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QUANTIFYING URBANISATION USING GEOSPATIAL DATA AND SPATIAL METRICS-A CASE STUDY OF MADRAS

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ABSTRACT

Urbanisation and urban sprawl phenomenon has become peak attention drawing topics around the world. Most of the countries are facing challenges with urban areas, its growth and impacts on the surrounding environments. A common method is not defined to investigate urbanisation till date because of its dynamic nature. This paper aims to study urbanisation pattern of Chennai metropolis area located at south eastern coastline of India, which has seen a tremendous increase in population as well as increase in industries past two decades. Remote sensing data were acquired temporally from 1991-2013. Land cover and land use analysis was performed. Land use with gradients with zonal boundaries along with spatial metrics were used to analyse finer details of urbanisation pattern. The result indicates rapid urban growth in the periphery and outskirts of the city which are highly fragmented.

Keywords: Urbanisation, Chennai, Remote sensing, Spatial metrics.

INTRODUCTION

Urban area is characterized mainly based on the population density and impervious surface. Annual rate of urban population growth in India is about 2.3% (World Urbanization Prospects, 2005). Also it has been estimated that by 2025, 60% of the globe inhabitants will live in urbanized areas, 72% by 2050 (Ramachandra et al., 2008; United Nations, 2012) in contrast with 53% of inhabitants living in urban areas at present. Urban regions start agglomerating and filling up patches of other land use and in process form the areas of dominating impervious surface creating various environmental problems such as heat island, etc., this process of agglomeration of impervious surface is called urbanisation.

Urbanisation is a complex irreversible socio-economic phenomenon that generates changes in land use and landscape patterns (Bharath et al., 2012; Jat et al., 2008; Deng et al., 2009). It is worth to mention that rural land undergoes several changes at landscape levels to finally result into an urban area leaving significant amount of environmental impacts. (Pickett et al., 2001; Weng, 2007). The aftermath of urbanisation includes escalated vehicle and traffic density (Ewing et al. 2002), severe problems on the biodiversity, environment and ecosystem, (Riley et al., 2005; Xian et al., 2007; Li et al., 2010) Land use fragmentation, and most importantly the rapid changes in hydrological cycle i.e. changing rainfall patterns and flooding regimes (Bronstert et al. 2002, McCuen et al. 2003). Rural landscape as well as the small towns and the villages lying in the vicinity of a city or a metropolis is also vulnerable to urbanisation (Antrop et al. 2000).

Furthermore urbanisation process leads to unbalanced urban population density, unplanned infrastructure and significant lack of basic necessary facilities (Ramachandra et al., 2012). Haphazard dispersed development at the fringes of a city which attenuates resources as a consequence of large land use change (conversion of green lands, water bodies, parks, etc.) has become a serious issue to be addressed by the rapidly developing cities. This drastic change in land use and land cover can be stated as urban sprawl (Ramachandra et al., 2009, Ramachandra et al., 2012). Urban sprawl pattern refers to the trend or extent of urban expansions taking place at the fringes of a city which can identify the real dynamics of urban landscape transformation seen on a temporal basis with the aid of Remote sensing data (Weng 2007, Ramachandra et al., 2012). Urban sprawl results in multidimensional issues related to flooding, loss of cultivable land, urbanisation of public infrastructure beyond threshold, increase in crime rates, sanitation problems and health impacts.

Sustainable planning, management and a proper approach for designing the requirements of population growth and urban expansion is achieved only when urban sprawl history is monitored and understood. The best way to analyse such changes is by mapping the urban neighbourhoods. Conventional mapping techniques cannot provide exact and precise description about the region under study. The modern day technology such as remote sensing with aid in technologies such as Geographic information system and image processing techniques can provide better inputs to analyse and plan the region of growth (Ramachandra et al., 2014a,b,c).Subsequently continuous monitoring of the study area helps the planners and decision makers to identify and visualize most favourable areas of urban growth and sprawl patterns (Ramachandra et al., 2012; Al-sharif and Pradhan, 2013).

Spatial metrics are the measurements derived from the digital analysis of thematic categorical maps exhibiting spatial heterogeneity of patches, classes of patches, or entire landscape mosaics of a geographic area (O'Neill et al., 1988, Herold et al., 2005). Spatial metrics has been prolonged, analysed and put into use in various urban researches crucially to understand and quantify various types of urbanisation process and urban sprawl patterns (Ramachandra et al., 2013b; Ramachandra et al., 2014e; Kong et al., 2012).

These metrics are broadly classified into two types, firstly those that quantify the composition of the map without any spatial attributes linked to it and second type quantifies the spatial configuration of the map which has spatial information as base data for the calculations (McGarigal et al., 1995, Gustafson 1998). In this study spatial metrics are employed along with classified data which helps in monitoring land use changes (Rainis, 2003). The spatial metrics can be broadly divided into six types: area and edge metrics, shape metrics, core-area metrics, contrast metrics, aggregation metrics and diversity metrics. The selection of spatial metrics also depends upon the study region (Furberg & Ban, 2012, Irwin & Bockstael, 2007) and experience of previous studies (Cymerman et al., 2011; Wu, 2006).

STUDY AREA

Chennai or formerly known as Madraspattinam, is capital city of Tamilnadu state, India. It is located at the eastern coast - Coromandel Coast line also known popularly as "Gateway to South India". It is one of the major metropolitan cities of India and has been one of the favourite destinations for tourism, industries, education, culture and commerce. Chennai, for having a wide range of automobile industries has famously been addressed as "Detroit of India". It has tropical wet and dry climate with temperatures ranging from 15˚- 40˚C. Latitude values ranges from 12˚51'04'' to 13˚17'29'' and longitude values 79˚59'45'' to 80˚20'16''. The jurisdiction of the Chennai (city) Corporation was expanded from 174 km^2 to 426 km^2 in 2011. Chennai Metropolitan Area (CMA) has an area of 1189 km^2 comprising of 8 districts including Chennai city district. Chennai is presently fourth most populous city in India. Population has increased steeply from 5.8 million (2001) to 8.9 million (2011) in CMA. Industrial development and establishments at Sholinganallur and Perungudi, SEZ at Ennore and Nandambakkam region has boosted Chennai to attract many multinational companies in the recent years.

DATA USED

Landsat data (30Mx30m) were downloaded from USGS Earth Explorer (http://earthexplorer.usgs.gov/) website. IRS LISS-III data was obtained from NRSC for the year 2012. Data used are as listed in table 1.

METHOD

Preprocessing: Landsat satellite images of Chennai were aquired for different time period from Global Land Cover Facility and United States Geological Survey (USGS). The remote sensing data obtained were geo-referenced, corrected, rectified and cropped pertaining to the study area. The Landsat satellite images were resampled to 30m in order to maintain uniformity in spatial resolution. The study region considered included the administrative area and 10 km buffer from the administrative boundary. Multi step analysis was carried out as shown in figure 2.

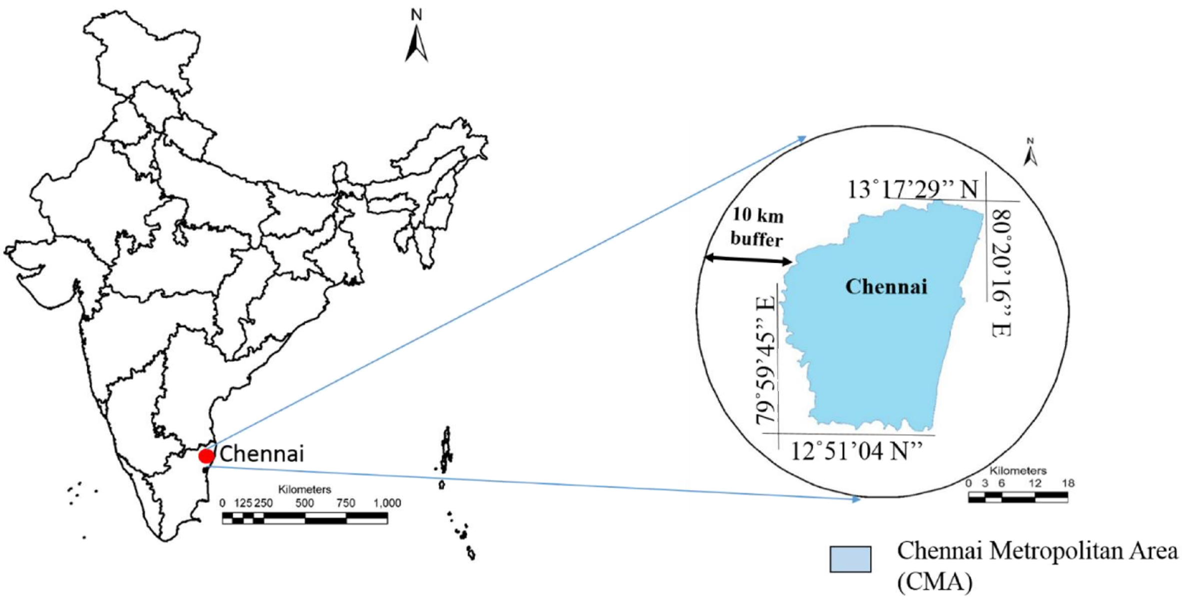


Figure 1: Study area: Chennai

Data	Year	Purpose
Landsat	1991, 2000	Land use and Land cover analysis.
IRS LISS III	2012	
Landsat	2013	
Google earth	2014	Geo-correction, classification Validation of remote sensing data.

Table 1: Materials and data used for the analysis.

Land cover analysis: Land cover refers to the original earth surface features that are formed naturally in the form of vegetation, water body, etc. (Ramachandra et. al., 2013a). Land cover analysis helps to understand the changes of the vegetation cover over the study area at different time periods. It is obtained by performing Normalised difference vegetation index (NDVI). NDVI value ranges from -1 to +1. Values consisting of -0.1 and below indicate soil, barren land, rocky outcrops, built up/urban cover, whereas water bodies are indicated by zero values. Low density vegetation is indicated in the range +0.1 to +0.3 while high density vegetation or thick forest canopy is given in the range +0.6 to +0.8.

Land use analysis: Land use analysis starts with generation of False colour composite (FCC) image. In this study we have taken three bands (Green, Red and NIR) for the analysis. Creation of FCC image directly helps in identifying heterogeneous patches in the landscape (Ramachandra et al., 2014). Training polygons are digitized based on the distinguishable heterogeneous features in FCC, covering at least 15% of the study area ensuring that polygons are picked from entire study area spreading invariably. These polygons and its coordinates are entered into GPS and ground truth data is verified with respect to corresponding land use type. Polygons were also collected from Google earth (https://www.google.com/earth) used as ancillary data for classification. 60% of these training polygons were used for classification purpose while the rest 40% for validation and accuracy assessment.

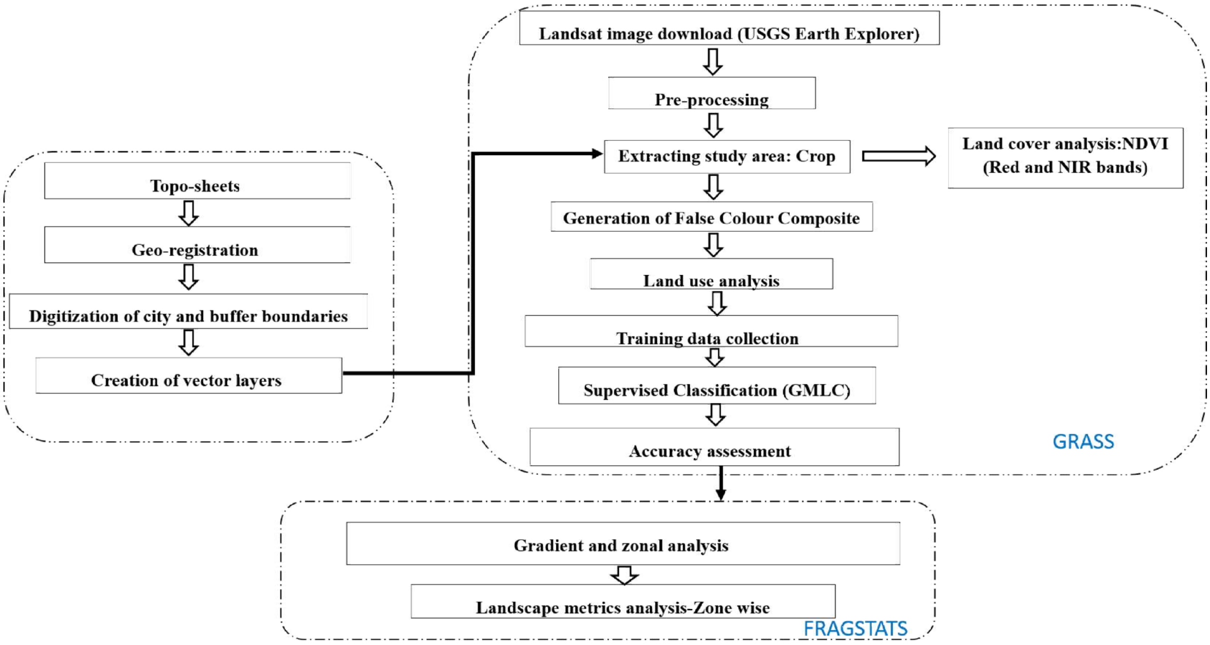


Figure 2: Methods involved in Urbanisation pattern analysis.

Supervised Gaussian Maximum Likelihood Classification (GMLC) was employed, since this algorithm is proved to be the eminent among other classifiers as it considers cost functions as well as probability density functions (Duda et al., 2000). It evaluates both variance and co-variance of the category when classifying an unknown pixel (Lillesand et al., 2012). Land use classification was done with the help of open source software called GRASS (http://grass.osgeo.org/) under four categories shown in table 2.

Category	Features involved
Urban	Houses, buildings, road features, paved surfaces etc.
Vegetation	Trees, Gardens and forest
Water body	Sea, Lakes, tanks, river and estuaries
Others	Fallow/barren land, open fields, quarry site, dry river/lake basin etc.

Table 2: Land use categories.

A classification is not complete until its accuracy is assessed. Congalton et al., (1999) has shown that classification accuracy can be obtained by preparation of error matrix or confusion matrix. Overall accuracy and Kappa were computed.

Density gradient and zonal analysis: Most of the researchers have studied urbanisation patterns based on political boundaries (Taubenbock et al., 2009; Jin et al., 2009). But to understand the growth locally specific to regions and neighbourhood, the entire study area was divided into four zones i.e. North East, North West, South East and South West based on directions. In addition to zone division, each zone was divided into concentric circle from the centre with an increment of 1km (37 circles). These finely divided zones helps to interpret, quantify and visualize urbanisation pattern and agents responsible for the same at local levels spatially along with classified data (Ramachandra et al., 2012).

Landscape metrics: Zone wise computation of the metrics which included Number of patches (NP), Normalised land shape index (NLSI) and Clumpyness index (CLUMPY), as indicated in table 3 were performed using FRAGSTATS software.

Sl.no	Indicators	Metric type and formula	Range
1	Number of patches- NP	NP = n (no. of patches in landscape)	NP>0, without limit
2	Normalised landscape shape index-NLSI	NLSI = $\frac{ei - \min ei}{\max ei - \min ei}$ e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i. min e_i = minimum total length of edge. max e_i = maximum total length of edge.	$0 \leq NLSI \leq 1$
3	Clumpiness-CLUMPY	$\frac{Gi-Pi}{Pi}$ for $G_i<P_i$ and $P_i<5$; else $\frac{Gi-Pi}{1-Pi}$ Where, $G_i = \frac{gii}{(\sum_{k=1}^{m} gik) - \min ei}$ g_{ii}= number of like adjacencies between pixels of patch type (class) i based on double count method. g_{ik}= number of like adjacencies between pixels of patch type (class) i and k based on double count method. min ei= minimum perimeter of patch type (class) i for maximally clumped class. Pi= proportion of the landscape occupied by patch type (class) i.	$-1 \leq CLUMPY \leq 1$

Table 3: List of spatial metrics used.

RESULT AND DISCUSSION

Land cover analysis: Temporal vegetation cover analysis was done through NDVI. Figure 3 and 4 indicates the land cover changes in the year 1991, 2000, 2012 and 2013. Vegetation cover has dramatically decreased from 70.47% in 1991 to 35.53% in 2013, whereas the non- vegetation i.e. built up, paved areas etc. have increased 29.53% in 1991 to 64.47% in 2013. To understand the land use categories like builtup areas and non-vegetation areas clearly, land use analysis was performed.

YEAR	VEGETATION (%)	NON-VEGETATION (%)
1991	70.47	29.53
2000	56.7	43.27
2012	48.18	51.82
2013	35.53	64.47

Table 4: Land cover changes 1991-2013

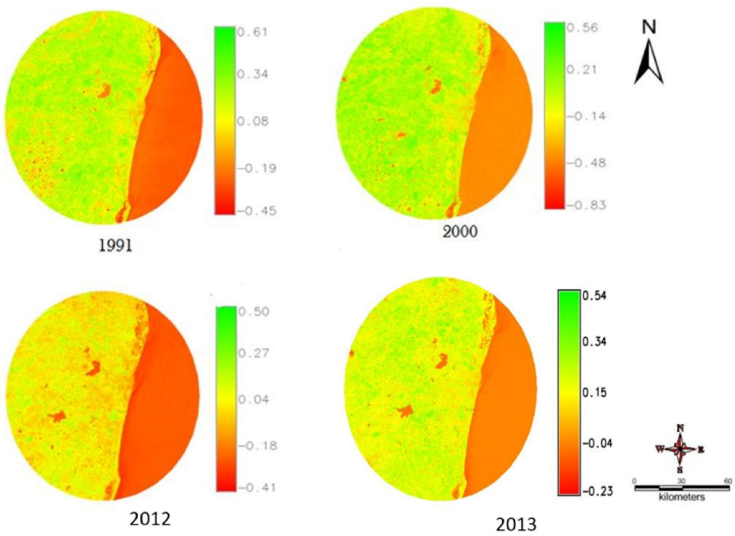


Figure 3: Vegetation cover changes from 1991 to 2013.

Land use analysis: Gaussian maximum likelihood supervised classifier was employed to perform land use analysis by considering four major categories. Figure 5 represents land use dynamics for Chennai region in past 4 deacdes with significant changes in all categories. Steep increase in built up areas were noted. Land use statistics is as tabulated in table 5. Overall accuracy obtained for the classification were 92%, 91%, 97% and 86.51% in the year 1991, 2000, 2012 and 2013 respectively. Both overall accuracy and kappa statistics are listed in table 6.

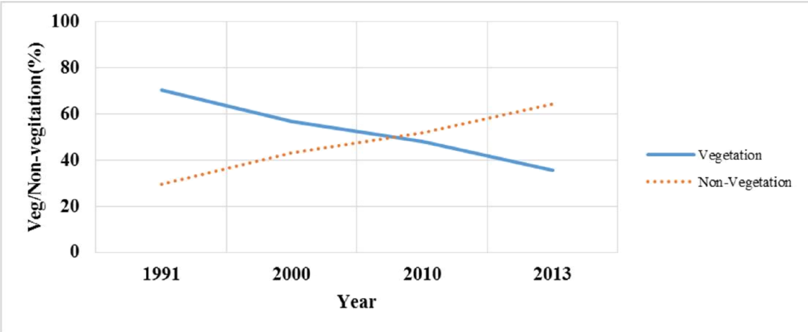


Figure 4: Vegetation vs Non-vegetation curve.

Table 5: Category wise changes in land cover.

Year / Statistic	Overall accuracy	kappa
1991	92	0.92
2000	91	0.9
2012	97	0.93
2013	86.51	0.78

Table 6: Overall accuracy and kappa statistics

Landscape metrics: Landscape metrics were calculated for each zone and gradient study region. Number of Patches (NP) indicates count of urban or built up patches. Figure 7 shows patches have increased in all periods of time but year 2000 and 2012 shows rapid growth in all the directions pointing out fragmentation in these years appear to be more. It is to be observed that in 2013, core city area (circles 1-9), each patch has agglomerated into a single large urban patch i.e. there is a saturated urban landscape with no other landscape type. Both North West and South west (circles 29-35) shows increase in number of patches from 300 in 2000 to 1400 in 2012 indicating urban sprawl in these zones.

Normalized landscape shape index provides measure of class aggregation. All four zones shows lesser value of NLSI in 2013 compared to 1991 as seen in figure 8. These minimum values (NLSI < 0.5) points out that the landscape consists of a single square urban patch or it is maximally compact (i.e., almost square) in contrast with the higher values in 1991 (NLSI ≈ 1) specifying that the urban patches are disaggregated maximally with complex shapes.

Clumpiness deals with aggregation and disaggregation for adjacent urban patches. Referring to figure 9, in 1991 the values closer to -1 in North West and South East zones (circles 26-29) indicates less compact growth or maximum disaggregation in comparison with values of 2013, curve shows values almost reaching +1 in all directions, which means to say that the growth is very complex and all the patches are maximally aggregated to form large urban monotype patch.

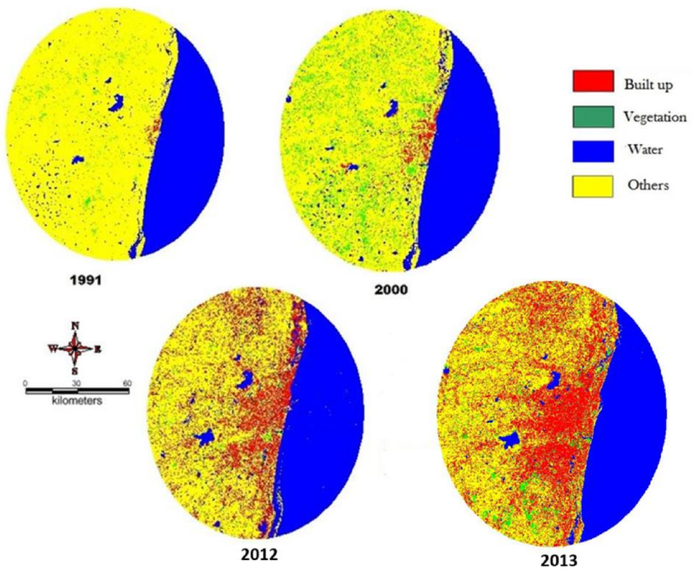
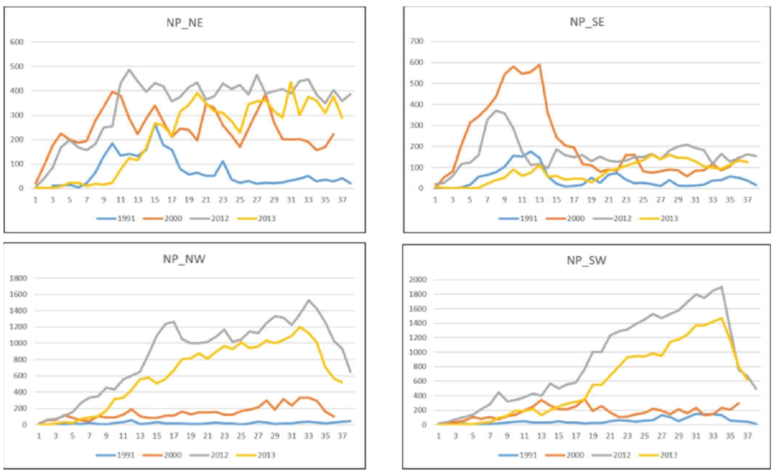


Figure 5: Land use dynamics from 1991 to 2013.

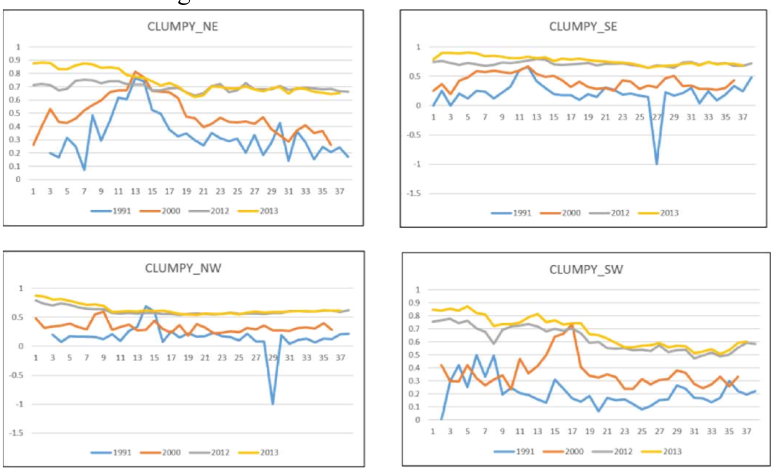


X axis: Concentric Circles at 1km, Y axis: Metric values

Figure 6: Number of patches – Direction and circle wise.

X axis: Concentric Circles at 1km, Y axis: Metric values

Figure 7: NLSI – Direction and circle wise.



X axis: Concentric Circles at 1km, Y axis: Metric values

Figure 8: Clumpiness – Direction and circle wise.

CONCLUSION

The analysis of land use change pattern in past 4 decades shows that the total urban area has been increased by more than 20 times mainly from the conversion of grazing, agricultural and open areas to urban impervious surface. In this paper, we integrate urban land use obtained from the satellite data along with spatial metrics to understand the urban growth pattern. To understand the phenomena landscape metrics were used considering the patch, shape, aggregation obtained through the moving window method to quantify the urban built up land density. The results indicate that the spatial metrics obtained method can actually provide an effective way of visualizing and quantifying the expanding footprints of built-up land. The analysis also revealed that the growth pattern of Chennai is sprawling in the periphery, especially along the highway road networks along with high fragmentation in the city jurisdiction near the boundary, also the process of densification has happened around the city centre and has spread out of the core during 1990's as well as they have started to get clumped during 2013. Aggregation and sprawl of built-up land has occurred on cost of fragmentation of various other classes for ex., agriculture land and urban green spaces. The results obtained helps the urban planners and modellers to provide decision-makers with fundamental information when formalizing development strategies for spatial development in future and accordingly the necessary measures could be adapted to control or mitigate the negative potential impacts on the urban environment.

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