LANDSCAPE METRICS FOR ANALYSING SPATIO-TEMPORAL CHANGES OF URBAN LAND USE PATTERN

Ankita P. Dadhich[1], Pran N. Dadhich[2], Rohit Goyal[1]
[1]Department of Civil Engineering, Malaviya National Institute of Technology, J.L.N. Marg, Jaipur 302 017, (Rajasthan) INDIA
[2]Department of Civil Engineering, Poornima Institute of Engineering and Technology, RIICO Institutional Area, Sitapura, Jaipur 302 022 (Rajasthan), INDIA
Email: ankitadadhich@mnit.ac.in, rgoyal.ce@mnit.ac.in, pran.dadhich@poornima.org

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ABSTRACT: Dynamic urban land use/land cover processes influence the landscape pattern at multiple scales in terms of infrastructure, amenities, environment quality and local climate. In addition rapid and unplanned urban expansion increase the social, physical and environmental problems in an area. Therefore, it is necessary to quantify and manage urban growth for sustainable development of city. This study intends to assess the effectiveness of landscape metrics in quantifying the urbanization-induced land use/land cover changes for Kota city of Rajasthan state. Based on satellite images derived land use/land cover data, landscape metrics were calculated to characterize long-term trends and patterns of urbanization during 1989-2016. Changes of landscape pattern during the study period were analyzed by different landscape metrics viz. shannon's entropy, Edge Density (ED), Number of Patches (NP), Largest Patch Index (LPI), patch cohesion index, clumpiness, Landscape Shape Index (LSI) and fractal dimension index. The spatial and temporal heterogeneity of the land use/cover changes reveals significant increase in built-up land. NP results explains that there was increase in number of patches for built-up and cropland class during 1989 to 2011, this signifies the patched/fragmented growth in city. However, in 2016, the NP decreases which indicates that there was coalescence of grown patches to a single patch. ED and LPI results reveal increasing trend for built up area during the study period. Agricultural land at the urban fringe is converted into residential and industrial areas, which has been supported by decrease in NP and ED of cropland and fallow land. Results reflects that city was more compact in 1989 and began to expand in all directions, especially in the north-east and north-west region of the city. This study will help the decision makers to understand and the landscape dynamics and linking the agents of change for better planning and sustainable development of the city.

INTRODUCTION

Growing population, changes in lifestyle and rapid urbanizations is changing the landuse pattern significantly around the globe (Hubacek and Vazquez 2002). Urban population across India has been growing consistently from 27.8% in 2001 to 31.2% in 2011(IIHS 2011). This rapid increase in urban population accompanied by fast transforming urban economy leads to unplanned sprawl, inadequate housing facilities, insufficient drainage, lack of sewerage, traffic congestion etc. The dramatic unplanned urban expansion and land use change have induced serious environmental issues threatening urban sustainable development (Li and Yeh 2004, Liu et al. 2007).

Kota, the third most populous city of Rajasthan, serves as the administrative headquarters for Kota district and Kota Division. Kota city is considered as a progressive industrial place of Rajasthan and "Education hub of India", hence people from various adjoining villages and different cities of the country are migrating to Kota. This leads to development of unplanned and uncontrolled settlements in the city and increase in population density of Kota. Population of Kota was 0.54 million in 1991, which has grown to 2.52 million in 2017 with population density of 374 persons per square kilometer (Indiapopulation 2017). Consequently, this massive increase in urban population creates bigger pressure on governments, policy makers, and urban planners to face challenges in resources reallocation, to overcome the problems that will arise in the future and to achieve a sustainable development of urban areas. Unfortunately, due to the lack of basic knowledge and timely information of the urbanization process and its long-term ecological impacts, planners worldwide have not been able to assess and analyze consistently, the urban ecosystems in both urban cores and suburban fringes (Deng et al. 2009). The integration of remote sensing and geographic information system (GIS) is a quite promising approach for detecting and analyzing the spatio-temporal dynamics of land transformation at local scale (Dadhich et al. 2017). Several studies have demonstrated the potential of geospatial techniques for analyzing the spatio-temporal dynamics of land transformation (Sudhira & Ramachandra 2007, Dadhich and Hanaoka 2011, Dadhich and Nadaoka 2012, Dadhich et al. 2017).

Herzog and Lausch (2001) proposed the use of landscape metrics that address landscape patterns and are based on analyzing the geometry and spatial arrangement of land use/land cover patches. Landscape metrics can be a useful tool for quantifying the structure and pattern of an urban environment directly from remote sensing mapping products (Herold et al. 2005, Dadhich and Hanaoka 2016). The combined application of remote sensing and landscape metrics can provide more detailed analyses of the spatio-temporal patterns of urban change (Porter-Bolland et al. 2007, Pham et al. 2011) and understanding of the impacts of urban development on the infrastructure facilities. The main purpose of this research is to examine the spatio-temporal pattern of urbanization in Kota city using remote sensing and landscape metrics techniques and to assess the effectiveness of landscape metrics in quantifying the urbanization-induced land use/land cover (LULC) changes.

MATERIAL AND METHODS

Study area

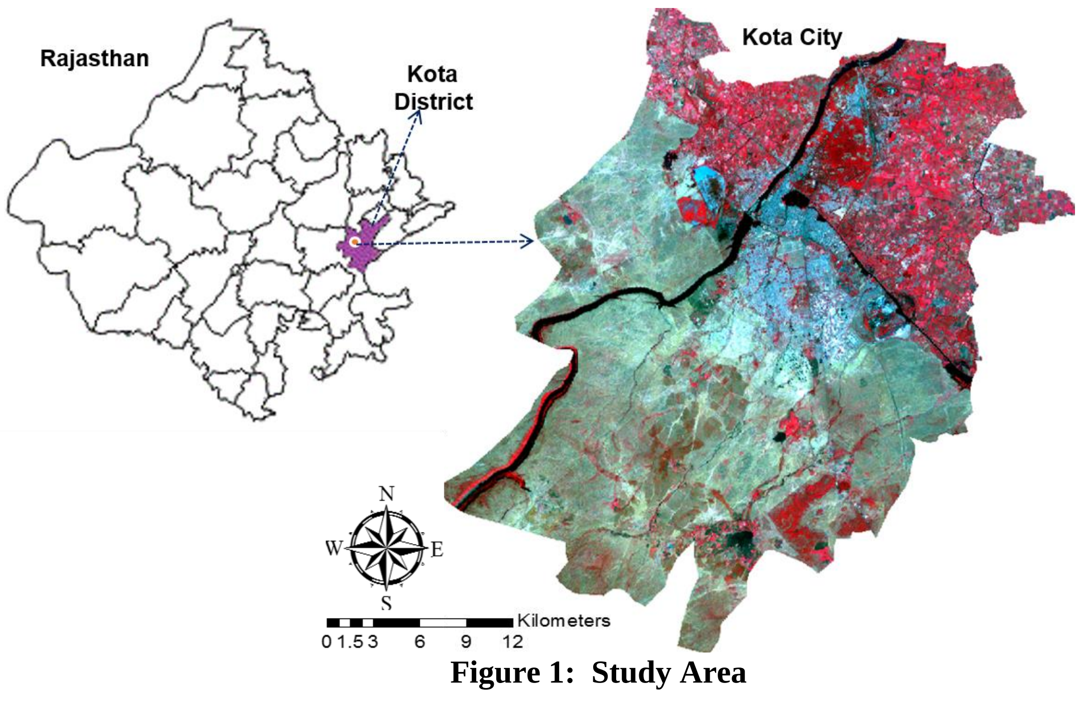

Figure 1: Study Area

Kota is the third largest city of Rajasthan after Jaipur and Jodhpur. It is located in the South East of the Rajasthan state (Figure 1) between 24°32’ & 25°50 N Latitude and 75°37’ & 76°34’ E Longitude. It is well connected with all major cities of India by broad gauge railway system. Kota city is situated on the bank of Chambal River, which is the only perennial river of Rajasthan. The climate of Kota varies from semi-arid to arid. The climate of Kota division is characteristic of South Eastern Rajasthan with a long and intensely hot summer, low rainfall and a short mild winter. The temperature normally varies from 10.6 °C to 24 °C in winter and 29.7 °C to 46.2^{0}C in summer. The average annual precipitation in the area is approximately 652 mm. As can be seen from the satellite image of Kota city in Figure 2, southern part of city is mostly barren and agriculture land mostly lies in northern part of city. River Chambal travels through city area from south west towards north of city area. Over time urban area has stretched more towards northern area with development of few sub urban patches.

Kota is a noteworthy coaching hub of the nation and has a number of engineering and medical coaching institutes for competitive examination preparations. Urban growth is one of the main problems that reduce the limited highly fertile land in this city; therefore Kota city is experiencing various urban environmental problems. Unfortunately, conventional survey and mapping techniques are expensive and time consuming for urban expansion estimations. Thus, governmental and private research centers have turned to the use of geospatial tools in monitoring, detecting, and analyzing urban growth (Huang et al. 2008). These tools were found to be cost effective, technologically efficient and, provide a synoptic overview for large regions.

Data Sources

The data has been collected from primary and secondary data sources. The required satellite imagery for the study area were downloaded from the USGS Earth Explorer and National remote sensing Centre, Hyderabad (Table 1) for the years 1989, 1999, 2011 and 2016. The data collected from secondary sources include the administrative boundary from municipal department, demographic data from the Directorate of Census Operations, Census of India. ERDAS and ArcGIS software have been used to generate various thematic layers, like district boundary map of Kota and Kota Municipal boundary map.

Table 1: Data Used for the Study

Data Type	Acquisition date	Spatial resolution (m)	Source
Landsat Thematic Mapper	9 October 1989	30	USGS*
Landsat Thematic Mapper	29 October 1999	30	USGS*
Resourcesat 2 LISS III	2 December 2011	24	NRSC#
Landsat 8 (PAN +MSS)	9 June 2016	15	USGS*

Remarks: PAN+MSS- Panchromatic + Multispectral Scanner

* United States Geological Survey (USGS), US

\# National Remote Sensing Centre (NRSC), Hyderabad, India.

Land use and Landscape pattern analysis

The tremendous expansion of urban population and urbanized area requires urban sprawl pattern analyses and computation of landscape metrics (Dadhich et al. 2016). In this study, FRAGSTATS spatial analysis program (McGarigal 2002) was used to characterize the urbanization pattern. Different landscape metrics in FRAGSTATS provide different information on changes in landscape pattern. The changes in landscape pattern during the study period (1989 to 2016) were quantified by different landscape metrics (Table 2) viz.

Table 2: Description of the Landscape Metrics analysed

Metrics	Description/ Calculation Scheme	Units	Range
Shannon's Entropy (E)	$$E = -(\sum_{i=1}^{k} P_i + ln(P_i))/ln(n)$$ Where, n= the number of classes in the image, P_i = the proportion i class of all classes in the image, i = the index for classes within the neighborhood, k= the total number of classes within the neighborhood	None	0 to 1
Number of Patches (NP)	$$NP = n_i$$ Where, n_i = number of patches in the landscape of patch type (class) i	None	NP≥1, no limit
Largest Patch Index (LPI)	$$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$$ Where a_{ij}=area (m^2) of patch ij, A= total landscape area (m^2)	Percent	0 < LPI≤100
Landscape Shape Index (LSI)	$$LSI = \frac{0.25\sum_{k=1}^{m} e^{*}_{ik}}{\sqrt{A}}$$ Where, e*ik= total length (m) of edge in landscape between patch types (classes) i and k, includes the entire landscape boundary and some or all background edge segments involving class i, A= total landscape area (m^2)	None	LSI≥1, no limit
Edge density (ED)	$$ED = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$$ Where, eik = total length (m) of edge in landscape involving patch type (class) i, includes landscape boundary and background segments involving patch type i, A= total landscape area (m^2)	Meters per Hectare	ED≥0, no limit
Patch Cohesion Index	$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}^{*}}{\sum_{j=1}^{n} p_{ij}^{*}\sqrt{a_{ij}^{*}}}\right] . \left[1 - \frac{1}{\sqrt{Z}}\right]^{-1} . (100)$$ Where, pij*=perimeter of patch ij in terms of number of cell surfaces, aij*= area of patch ij in terms of number of cells, Z= total number of cells in the landscape	Percent	0<COHESION<100
Fractal Dimension Index (FRAC)	$$FRAC = \frac{2\, ln\,(0.25\, p_{ij})}{ln\, a_{ij}}$$ Where, pij=perimeter (m) of patch ij, aij= area (m^2) of patch ij	None	1≤FRAC≤2
Clumpiness Index	$$G_i = \left[\frac{g_{ii}}{(\sum_{k=1}^{m} g_{ik}) - min\, e_i}\right]$$ $$CLUMPY = \left[\begin{array}{l} \left(\frac{G_i - P_i}{P_i}\right)\ for\ G_i < P_i \text{ and } P_i < 5; \\ else \quad \left(\frac{G_i - P_i}{1 - P_i}\right) \end{array}\right]$$ Where, gii = number of like adjacencies (joins) between pixels of patch type (class) i based on the double count method, gik = number of adjacencies between pixels of patch types i and k based on the double count method, Pi= proportion of the landscape occupied by patch type (class) i.	Percent	-1 ≤ CLUMPY ≤ 1

shannon's entropy, Edge Density (ED), Number of Patches (NP), Largest Patch Index (LPI), patch cohesion index, clumpiness, Landscape Shape Index (LSI) and fractal dimension index using satellite images derived land use/land cover data. The standard image processing techniques, such as image extraction, rectification and classification have been used for the analysis of four satellite images. The pre-processed images were then classified using hybrid classification approach i.e. combination of supervised and unsupervised algorithm followed by visual interpretation. In un-supervised classification method the ISODATA clustering algorithm was adopted, however in the supervised classification technique the maximum likelihood algorithm was used to classify the image based on the training sets (signatures). The land use/land cover data classified into various classes viz. built-up, cropland, fallow land, scattered vegetation, barren, waterbody, railway, road and airport. The classification results obtained from hybrid classification were re-checked with ground data and other secondary data to find out wrongly classified or missing pixel and these pixels were updated adequately. The overall accuracy was used to determine the classification accuracy by comparing the classified output with the ground truth locations using Erdas Imagine. The spatio-temporal change detection was then carried out by comparing the areas under each LULC class of the respective years.

RESULTS AND DISCUSSION

Land use/cover (LULC) change analysis

Anthropogenic activities have profoundly changed land use/land cover in Kota city during the study period. Spatio-temporal changes in LULC of Kota urban area (Figure 2) were quantified using classified images of four different year viz. 1989, 1999, 2011 and 2016. The LULC analysis (Table 3) show tremendous increase in built-up area ie. 1656.1 (1998) to 8921.18 hectares (2016), an increase of more than 430% in 27 years span. The area under cropland and fallow land in Kota city is lesser because only 35.46 % land is suitable for

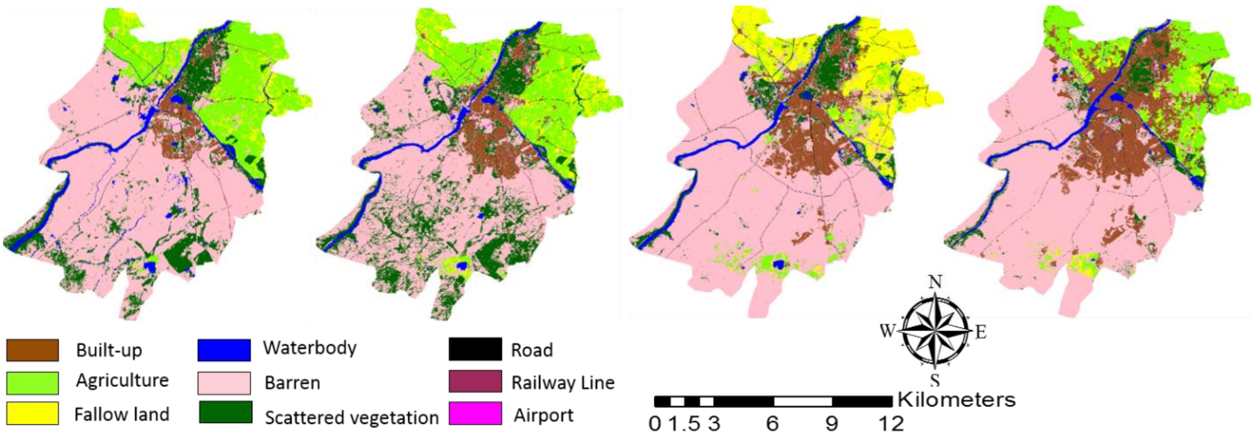

Figure 2: Spatio-temporal changes in LULC of Kota city

agriculture (Dadhich et al. 2017). The change detection analysis reveals that in last 27 years (1989-2016) there is significant decrease in cropland (8780 to 6851.9 ha.) and fallow land (1795.64 to 1086.82). The analysis implies that urban expansion has declined the cropland and fallow land in north-east and north-west direction of the Kota city. Urban area is expanding at city periphery due to large availability of land at affordable price. The overall classification accuracy of Kota city for the years 1989, 1999, 2011and 2016 was 83.67%, 85%, 84.29% and 88.31% respectively.

Table 3: LULC change statistics of Kota city during study period (in %)

LULC class	1989	1999	2011	2016
Built-up	3.39	6.17	9.44	18.27
Cropland	17.98	16.83	4.78	14.04
Fallow land	3.68	5.74	14.96	2.23
Waterbody	4.04	3.04	2.89	2.65
Barren	57.40	48.86	59.51	56.21
Scattered vegetation	12.68	18.38	7.24	5.41
Railway Line	0.39	0.39	0.39	0.39
Road	0.42	0.58	0.77	0.79
Airport	0.02	0.02	0.02	0.02

Landscape metrics analysis

Landscape metrics can be computed as patch-based indices (e.g. size, shape, edge length, patch, density, fractal dimension) or as pixel-based indices (e.g. contagion) computed for all pixels in a patch. In this study different landscape metrics were computed for classified land use data using FRAGSTATS software to understand the extent of urban growth and its characteristics. Shannon's entropy Index or Diversity index is normalized by the maximum entropy for the number of landcover classes involved. Shannon's Entropy value from the remotely sensed data can efficiently identify and characterize the urban sprawl. (Sudhira et.al 2004, Li. 2009). This index ranges from 0 to1, in which 0 indicates the uniform landcover within the neighborhood, however 1 indicates maximum diversity.

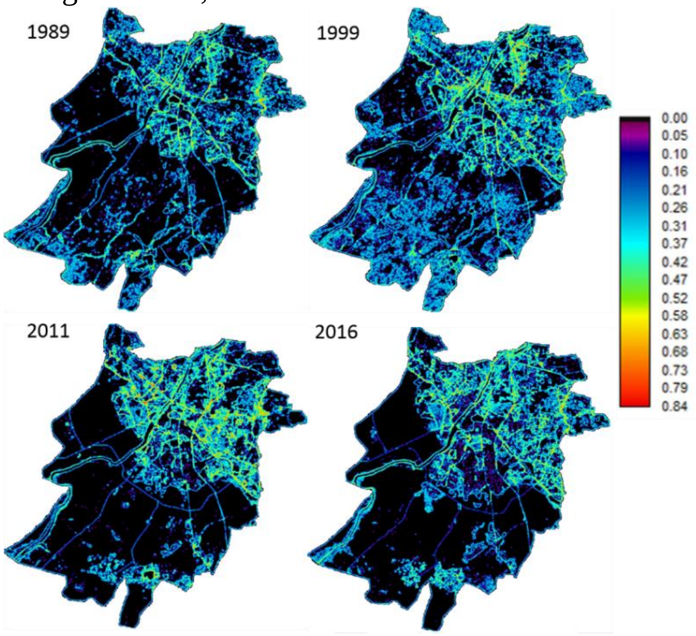

Figure 3: Shannon's entropy index for all LULC classes

The results of entropy reveals that the index value calculated in this study for all LU/LC classes (Figure 3) is 0.84 which indicates more dispersion. Spatio-temporal variations in Shannon's Entropy index were also quantified for major LULC classes such as built-up, cropland and fallow land. Figure 4 illustrates the changes in diversity index for built-up during the study period. In year 1989, most of the land development was concentrated in the urban core, but gradually the process of urbanization is spreading outside the core of

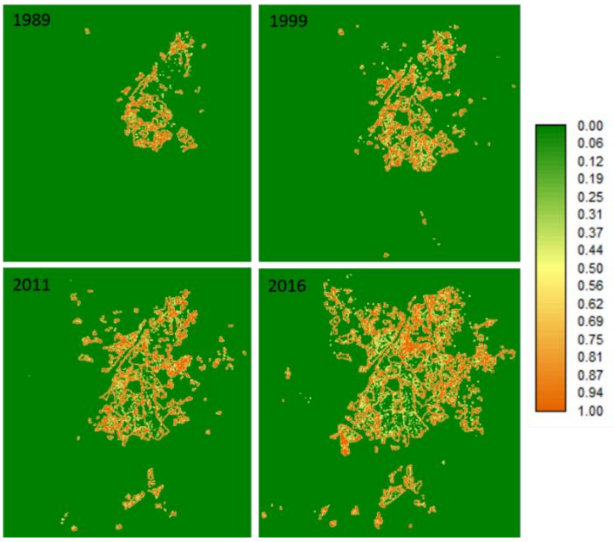

Figure 4: Shannon's entropy index for Built-up

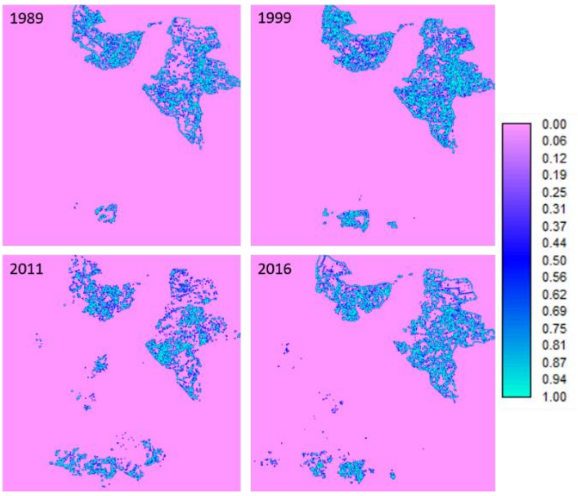

Figure 5: Shannon's entropy index for Cropland

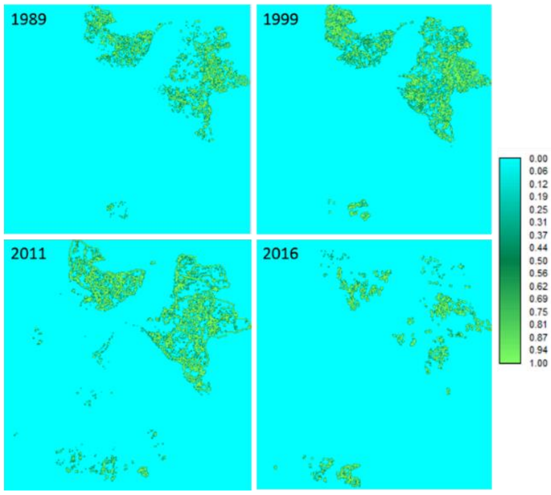

Figure 6: Shannon's entropy index for fallow land

the urban area. The larger value of entropy reveals the occurrence of urban sprawl especially in north-east direction on productive agriculture land. Results of entropy index for cropland indicates more dispersion in year 1999 and 2016 (Figure 5), however, for fallow land more dispersion was in 1999 and 2011 (Figure 6). Entropy index variations in cropland and fallow land reflects the low dominance of cultivated land at the city center and the gradual loss towards the outskirt areas of the city through time. Number of Patches (NP) signifies the extent of subdivision or fragmentation of the particular patch type (class) in the landscape. It explains the growth pattern (patched/fragmented or unpatched/clumped) in the considered region. The results of NP explains that there was increase in number of patches for built-up and cropland from 1989 to 2011, this signifies that there was a patched/fragmented growth. However, in 2016 (Figure 7a), the NP decreases for built-up and cropland which indicates that there is coalescence of grown patches to a single patch. For fallow land the NP was higher in 1989 and 1999 and indicating decreasing trend from 2011 to 2016. Thus the decrease in NP indicates more compact growth pattern. This also indicates saturation in urban area slowly occurring from core towards the outer area leading to unified urban class.

Absence of patches of other than urban class would indicate degrading environmental quality leading to lower quality of urban life.

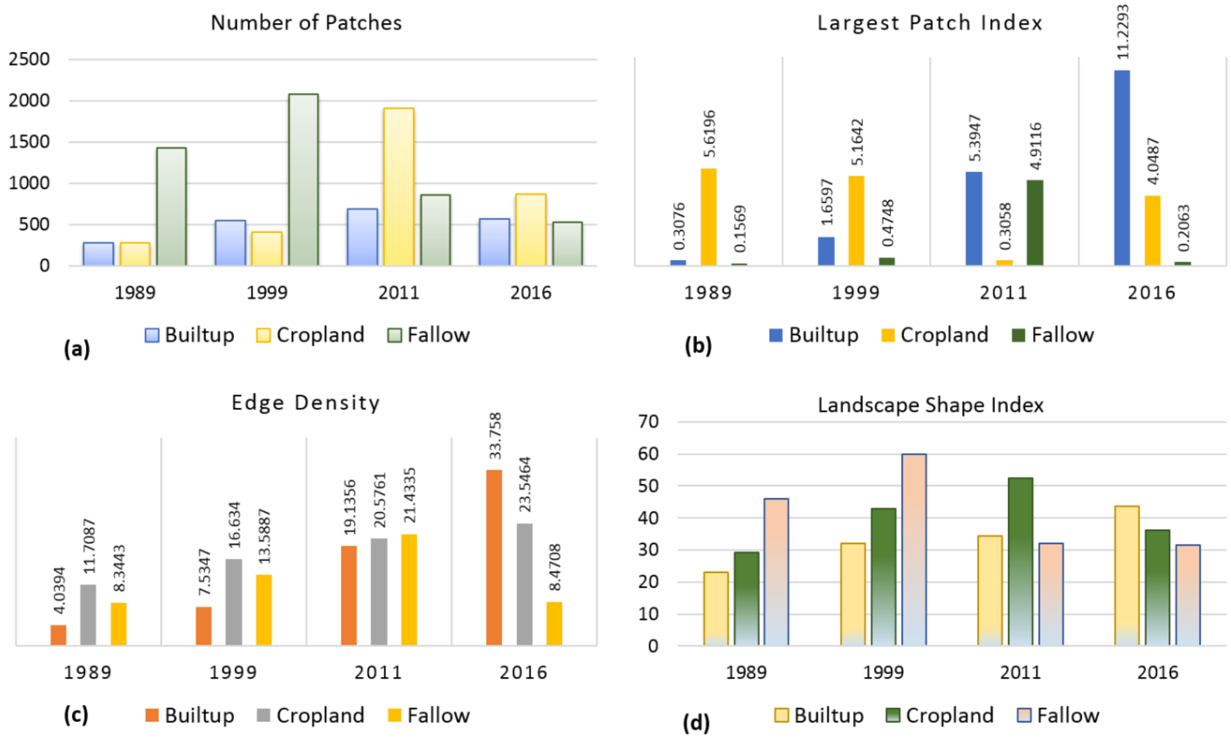

Figure 7: Spatial metrics analysis (a) Number of Patches (b) Largest Patch Index (c) Edge Density (d) Landscape Shape Index (refer Table 2 for parameter descriptions)

Largest patch index (LPI) quantifies the percentage of total landscape area comprised by the largest patch. LPI is 100 when the entire landscape consists of a single patch of the corresponding patch type. LPI is a simple measure of dominance. Figure 7b illustrates the increasing trend of LPI values for built-up ie. 0.31 (1989) to 11.23 (2016), however for cropland and fallow land, it indicates decreasing trend except year 2011. The higher LPI value of fallow land (4.91) and low LPI value for cropland (0.31) was observed in 2011, which indicates the dominance of fallow land in 2011 because of less amount of rainfall. Edge Density (ED) is a simple measure of fragmentation. ED metrics is used to measure the total length of edges in landscape of the corresponding patch type. Figure 7c implies the changes in ED for built-up, cropland and fallow land of Kota city. ED shows increasing trend for all these classes during 1989-2016. However, significant decrease was observed in fallow land in 2016 i.e. 8.5 meters/hectare. ED results demonstrates the new built-up and cropland development in outer part of the city. Edge density is also a fragmentation index, which counts the edges formed by forming new classes in the landscape, the edge density increases between 1989 to 2016 indicative of fragmented growth for built-up and cropland. The decline in ED values of fallow land is indicative of clumped growth and spread of urban area on this land. Landscape Shape Index (LSI) measures the shape of the class in the landscape and LSI = 1, when the landscape consists of a single square patch of the corresponding type and LSI increases as landscape shape becomes more irregular. LSI results (Figure 7d) implies the increasing trend for built-up during the study period i.e. 23.15 in 1989 and 43.58 in 2016, however for cropland LSI values show increasing trend from 1989 (29.17) to 2011 (52.50) and decreased in 2016 (36.09). For fallow land the LSI was higher in 1999 (59.88) and reduced to 31.65 in

2016. Higher value of LSI also indicates unplanned growth, because with planning typically shapes have less number of sides and lower LSI values.

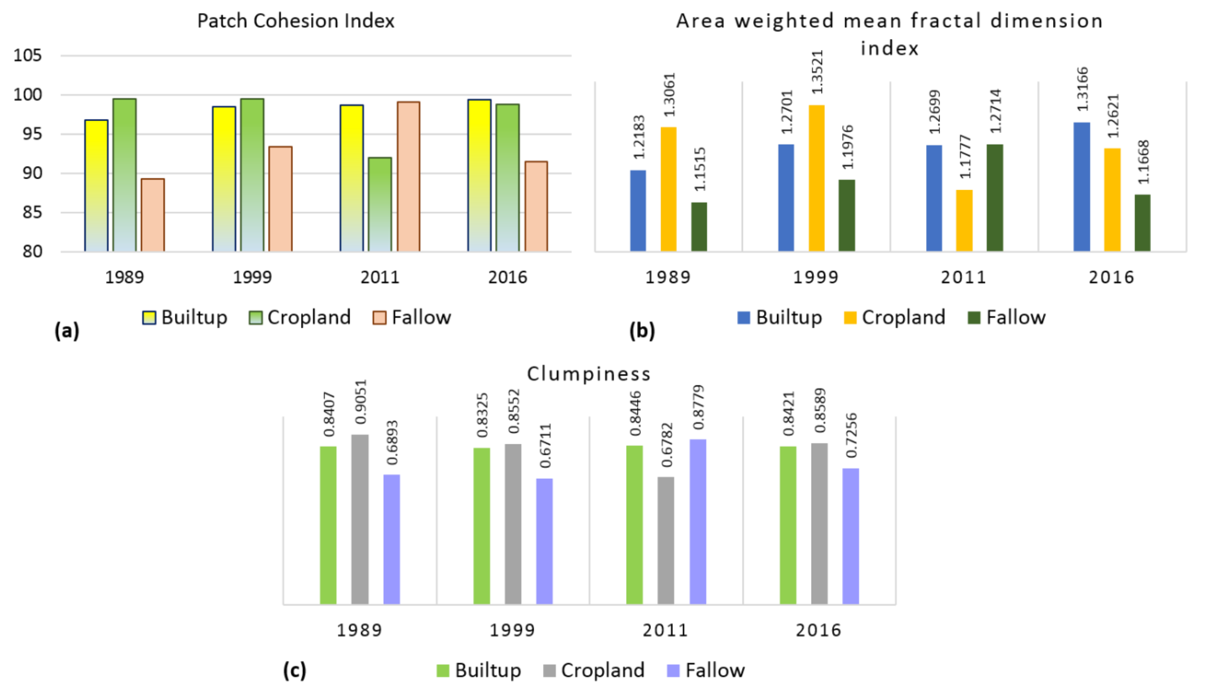

Figure 8: Spatial metrics analysis (a) Patch cohesion Index (b) Fractal Dimension Index (c) Clumpiness (refer Table 2 for parameter descriptions)

Patch cohesion index measures the physical connectedness of the corresponding patch type. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution. Figure 8a illustrates that all classes (built-up, cropland and fallow land) have high cohesion values during the study period (1989-2016). Fractal property of patch has been measured to find out shape complexity, if the patches are more complex and fragmented, the parameter increases to a higher fractal dimension. Fractal dimension index approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 with highly convoluted perimeters. Figure 8b exhibit slight increasing trend for built-up from 1989-2016, which indicates complex urban development during the study period. Clumpiness index is a measure of adjacency indicating the extent of clumped or fragmentations in the urban growth. This values ranges from -1 (complete disaggregation) to 1 (maximal aggregation) and values near to 0 indicates of random distribution of patches. Figure 8c indicates highly concentrated aggregated clumped growth during the study period in Kota city.

CONCLUSION

Urban expansion in peri-urban region remains a major issue for regional planning and development, as it converts most of the land cover into built-up settlements rapidly and extensively.Overall analysis of landscape metrics indicates that Kota city has been growing rapidly but without significant planning. Typically development of city planning maps take so much time that area considered for planning is already semi developed but in highly unplanned manner. This leads to failure of implementation of planned map. It is high time that planners should learn from their past experience and should use various scientific methodologies and indices discussed above to expedite release of future city planning maps.

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