengal has been taken as the area of study. It lies between 87°47′ E and 87°03′ E and 23°10′ N and 23°20′ N.

Objectives

The major objectives of the study are as follows

1. To study the extent of urban growth in and around Burdwan city during 1980 – 2010
2. To find(out) the nature of discrepancy in

3. To examine the degree *of sprawl* in and around Burdwan city during 1980 2010.

Review of Literature

Researches on urban form till now have mostly focused on defining and quantifying urban sprawl that is synonymous with unplanned growth posing problems for urban landuse planning. This term is so widely used that it has become as ambiguous as 'compactness' or 'sustainable urban form'. According to Ewing (1997), sprawl is a condition of urban form or landuse characterized by low-density, scattered and commercial strip development and leapfrog (i.e. discontinuous) pattern of growth. On the other hand, some viewed sprawl as a 'process' of urban form. However, limited attempts have been made to quantitatively analyze sprawls in terms of compactness of urban form.

Urban form refers to the physical structure of an urban area that expresses the spatial pattern of human activities at a certain point of time (Anderson et. al. 1996). It can also be viewed from aggregate and disaggregate perspectives. 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 forms can be viewed at continent (Fina and Siedentop, 2011), country (Cirilli and Veneri, 2008) and regional (Bertaud and Malpezzi, 1999) levels.

Significant number of studies has been conducted to find out the measures and indices to quantify sprawl. Still, contentions are in place as to which technique 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 who recognize the sprawl as a 'condition' of urban form. The present study is about quantifying and analyzing a particular urban area. Thus, it considers the second approach. The most widely used measure of urban form is density, which is measured by the land consumption per capita. Torrens and Alberti (2000) determines the density level at which the urban form can be considered as sprawling. But again 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 researchers have (also) applied one or more of these indicators to explain the urban form. Centrality and proximity are closely linked. Fractal dimension (Terzi and Kaya, 2008) and total core area index (Fina and Siedentop, 2008) refer to the geometric aspects of urban form and not to the activity or land use distribution. Hence, these have been excluded from this analysis.

Materials and Methods

Data Used

In order to study the spatial pattern and extent of sprawl during 1980 2010, Landsat TM (P/R: 139:44) for 1980, Landsat TM (P/R: 139:44) for 1990 and Landsat ETM$^+$ (P/R: 139:44) for 2000 satellite images have been taken up for analysis. To identify the current status of sprawls in the the study area, Google Image of 2010 has been taken up for analysis.

Methods

Classification of Images

eCognition Developer 8 software has been used for image classification as it enables object-oriented classification that effectively avoids the mixed pixel problems which usually occur in the images of urban areas. The images have been obtained as standard product, both geometrically and radiometrically corrected. But the overlay of the images does not match with considerable accuracy probably because of different standards and references used by the image supplying agencies. To resolve this problem, images have been co-registered, so that the overlay matches with sub-pixel accuracy (root mean square errors = 0.22). Nearest-neighbour resampling method has been used to transform the images so that the original pixel value can be retained.

Chi-square Analysis

Observed urban growth has been compared with the expected urban growth to understand the nature of discrepancy in urban growth. Chi-Square analysis has been performed to find out the degree of freedom (Chi-Square value). The Chi-square has a lower limit of 0, when the observed value exactly equals the expected value. Higher the chi-square (degree-of-freedom) value, more the discrepancy between the actual and expected urban growth.

Shannon's Entropy

Shannon's entropy is a well accepted method for determining the sprawled urban pattern (Kumar et al., 2007; Lata et al., 2001; Li & Yeh, 2004; Sudhira et al., 2004; Yeh & Li, 2001). The entropy value ranges from 0 to $\log_n(m)$. Value closer to zero indicates compact distribution whereas larger values indicates the occurrence of sprawl. To identify the nature of sprawling, the study area has been divided into eight directions from the centre at the city of Burdwan.

Degree of Goodness

Since the Chi-square (degree-of-freedom) and entropy (degree-of-sprawl) are different measures and the result of one may contradict other in some of the instances (as it is evident in this study), the 'degree-of-goodness' of urban growth has been determined. It refers to the degree at which the observed growth relates to the expected growth and the magnitude of its compactness (as opposed to sprawl).

Results

Extent of Urban Growth

The classification of satellite images into built-up (along with other impervious) and non-built-up areas during 1980-2010 have produced abstracted and highly simplified visual images in the study area (Fig. 4a - 4d) which define expression of urban area in different time period.

After examining four classified images, it is found that that expansion of the city in the specified zones of the study area has different signatures: some zones are very compact while others have more open spaces between built-up areas. In some areas the boundary between the built-up and non-built-up portion is very sharp, while in other areas these can not be easily segregated.

By interpreting these images, one can easily understand whether the city is experiencing the development of sprawls over time or not. To describe its nature and pattern quantitative analysis has been done with relevant data.

Built-up Area and Urban Growth

The proportion of an area covered by impervious surfaces such as asphalt and concrete is a straight forward measure of urban growth (Barnes et al., 2001). Naturally, the developed areas have greater proportions of impervious surfaces compared to the lesser-developed areas (Sudhira et al., 2004).

Table - 2 shows that the built-up area of the city has changed over the time in different directions. Observed growth in built-up area (Table - 3) has been calculated for the time spans 19801990, 19902000 and 20002010. The rates of decadal variation have also been computed (Table - 4). It shows that the rate of urban growth fluctuated with time and all the zones have achieved maximum growth rate during 1990-2000.

Chi-Square Analysis

Observed growth is to be compared with expected growth to understand the level of discrepancy. Table - 3 shows the observed growth in urban land-cover, from which the theoretical expected urban growth has been calculated by applying Eqn. 1. Let Table -3 be called matrix UG, with elements UG_{ij}, where i = 1, 2... n (specific time span of analysis, rows of the table) and j= 1, 2, .., m (specific zone, columns of the table). The expected built-up growth for each variable has been calculated by the products of marginal totals, divided by the grand total (Almeida et al., 2005). Therefore, the expected growth UG_{ij} for the i^{th} row and j^{th} column is given by Equation - 1 as (Table - 5) –

$$UG_{ij}^{E} = \frac{UG_i^s x UG_j^s}{UG_g}$$

where, UG_i^s = row total, UG_j^s = column total and UG_g = grand total.

The discrepancy of urban growth for each zone and in each temporal span has been computed by subtracting the values of Table- 5 from Table- 3 (Table-6). Negative values indicate less growth and positive values show more growth than expected. Degree of deviation can also be identified by the magnitudes. This analysis clearly shows that the observed built-up growth in some of the zones for different temporal span (especially in North and Northeast in 1990 - 2000 and 2000 - 2010) has been deviated from the expected value to a considerable level. This higher deviation shows the independence (freedom) of a variable; i.e., if the deviation is high it can be said that the variable is independent in comparison to variables of same category.

However, there were four to five temporal instants in the analysis having the positive discrepancy during 1980-2010. Some additional temporal instants in the analysis may provide better knowledge on the independence of variables (Bhatta, 2009).

Since the city and its surroundings grew in unplanned fashion, no such projected expectations are found. However, areas available for development in each zone are highly uneven due to topographical barriers. Zones with relatively smaller amount of developable land obviously have a smaller amount of expected growth. Pearson's chi-square statistics helps in checking of freedom amongst pairs of variables chosen to explain the same category of land-cover change (Almeida et al., 2005). Therefore, to determine the 'degree-of-freedom', chi-square test was performed to reveal the freedom or degree of deviation for the observed urban growth over the expected. For Table-3 (observed) and Table-5 (expected), the Chi-square statistics for each temporal span (χ^2) was calculated with Equation - 2 (Table -7) as:

$$\chi_i^2 = \frac{\sum \left(UG_i - UG_j^E \right)^2}{UG_j^E}$$

where, UG_i = observed built-up area in jth column for a specific row, UG_j^E = expected built-up area in jth column for a specific row. Now, if we replace j (column) by i (row), and m (number of columns) by n (number of rows) in eq. (2), we can determine the degree-of-freedom for each zone also.

The Chi-square has a lower limit of 0, when the observed value exactly equals the expected value. Table -7 clearly shows that the degree-of-freedom is low (i.e., similarity between observed and expected values) for both of the temporal spans. It is low (i.e., similarity in observed and expected values or very near) for only north, north east and south directions whereas it is high for west and east directions. Needless to say, the overall degree-of-freedom is very low to moderate. Lower overall freedom indicates equal weightage and consistency in planning with the entire city in consideration. Lower degree-of-freedom for a zone is an indication of stable development within the zone with the change of time and lower degree-of-freedom for a temporal span can be considered as lower inter-zone variability in urban growth. However, it is worth mentioning that lower degree-of-freedom can be considered as sprawl (Bonham-Carter, 1994; Almeida et al., 2005).

Entropy of Urban Growth

Shannon's entropy is a popular method for determining the sprawled urban pattern (Kumar et al., 2007; Lata et al., 2001; Li & Yeh, 2004; Sudhira et al., 2004; Yeh & Li, 2001). In this, for each temporal span it (Hi) has been computed from Table - 4 with the help of Equation - 3 as:

$$H_i = -\sum P_j \log_e P_j$$

where, Pj = proportion of the variable in the jth column (i.e., proportion of built-up growth rate in jth zone, calculated (from Table - 4) by: built-up growth in jth zone/ sum of built-up growth rates for all zones) and m = number of zones (8).

As the entropy values are much higher than the half-way mark of $\log_e$ (m), the city is said to be experiencing sprawl with increasing tendency (Table 8). It contradicts the findings of Richardson, Bae and Baxamusa (2000) that-cities in developing countries are becoming more compact in spite of decentralization and also Acioly and Davidson (1996) that in developing countries the general processes of change have been leading to more compact cities. The findings of the present study also support the concept that administrative boundaries cannot provide the real insight of urban growth. The entropy value is higher than the half-way mark of $\log_e$ (n) i.e. 0.55 in every direction except to the west which means these zones are sprawling, especially the south and northwest zone has a highest possible sprawl (Table 9). The city has a general sprawling tendency towards north and northwest direction especially along SH-7, SH-2 and Katwa-Barddhaman railway line. The temporal analysis indicates a steady inclination towards the sprawling in urban growth, implying the importance of Burdwan city as service centre; sprawling mainly takes place along the transport arteries. The zonewise analysis entropy value reveals more or less the same trend except in the northwest and west directions where the intensity of sprawl has increased.

Degree of Goodness of Urban Growth

This can be calculated for each temporal span as:

$$G_i = \log_e \left[\frac{1}{\chi^2 \left(\frac{H_i}{\log_e m} \right)} \right]$$

Where, Gi =degree-of-goodness of urban growth for i[th] temporal span, χ^2 = degree-of-freedom for i[th] temporal span, Hi =entropy for i[th] temporal span, m= total number of zones (4). For each zone (Table - 9), it has been calculated replacing i by j and m by n as follows (Equation - 5):

$$G_i = \log_e \left[\frac{1}{\chi^2 \left(\frac{H_i}{\log_e n} \right)} \right]$$

where, χ^2 is the overall degree of freedom and Hi is overall sprawl.

It is a straightforward measure, positive values indicating 'goodness' or good growth, whereas negative values indicate 'badness' or not spectacular growth. It can also be identified by the magnitudes from Table - 10 and 11 that show how goodness varies in different zones in different time periods and in different directions (positive or negative). The city and its surroundings have experienced little goodness of urban growth during the post-2000 period; it is positive along the north, south, northeast, southwest and southeast directions and negative along the east and west-northwest directions.

Analysis

As mentioned earlier, the study was conducted by using four temporal remote sensing imageries (Table - 1) at 10-year interval (1980, 1990, 2000 and 2010). Different zones illustrate variety in the pattern of growth so a single policy aiming at managing sprawl for the entire city never works with equal degree of effectiveness. The city has been divided into circular zones equidistant from the city-centre in order to understand how population density changes away from central business district. Analysis here is based on built-up areas in each zone; however, amount of land available for development in each zone is not uniform. Therefore, it would have been better if the three measures (freedom, sprawl, and goodness) could have been considered by excluding the non-developable land. But, it cannot be measured directly from the remote sensing data. In developing countries cities have grown in unplanned manner lacking historical data of urban development and temporal inventory of land-use/land-cover data.

The expected urban growth was statistically calculated and a detailed report of urban growth has been prepared to facilitate the local administrators and planners. The understanding of the complexity of urban growth essentially provides us with some of the tools necessary to meet it in an efficient, equitable and sustainable manner in the years to come. Finally, whether a higher degree-of-goodness is an indicator of sustainable development or not may be debated, but there is little doubt that a lower degree-of-freedom and lower degree-of-sprawl are generally expected. Further research would throw some light on the correlation between the degree-of-goodness and sustainable urban growth.

Conclusion

The analysis shows that the city has a general high degree-of-freedom and it is sprawling as well. It is interesting to note that despite a decline in urban growth rate the sprawl is unabated. A new relation can be derived from the preceding analysis and discussion: *degree-of-goodness in urban growth has to be taken into consideration while discussing sustainable urban development*, which has a policy implication and may motivate the researchers to undertake the study on sustainable urban growth in future.

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Table - 1: Data Used in the Study

Data Used	Year	Toposheet No. / Path: Row	Scale / Resolution	No. of Bands	Source
Landsat TM	1980	139/44	28.5 m.	4	Landsat.org
Landsat TM	1990	139/44	28.5 m.	7	Landsat.org
Landsat ETM	2000	139/44	28.5.	4	Landsat.org
Google Image	2010	-	1:01	True Colour Composite	Google Pro.
Burdwan City Guide Map	-				Municipality Office

Table - 2: Built-up Area of Burdwan City and its Surroundings (1980 – 2010)

(sq. km)

Year	Direction								Column Total
	E	W	N	S	NW	NE	SW	SE	
1980	17.25	3.88	6.94	2.50	6.25	17.50	1.00	1.44	63.75
1990	19.81	4.38	15.75	3.06	12.13	28.44	2.25	2.56	88.38
2000	30.00	6.38	21.06	4.50	14.88	42.00	4.69	6.44	129.94
2010	32.56	9.31	25.37	4.90	18.01	48.61	5.39	7.52	119.27
Row Total	99.62	23.93	69.12	14.96	51.26	136.54	13.32	17.96	401.33

Source: Computed by Authors

Table - 3: Observed Decadal Growth in Built-up Area in the Study Area

(sq. km.)

Temporal Span	Direction								Whole Region
	E	W	N	S	NW	NE	SW	SE	
1980 – 1990	2.56	0.50	8.81	0.56	5.88	10.94	1.25	1.13	31.63
1990 – 2000	10.19	2.00	5.31	1.44	2.75	13.56	2.44	3.88	41.56
2000 – 2010	2.56	2.93	4.31	0.40	3.13	6.61	0.70	1.08	21.72
Total	15.31	5.43	18.44	2.40	11.76	31.11	4.39	6.08	94.91

Source: Computed by Authors

Table - 4: Observed Decadal Growth Rate of Built-up Area in the Study Area

(%)

Temporal Span	Direction								Whole Region
	E	W	N	S	NW	NE	SW	SE	
1980 - 1990	14.86	12.90	127.03	22.50	94.00	62.50	125.00	78.26	49.61
1990 - 2000	51.42	45.71	33.73	46.94	22.68	47.69	108.33	151.22	47.03
2000 - 2010	8.54	45.96	20.47	8.89	21.07	15.73	14.92	16.81	16.72

Source: Computed by Authors

Table - 5: Expected Decadal Growth of Built-up Area in the Study Area

(sq. km)

Temporal Span	Direction							
	E	W	N	S	NW	NE	SW	SE
1980 - 1990	5.10	1.81	6.14	0.80	3.92	10.37	1.46	2.03
1990 - 2000	6.70	2.38	8.07	1.05	5.15	13.62	1.92	2.66
2000 - 2010	3.50	1.24	4.22	0.55	2.69	7.12	1.00	1.39

Source: Computed by the Authors

Table - 6: Difference between the Actual and Expected Growth of Built-up Area

(sq. km.)

Temporal Span	Direction							
	E	W	N	S	NW	NE	SW	SE
1980 - 1990	2.54	1.31	-2.67	0.24	-1.96	-0.57	0.21	0.90
1990 - 2000	-3.48	0.38	2.76	-0.39	2.40	0.06	-0.52	-1.21
2000 - 2010	0.94	-1.69	-0.09	0.15	-0.44	0.51	0.30	0.31

Source: Computed by Authors

Table - 7: Decadewise Chi-square Values for Growth of Built-up Area in each Direction

Temporal Span	Directions								Column Total
	E	W	N	S	NW	NE	SW	SE	
1980 - 1990	1.26	0.95	1.16	0.07	0.98	0.03	0.03	0.40	4.88
1990 - 2000	1.81	0.06	0.94	0.14	1.12	0.00	0.14	0.55	4.76
2000 - 2010	0.25	2.29	0.00	0.04	0.07	0.04	0.09	0.07	2.86
Row Total	3.32	3.30	2.10	0.25	2.17	0.07	0.26	1.02	

Source: Computed by Authors

Table - 8: Decadewise and Directionwise Shannon's Entropy

Temporal Span	Direction							
	E	W	N	S	NW	NE	SW	SE
1980 - 1990	0.30	0.26	2.56	0.45	1.89	1.26	2.52	1.58
1990 - 2000	1.09	0.97	0.72	1.00	0.48	1.01	2.30	3.22
2000 - 2010	0.51	2.05	1.22	0.53	1.26	0.94	0.89	1.01
Entropy (H_i)	0.96	0.78	0.97	1.03	0.97	1.09	1.02	0.98
$Log_e(m)$	1.10							
$Log_e(m)/ 2$	0.55							

Source: Computed by Authors

Table - 9: Shannon's Entropy Analysis (Zone and Decadewise)

Time Span	1980 – 1990	1990 – 2000	2000 – 2010
Entropy (H_i)	1.69	1.90	1.94
$Log_e(n)$	2.08		
$Log_e(n)/2$	1.04		

Source: Computed by Authors

Note: Here, n=3; As entropy > half way mark, dispersion evident

Table - 10: Degree-of-Goodness

Decades	1980-1990	1990-2000	2000-2010
Degree-of-Goodness	- 0.43	- 0.21	0.018

Source: Computed by Authors.

Table - 11: Degree-of-Goodness (Zone Wise)

1980 - 2010	E	W	N	S	NW	NE	SW	SE
Degree-of-Goodness	-0.43	-0.21	0.018	2.08	-0.012	3.32	2.05	0.73

Source: Computed by Authors

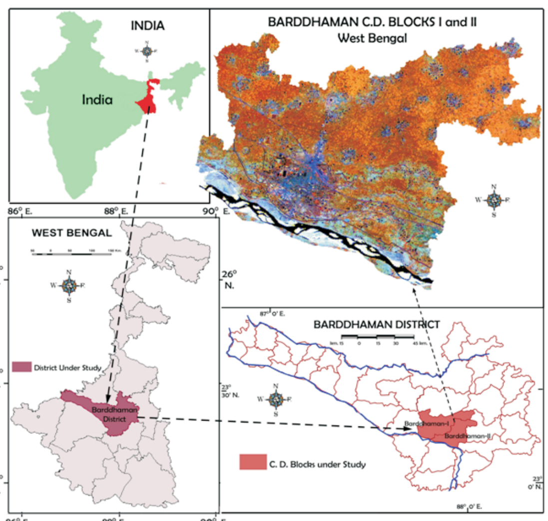


Fig.1. Location of the Study Area

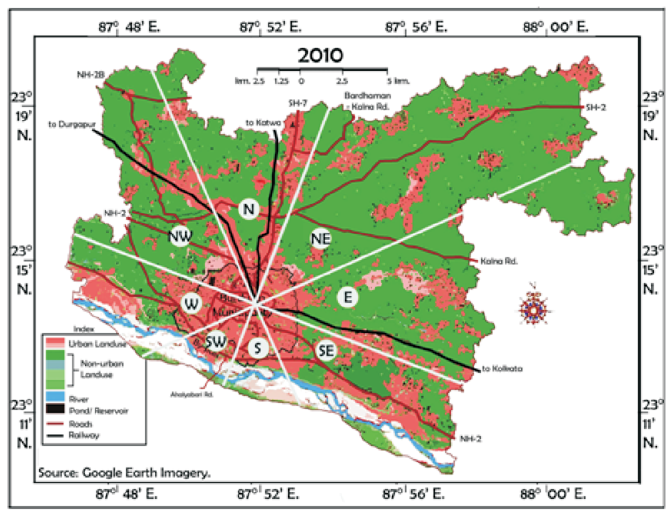


Fig.2. Spatial Pattern of Built-up Area in and around Burdwan City

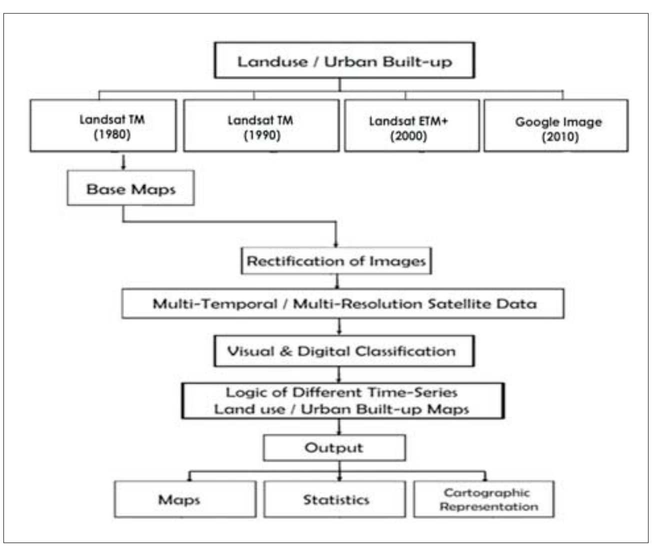


Fig.3.Flowchart of Methodology

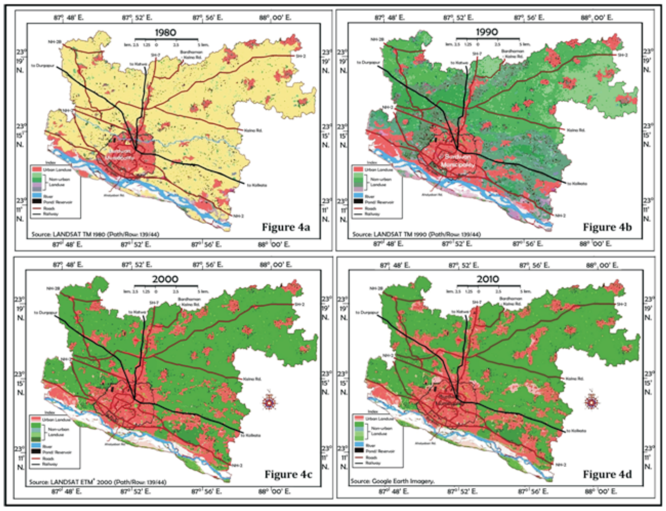


Fig.4a-4d: Urban Growth in and around Burdwan City during 1980 2010

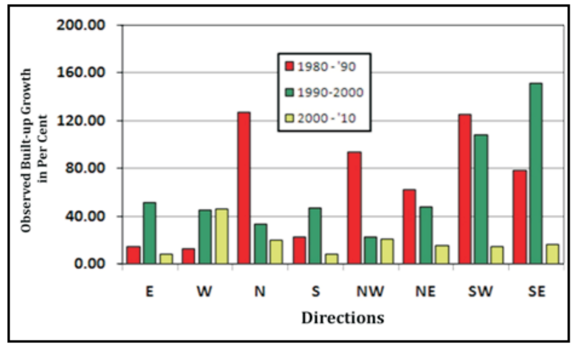


Fig.5: Observed Growth Rate of Built-up Area

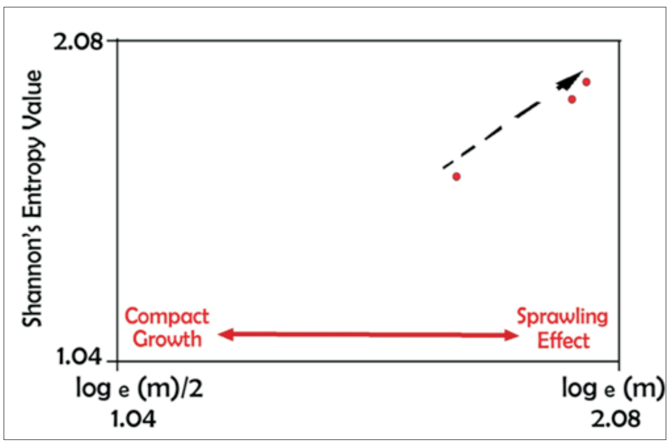
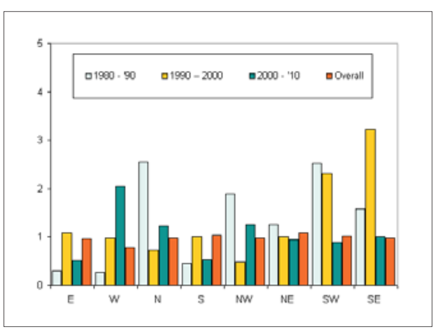
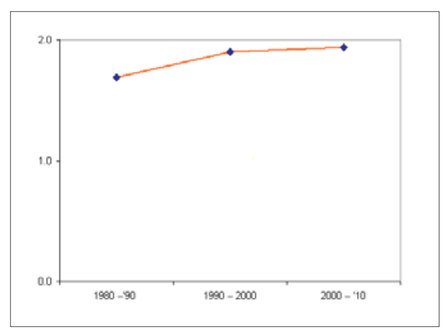


Fig.6: Shannon's Entropy Model for the Study Area



(A)



(B)

Fig.7 A -B : Spatio-Temporal Pattern of Shannon's Entropy for Burdwan City and its Surroundings, 1980 2010.

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