MAPPING URBAN GROWTH DYNAMICS USING CENTROGRAPHIC TECHNIQUE

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Abstract

Urbanization is increasing at a rapid rate in today's world. It is one of the major problems behind climate change today. For a developing country like India, on one side where development, of which urbanization is a major part, is necessary on the other hand this development has started wreaking havoc to the environment. Increase in urbanization is also associated with a rapid increase in population which is prominent especially in the metropolitan areas. As per 2011 census, Delhi's population rose by 4.1%, Mumbai's by 3.1% and Kolkata's by 2% compared to 2001 census. Increase in population in turn leads to an increase in the land surface temperature. This study sees the relation of urban growth and population using centrographic technique and then relating the output of this analysis with land surface temperature. Kolkata was taken as the study area with an extent of 22°49'N, 88°12'E. The mean centers of all the wards in the city of Kolkata was calculated and then a single mean center using the mean centers of individual ward was calculated for multitemporal datasets of 2000 and 2010. The shift in the mean center in the multi temporal dataset will give us the directional shift of population. The proportion of population distribution around the mean center has been analyzed. The concept of standard deviation and normal distribution has been used to analyze this. The increase in impervious area was then associated with land surface temperature.

About the Author

Ms. Kasturi Deb

I am currently pursuing M.Sc in Geoinformatics from TERI University, studying in semester three of the course module. My area of interest includes looking into the causes and effects of urbanization, urban sprawl and urban planning using Remote Sensing and GIS techniques.

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Introduction

Centrography is “the trend in thought directed towards the establishment of laws of the distribution of phenomena based on the relationships and migrations of their centers of gravity” (Poulson, 1959) (Omaha Demographic Centers, n.d.). Hence, Centrographic technique is a statistical technique which can be utilized to describe and measure the salient features of a spatial distribution and for facilitating temporal and comparative analyses in discerning trends. This technique has been used for more than a century but has experienced a rapid renewal over the last few years mostly due to its integration with GIS. It has been used for the analysis of various features some of which are spatial dynamics of rape, intra – urban migratory phenomenon etc. (James L. LeBeau ., 1987)

Measures of center are geographical techniques for locating the position of a point (or area) that represents the average location of the entire population sampled. According to (Sviatlovsky & Eells, 1937), to accurately compute these centers “it is necessary to divide a region into sections small enough to constitute a basis for a relatively precise evaluation of the features involved”. Mean center can be calculated using two methods. The first method is called the spatial mean or mean center. According to (Wong & Lee, 2005), the mean center is "a central or average location of a set of points." The calculation of the mean center involves the summation of the X coordinates, the summation of the Y coordinates, then finally dividing each sum by the number of sample points. This produces an average X, Y coordinate pair (an average point) of all the sample points. This average X, Y coordinate pair is the mean center. It provides the zone of concentration of the phenomenon under study. This study relates the zone of concentration of population and then relating it to built- up density using centrographic technique. (Omaha Demographic Centers, n.d.). The other methods include calculating centers, including the median point calculation, quartilides, decilides and centrioles.

The process of urbanization has significant effect on the environment with removal of natural land-cover types and their replacement with common urban materials such as concrete, asphalt, stone, brick and metal. Due to this an increase in heat storage and transfer can be sensed which leads to a significant change on the local weather and climate. This rise in temperature can be accounted for by a rise in population.

Study Area

Kolkata formerly Calcutta is the capital of West Bengal. It is situated between 22° 32' N - 23° 58' N latitude and 87° 32' E - 88° 24' E longitude. It has an elevation of 1.5 – 9 m above mean sea level and an area of 1886.67 km^2. It lies along the east side of river Hoogly and is has an annual mean temperature of 26.8 °C and monthly mean temperatures varying from 19–30 °C (66–86 °F). As of 2011, the city had 4.5 million residents; the urban agglomeration, which comprises the city and its suburbs, was home to approximately 14.1 million, making it the third-most populous metropolitan area in India. Over the decade of 2001-2011 the population density has decreased by 1.88% and the urban agglomeration population growth has been of 7.6%. (Wikipedia, n.d.)

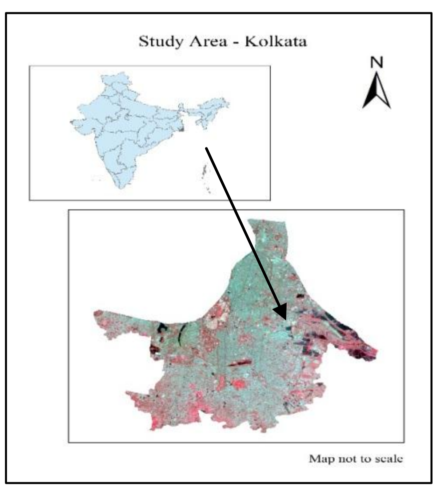


Fig: 1 – Study Area

Data used

The following ten year interval temporal satellite images have been used to execute the study:

(i) Landsat 7ETM+ image (path 138 and row 44) of 26 April, 2001.

(ii) Landsat 5 image (path 138 and row 44)of 11 April, 2010

(iii) Ward wise boundary map of Kolkata as Geodatabase.

(iv) Ward wise population data of Kolkata for the years 2000 and 2010.

Table 1

Spectral Details of the satellite imageries

LANDSAT 5		LANDSAT 7 ETM+	
Bands	Spectral Resolution(µm)	Bands	Spectral Resolution(µm)
1	0.45-0.52	1	0.45-0.52
2	0.52-0.60	2	0.52-0.60
3	0.63-0.69	3	0.63-0.69
4	0.76-0.90	4	0.77-0.90
5	1.55-1.75	5	1.55-1.75
6	2.08-2.35	6	10.40-12.50
7		7	2.09-2.35
		8	0.52-0.90

Source - http://landsat.usgs.gov/band_designations_landsat_satellites.php

Methodology

Both the images were classified using maximum likelihood classifier to extract built-up area including other impervious surfaces to determine the urban class. In this study, we are mostly interested in urban built up class hence not much classes are required while classifying the image. Only broad classes such as water, grassland, bare land, built up and dense vegetation were classified. The classified maps were then cross checked with the existing land use land cover maps for accuracy assessment. The accuracy obtained was 90% for 2001 and 85% for 2010. Since accuracy depends on a lot of factors namely suitability of training sites, sensor performance and resolution, method of classification and others, reviewing the literature suggests the accuracy obtained for classification of the satellite images can be accepted. (B. Bhatta, 2010)

In the next step, the mean center of the study area was calculated using Arc GIS mean center tool. The mean center will give the center of concentration of population for respective year. When the direction of the shift in mean center is followed it will give us the direction of urban growth. Usually the direction in which the population increases is the direction in which the urban built-up also increases. After this step taking mean center as the center, circles were drawn taking radius equal to 1, 2, 3 standard distance measure. This standard distance measure was calculated using the following formula:

$$\sqrt[2]{(\sum((X - Xc) * P) + \sum((Y - Yc) * P) / \sum(P))}$$

The radius for this circle is actually the standard deviation. Taking the concept of normal distribution we know that 68.2% of the total population should lie within 1standard deviation of the normal distribution. In this case the first circle should contain 68.2% of the total population of Kolkata. The population density was calculated and the built up area for each dataset from the respective classified image was found out using the conditional query in Arc GIS, and the amount was found using zonal analysis in Arc GIS. After this the surface temperature was found out using the following equations:

For calculating the Radiance from DN values:

$$L_\lambda = \left(\frac{LMax_\lambda - LMin_\lambda}{Q_{cal\max} - Q_{cal\min}} \right) (Q_{cal} - Q_{cal\min}) + LMin_\lambda$$

L_λ = Spectral radiance at the sensor's aperture [W/(m^2 sr µm)], Q_{cal} = Quantized calibrated pixel value [DN], Q_{calmin} = Minimum quantized calibrated pixel value corresponding to LMINλ [DN], Q_{calmax} = Maximum quantized calibrated pixel value corresponding to LMAXλ [DN], $LMin_\lambda$ = Spectral at-sensor radiance that is scaled to Qcalmin [W/(m^2 sr µm)], $LMax_\lambda$ = Spectral at-sensor radiance that is scaled to Qcalmax [W/(m^2 sr µm)]

Radiance to At-sensor Brightness Temperature:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1 \right)}$$

where,

T = Effective at-sensor brightness temperature [K], K_1=671.62 (L4TM), 607.76 (L5TM), 666.09 (L7ETM+) [W/ (m^2srµm)], K_2=1284.30 (L4TM), 1260.56 (L5TM), 1282.71 (L7ETM+) [K],
L_λ = Spectral radiance [W/ (m^2srµm)], ln= natural algorithm

Radiance to ToA reflectance:

$$\rho_\lambda = \frac{\pi . L_\lambda . d^2}{ESUN_\lambda . \cos\theta_s}$$

Where,

ρ_λ = ToA reflectance [unitless], L_λ = Spectral radiance [W/ (m^2sr µm)], d= Earth-sun distance [Astronomical units], $ESUN_\lambda$ =Mean exo-atmospheric solar irradiance [W/ (m^2µm)], θ_s= solar zenith angle [degrees]

Land surface temperature using radiance and emissivity images:

$$T = \frac{K_2}{\ln\left(\varepsilon f_{inal} \frac{K_1}{L_\lambda} + 1 \right)}$$

After the LST was computed for each dataset, zonal analysis was done to obtain the surface temperature pertaining to each ward. Then all the three parameters namely built-up density, population density and land surface temperature were then classified using Arc GIS to obtain the region of concentration for each parameter.

Result

The following results were obtained for mean center.

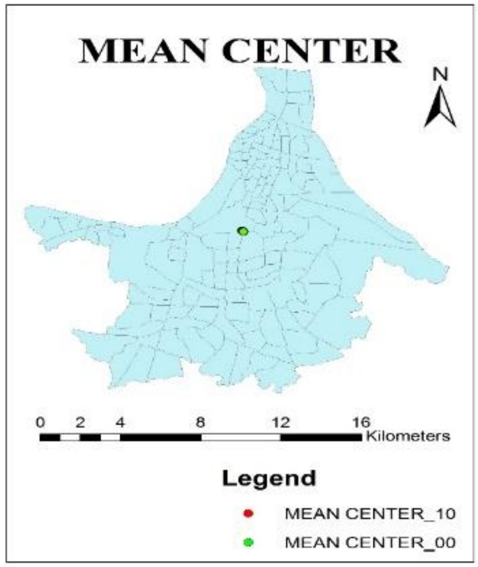
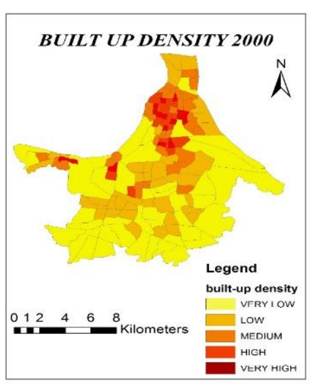


Fig: 2 – Mean Center

As can be seen from the mean center calculations there is not much shift in the mean center for population in period of 2000 – 2010. This is for the reason that there has only been an increase of 53174 in the total population of Kolkata in this decade. Mostly there is a daily migration of people in to the city for work.

For the results of standard distance measure, we obtained that within the first standard distance measure, 51.22% of the total population resided in 2000 and in 2010 the figure rose to 61. 55%. Both these are less than the specified 68.2% value. From the mean center radius of 1, 2 standard distance measurement obtained from equation above was drawn and the population residing within the standard distance circle was calculated. Theory says that 68.2% of the total population should reside within the first standard deviation. This is because towards the western and south eastern part of the city, there are mostly grasslands, open lands, factories and stadiums where no person resides. Hence this dichotomy is seen.

When the built up density and population density were classified the following results were obtained:



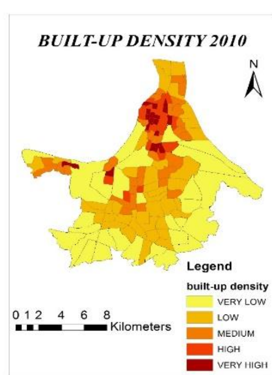
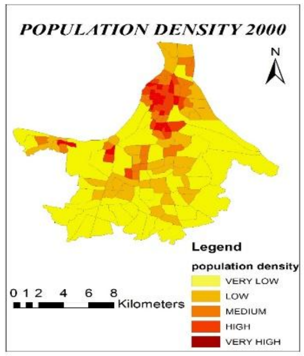


Fig: 3 – Built-up density 2000 **Fig: 4 – Built-up density 2010**



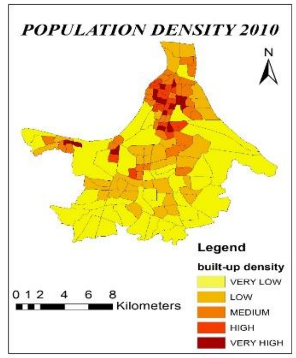
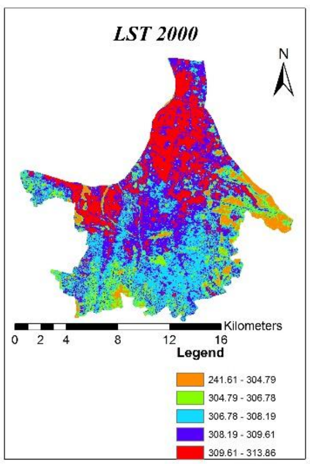
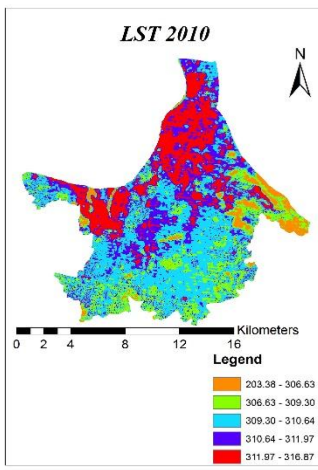
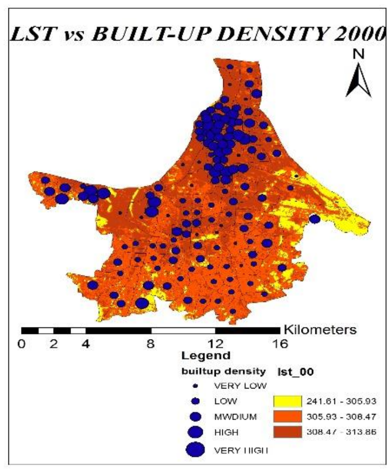


Fig: 5 – Population density 2000 **Fig: 6 – Population Density 2010**

It can be seen that the population density as well as built up density has increased in the direction of mean center.







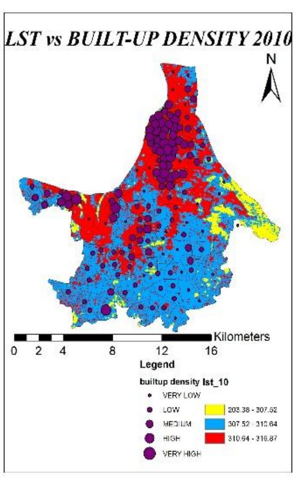
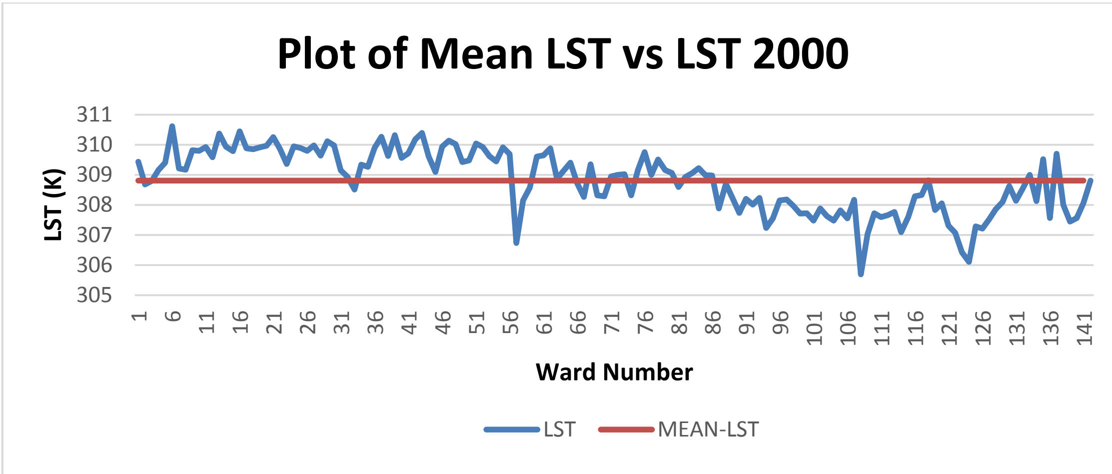
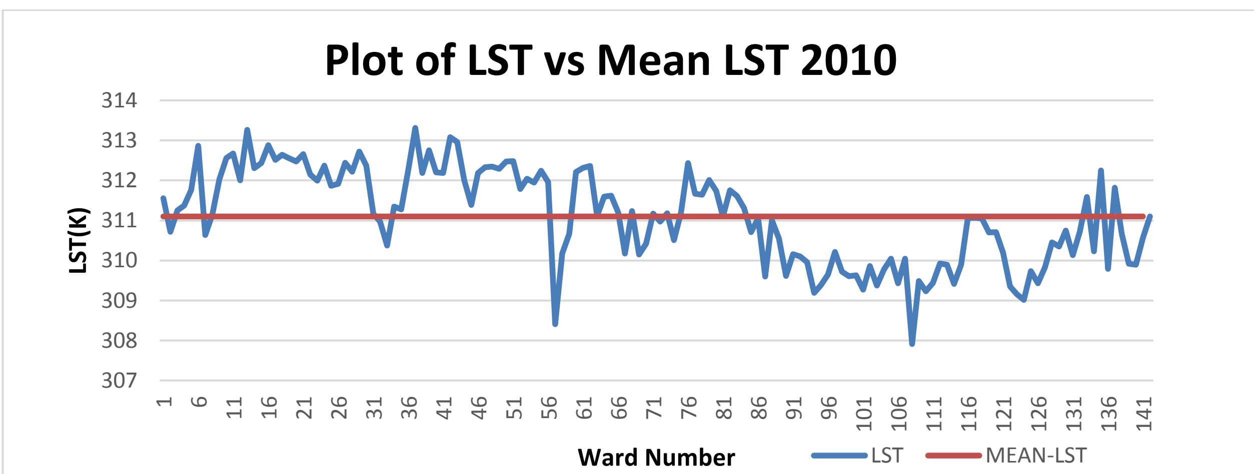


Fig: 7 – LST 2000 **Fig: 8 – LST 2010** **Fig: 9 – LST vs. Built-up density 2000** **Fig: 10–LST vs. Built-up density'10**

As can be seen from the image, the increase in LST in respective areas is attributed to the fact that in 2000 those areas were covered with grasslands and trees which were now cut for built-up area. There has been an overall increase in land surface temperature and built up density is concentrated in the areas of high land surface temperature. The concentration of surface temperature is seen in the area having high built-up density.



The mean surface temperature is high for certain wards namely 6, 13, 21, 16, 37, 39, 43, 44. Except ward 6 all other wards have very high built up density associated with very high population density contributing to high surface temperature. In ward 6, there is low built up density and population density but it still has higher than mean LST because this ward constitutes lots of open spaces and factories due to which both the population and built up densities are low. Wards 58, 108 and 124 have very low LST compared to mean LST because these wards constitute water bodies and grasslands and trees. Other wards for which LST is comparatively lower than mean LST can be contributed to the fact that they have comparable built up and population density.



In 2010, wards 31-35 have lower surface temperatures than mean LST due to grasslands, water bodies and dense vegetation in these wards. They also have low population and built up densities. Wards 126 – 136 have low built up and population densities attributed to the presence of more grasslands, and small water bodies surrounded by dense vegetation. Wards 58 and 108 have very low LST compared to mean surface temperature as these wards constitute water bodies. Other wards which had lower surface temperatures in 2000 have higher temperature in 2010.

Conclusion

The population density and built up density is increasing in the direction directed by the mean center. There has not been much shift in the mean center due to the daily migration of people. However if more multi temporal datasets could be taken then better results could be obtained. The land surface temperature is increasing in the direction in which the built up density is increasing and it is concentrated in the region where built-up density is concentrated. Further analysis of urban heat island can be done from this study.

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