Urban Footprint Analysis using FOSS

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***Abstract*— Urban footprint is measured through the quantification of paved surface that humans use. It is the amount of land required to sustain urban metabolism including the process of waste assimilation. The basic indicator to quantify urban footprint is the proportion of built up and the reduction of other land use types. The physical growth of urban areas happens as a result of rural migration and even suburban concentration into cities in response to the urbanisation process. Urbanization in India is taking place with the increase in urban population which is growing at around 2.3 percent per annum. Understanding the dynamics of urban expansion is critical for providing basic amenities and infrastructure. Unplanned urbanization results in overcrowding, lack of requisite infrastructure and basic amenities to all sections of the society, traffic congestions, enhanced pollution levels, reduced assimilative capability of the ecosystems. Consequence of uncontrolled urbanization is the sprawl or dispersed growth in the region. Planned urbanization requires spatial data for longer time periods. Availability of remote sensing data since 70's along with the capability to handle the spatio-temporal data and metrics has helped in visualizing the urban growth. Urban footprint analysis has been done for Delhi in cost effective way through Free and Open source GIS (GRASS: http://ces.iisc.ernet.in/grass) using remote sensing data available in public domain (http://glovis.usgs.gov). Spatial configurations were assessed through metrics using FRAGSTATS. Land use analysis shows an increase of 105.3 (in 1970's) to 733.2 (in 2000's).**

Keywords- Urban footprint, land use dynamics, spatial metrics, FOSS

I INTRODUCTION

Urbanization is characterized by the higher population densities resulting in the expansion of urban areas modifying substantially land cover of the region [13] influencing the availability natural resources. Land use changes are one of the driving forces of global warming and consequent changes in the climate. The physical transformations of landscapes with the enhanced human activities have contributed to cause global environmental changes [4]. Rural to urban migration leads to the expansion of urban area resulting to land cover transformations. Unplanned urbanization process tends to increase the construction of the buildings and decreases the quality of the environment, infrastructure, and natural resources affecting the urban structure [6]. Uneven development, degraded infrastructure of the city and higher population densities results in urban growth and sprawl. Urban sprawl refers to the uneven development along the highways or surrounding the city or in the periurban region resulting in the destruction of agricultural land and ecological sensitive habitats [10] whereas urban growth refers to the absolute increase in the physical size and population of an urban area [1]. Increased urbanization in turn causes irregular and unplanned urban development areas. The unplanned urbanization alters drainage characteristics which increases rate of surface runoff [11] and is considered to be critical issue resulting in fragmented urban patches at the fringes [3].
Indian cities are facing massive urbanization process as well as economic growth subsequent to globalization has drastically changed ecology, area, population, economic, social aspects, etc. Understanding the land use land cover (LULC) changes plays a significant role in planning process [4].

Delhi being the National capital city has attracted migrants from other cities due to higher economic activities. Delhi urban agglomeration is third Indian agglomeration after Mumbai and Kolkata. This high growth of urban areas has great influence on the city's economy and infrastructure development. The population density of the city has been increasing and according to the 2011 census, the city's population is reached up to 16,753,235 persons. Due to the massive immigration of population into the city has also resulted in the unplanned development of the city [6]. Delhi is one of the major places for political activities still lack in the field of planning and infrastructure evident from transportation and infrastructure problems.

Landcover and landuse analysis provide an opportunity to understand the urban growth analysis due to human activities. Temporal remote sensing data and geospatial technologies aid in identifying the temporal LULC dynamics [3]. The spatial characteristics of landuse features are measured using spatial metrics through free software FRAGSTATS [10]. Availability of temporal remote sensing data, free and open source GIS (GRASS, http://ces.iisc.ernet.in/grass) and spatial metrics along with ancillary data helped in understanding the spatial characteristics of Delhi useful for development and planning purpose.

II STUDY AREA

Delhi is the capital of India and it is the fastest growing city in the country. It is largest metropolis by area and second largest metropolis by population after Mumbai. It is the eighth largest metropolis in the world by population with more than 16.75 million inhabitants in the territory and with nearly 22.2 million residents in the National capital region. It is located at 28.61° north latitude and 77.23° east longitude. It borders the Indian states of Uttar Pradesh to the east and Haryana on the north, west and south and is situated on the banks of the River Yamuna.

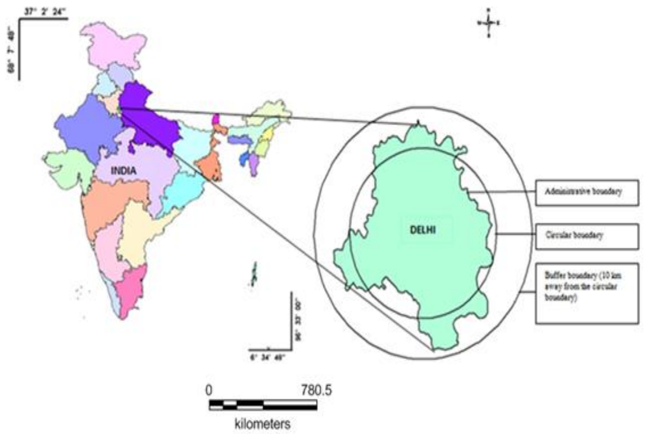


Figure 1 Map depicts the Delhi administrative boundary.

III DATA ACQUISITION

Landsat satellite images of Delhi were acquired for different time period from Global Land Cover Facility (GLCF) (http://www.glcf.umd.edu/index.shtml and http://www.landcover.org/), United States Geological Survey (USGS) Earth Explorer (http://edcsns17.cr.usgs.gov/NewEarthExplorer/) and Glovis (http://www.glovis.usgs.gov.) websites. Table 1 provides the details of the LANDSAT satellite image that are used in the study.

Table 1: LANDSAT satellite data used for the analysis

LANDSAT (Sensor)	***Date of acquisition (dd/mm/yyyy)***	***Number of bands***	***Resolution (m)***	***Wavelength (micrometers)***
MSS (Multispectral scanner)	08/03/1977	4	60 60 60 60	0.5 - 0.6 0.6 - 0.7 0.7 - 0.8 0.8 - 1.1
MSS (Multispectral scanner)	07/01/1980	4	60 60 60 60	0.5 - 0.6 0.6 - 0.7 0.7 - 0.8 0.8 - 1.1
TM (Thematic mapper)	01/03/1998 and 24/03/1998	7	30 30 30 30 30 60 30	0.45 - 0.52 0.52 - 0.60 0.63 - 0.69 0.76 - 0.90 1.55 - 1.75 10.40 - 12.50 2.08 - 2.35
TM (Thematic mapper)	14/02/2010	7	30 30 30 30 30 60 30	0.45 - 0.52 0.52 - 0.60 0.63 - 0.69 0.76 - 0.90 1.55 - 1.75 10.40 - 12.50 2.08 - 2.35

IV METHOD

Urban dynamics was analysed using temporal remote sensing data of the period 1977 to 2010. The time series spatial data acquired from Landsat Series Multispectral sensor (57.5m) and Thematic mapper (28.5m) sensors were downloaded from public domain (http://glcf.umiacs.umd.edu/data). Multispectral sensor data was resampled to Thematic mapper resolution i.e., 28.5m before processing. Survey of India (SOI) topo-sheets of 1:50000 and 1:250000 scales were used to generate base layers of city boundary, etc. The process of the analysis includes preprocessing, analysis of land cover and land use, computation of Shannon entropy and metrics. The study region include Delhi city administration with 10 Km buffer is chosen to account for landscape dynamics due to urbanization in Delhi and to account the regions which are likely to undergo changes in the next decade.

Landcover analysis was done using Normalized Difference Vegetation Index to show the changes in vegetation cover. NDVI is given by (1),

$$NDVI = NIR\text{-}Red/NIR+Red, \qquad (1)$$

NDVI values ranges from -1 to 1. The negative value indicates the non-vegetation and presence of built-up, water, sand etc. The increasing value from 0 indicates the presence of vegetation.

The four decades temporal images were classified using Gaussian maximum-likelihood supervised classifier in GRASS considering four landuse classes; built-up, vegetation, water and others. The excessive noise in the classified images was removed through 3 X 3 median filter.

Shannon's entropy was used to analyze the dynamic urban sprawl changes. It is calculated for four directions Northeast, Northwest, Southwest and Southeast direction in 1 Km interval from the centroid of the study area. Shannon's entropy measures the rate of urban sprawl pattern and the value range from 0 to log n, indicating very compact distribution for values closer to 0. The values closer to log n indicates that the distribution is very much dispersed. It is computed using (2) [17],

$$H_n = -\sum P_i \log_{10}(P_i) \qquad (2)$$

Where Pi is the Proportion of the variable in the ith circle and n is the total number of circles. If the value is closer to zero - the distribution is very compact and if the value closer to Log (n) - the distribution is dispersed [14]

Spatial metrics were computed using FRAGSTATS [10] to quantify the characteristics of the landscape. FRAGSTATS is software that quantifies the spatial heterogeneity of the landscape. FRAGSTATS mainly computes patch, class and landscape level metrics; current study includes class level metrics calculation. Selected spatial metrics were used to anlayse the urban dynamics of the Delhi from the classified data. This computation is done at three levels: patch, class and landscape levels. Patch indices have very little interpretive value [10], hence for this study metrics at class have been considered. Table 2 gives the description of the metrics considered.

Area metrics: Area metrics quantifies the composition of the landscape and provides information about the area occupied by various patches in the landscape.

Indicator	**Table2 :Description of the Area metrics (Source: Mc Garigal and Marks, 1994)**		
	Abbreviation	***Formula***	***Description***
Number of patches (Built-up)	NP	$N = n_i$ Range: NP≥ 1	NP equals the number of patches of the corresponding patch type. ni is the number of patches of a particular type.
Percentage of landscape (Built-up)	PLAND	$PLAND = P_i = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100)$ Range: 0<%Land≤ 100	PLAND equals the percentage the landscape comprised of the corresponding patch type. a_{ij} = area (m^2) of patch ij. A = total landscape area (m^2).

Shape Metrics: Shape metrics quantify the landscape configuration by measuring shape complexity of patches at patch, class and landscape level. Shape is a difficult parameter to quantify concisely in a metric [10]. All the shape indices are based on perimeter to area ratio and thus they help in interpreting irregularities in urban patches. Table 3 lists the select shape metrics considered in this study.

Indicator	**Table3 : Metrics to compute shape complexity of patches (Source: Mc Garigal and Marks, 1994)**		
	Abbreviation	***Formula***	***Description***
Area-Weighted Mean Shape Index	AWMSI	$AWMSI = \sum_{i=1}^{m}\sum_{j=1}^{n}\left[\left(\frac{0.25p_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{A}\right)\right]$ a_i and p_i are the area and perimeter of patch i, and N is the total number of patches. Range: AWMSI $\geq$ 1, without limit.	It weights patches according to their size, larger patches are weighed more heavily than smaller patches.
Normalized landscape shape Index	NLSI	$NLSI = \frac{e_i - \min e_i}{\max e_i - \min}$ Range: 0 to 1	Normalized Landscape shape index is the normalized version of the landscape shape index (LSI) and, as such, provides a simple measure of class aggregation or clumpedness. It measures the perimeter-to-area ratio for the landscape as a whole.

V RESULTS AND DISCUSSION

Table 6 represents vegetation and non-vegetation categories as per vegetation analysis using NDVI.

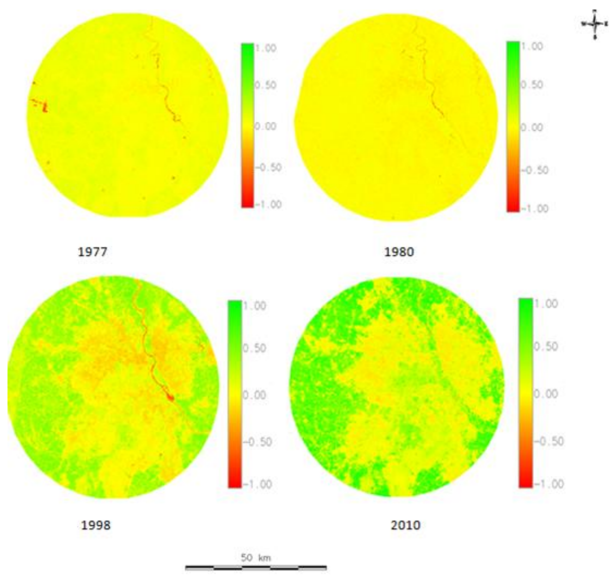


Figure 2: NDVI from LANDSAT 1977, 1980, 1998 and 2010 for Delhi region.

NDVI INDEX	Table 4: NDVI for Delhi region.	
	Vegetation (%)	*Non-vegetation (%)*
1977	38.85	61.15
1980	30.7	69.3
1998	32.86	67.14
2010	26.44	73.56

Remote sensing data corresponding to Delhi were classified accordingly for temporal analysis of data for 1970's, 80's, 90's and 2000's. Accuracy assessment of the classified images was done using error matrix, overall accuracy and kappa statistics. The data with higher accuracy was considered for the analysis as it gives the better consistency and reliability for computation of landscape metrics. Figure 3 shows the classified images. Table 5 shows land use statistics of classified images. Table 6 depicts the overall accuracy and kappa statistics for the classified images.

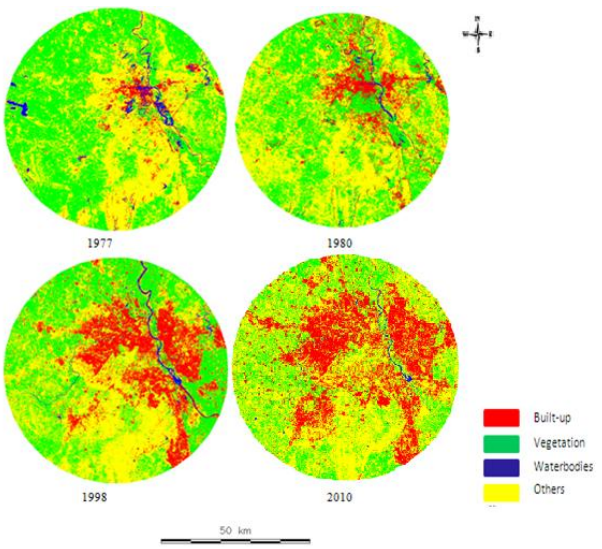


Figure 3 depicts the classified images of Delhi.

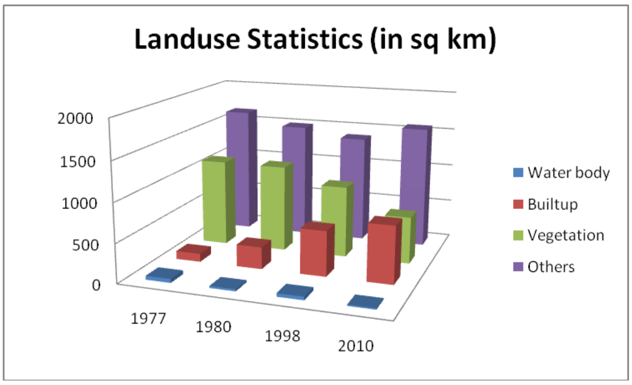


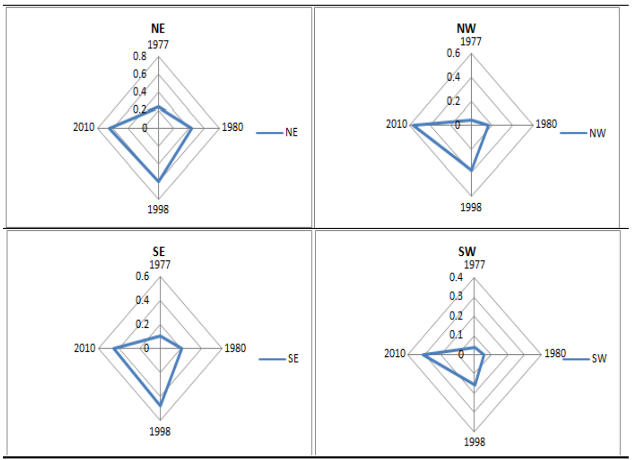
Figure 4: Land Use statistics

Delhi (years)	Table 5: Land Use statistics of the classified images.							
	Built-up		***Vegetation***		***Water bodies***		***Others***	
	Area (sq.km.)	*Area (%)*	*Area (sq.km.)*	*Area (%)*	*Area (sq.km.)*	*Area (%)*	*Area (sq.km.)*	*Area (%)*
1977	105.3	3.60	1120.2	38.30	49.75	1.70	1650	56.40
1980	283.37	9.71	1115.1	38.22	26.3	0.90	1492.9	51.17
1998	580.83	19.85	918.64	31.39	43.05	1.47	1383.5	47.29
2010	733.20	25.06	603.10	20.62	17.00	0.58	1572.1	53.74

City	Table 6: Overall Accuracy and kappa statistics of classified images							
	OA	$\hat{k}$	**OA**	$\hat{k}$	**OA**	$\hat{k}$	**OA**	$\hat{k}$
Delhi	89	0.94	99	0.99	97	0.98	88	0.71

Shannon's entropy (Hn): Table 7 lists Shannon's entropy computed direction wise for 1977 to 2010. Figure 6 depicts the Shannon's entropy calculated for all four directions (Figure 6), NE and SW show the tendency of sprawl In NW direction, there is increasing trend from 1977 to 1980 and suddenly decrease in 1998, which shows compactness and slightly increases for 2010 with increasing fragmentation. In direction southeast, the graph shows increasing trend till 1998 and slightly decreases in 2010 indicating compactness.

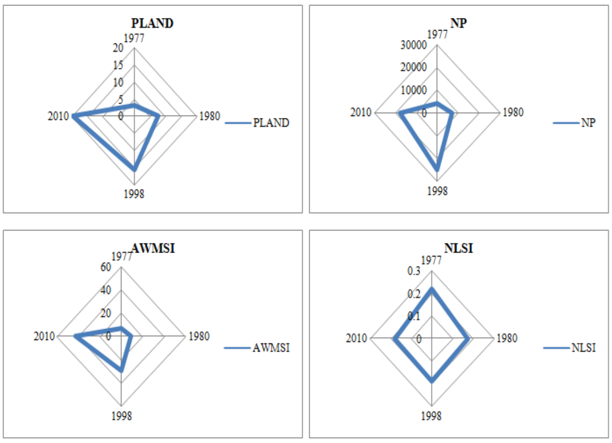
Year	Table 7 shows the Shannon's entropy for Delhi region.				
	NE	NW	SE	SW	Log N
1977	0.23	0.04	0.10	0.03	1.49
1980	0.43	0.16	0.20	0.05	1.49
1998	0.60	0.37	0.47	0.15	1.49
2010	0.64	0.57	0.45	0.31	1.49



x-axis represents year and y-axis represents indicator values

Figure 6: Shannon's entropy for year 1977 to 2010.

Figure 7 illustrates four spatial metrics; above two graphs represents the area metrics i.e., built-up percentage of landscape (PLAND), number of urban patches (NP), and below two graphs represents shape metrics i.e., Area weighted mean shape index (AWMSI) and normalized landscape shape index (NLSI). PLAND indicates increasing trend from 1977 to 2010 that showed 3.19 % in 1977 and by 2010 increased to 19.65%, number of patches represented the fragmentation of urban patches that showed maximum for 2010 (4208 in 1977 and 17949 in 2010). The shape metrics shows the complexity of the urban patches, AWMSI showed maximum complexity of urban patches during 2010 (43.04 m^2) and regular and simple urban patches were predicted during 1977 (6.6 m^2). The NLSI accounts for normalized value of shape index and provides the simple measure of aggregation or clumpyness. The value ranged 0.2198 (for 1977) and 0.1799 (for 2010) indicating disaggregation of urban patches with time.



x-axis represents year and y-axis represents indicator values

Figure 7 Percentage of landscape, Number of patches (Area metrics) and Area weighted mean shape index, Normalized landscape shape index (Shape metrics) for urban patches.

VI CONCLUSION

Urbanization process in Delhi is quantified using temporal remote sensing data, which show an increase of builtup from 105.3 (1970's) to 672 (2000's) at the cost of vegetation and open spaces. NE and SW show the tendency of sprawl as per the Shannon's entropy. Spatial metrics reveal aggregation at city centre with sprawl at outskirts in NE and NW directions.

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