Mapping the Spatio-Temporal Extent of Urban Built-up Footprint Using Urban Landscape Analysis Tool (ULAT): A case Study of Jaipur City, Rajasthan

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Introduction

With respect to the global concern about discriminate and haphazard growth in the built-up area which brings lots of serious social and environmental concerns, especially in urban areas, there has been a need to adopt a scenario wise approach in the context of rapid urbanization. In view of the above, this research has been undertaken with the objective to analyse the actual state of the built-up area in Jaipur urbanizable area (U1) and to map its dynamic nature over the time. The main aim of this particular case study is, to calculate various statistics to quantify urban built-up change and to explore spatial pattern and trend of urban sprawl with special reference to urbanization in the study area using remote sensing and GIS as a tool.

Abbreviations: - *Land Use/Land Cover – LULC, Geographic Information System – GIS, Centre for Land Use Education and Research – CLEAR, Urban Landscape Analysis Tool – ULAT*

Study Area

The study area consists of the urbanizable Area (U1) of Jaipur Development Authority (JDA) Region, demarcated and defined in Jaipur Master Plan -2025 and form a part of Jaipur district. Normally these kinds of studies of an urban area are limited to its local body governance boundary which is Jaipur Municipal Corporation (JMC) in this case. But in this particular study, the urbanizable area (U1) of JDA region is chosen as the study area because presently the urban agglomeration of Jaipur is expended beyond the city limit so most of the land use/land cover changes are occurred beyond the JMC limit.

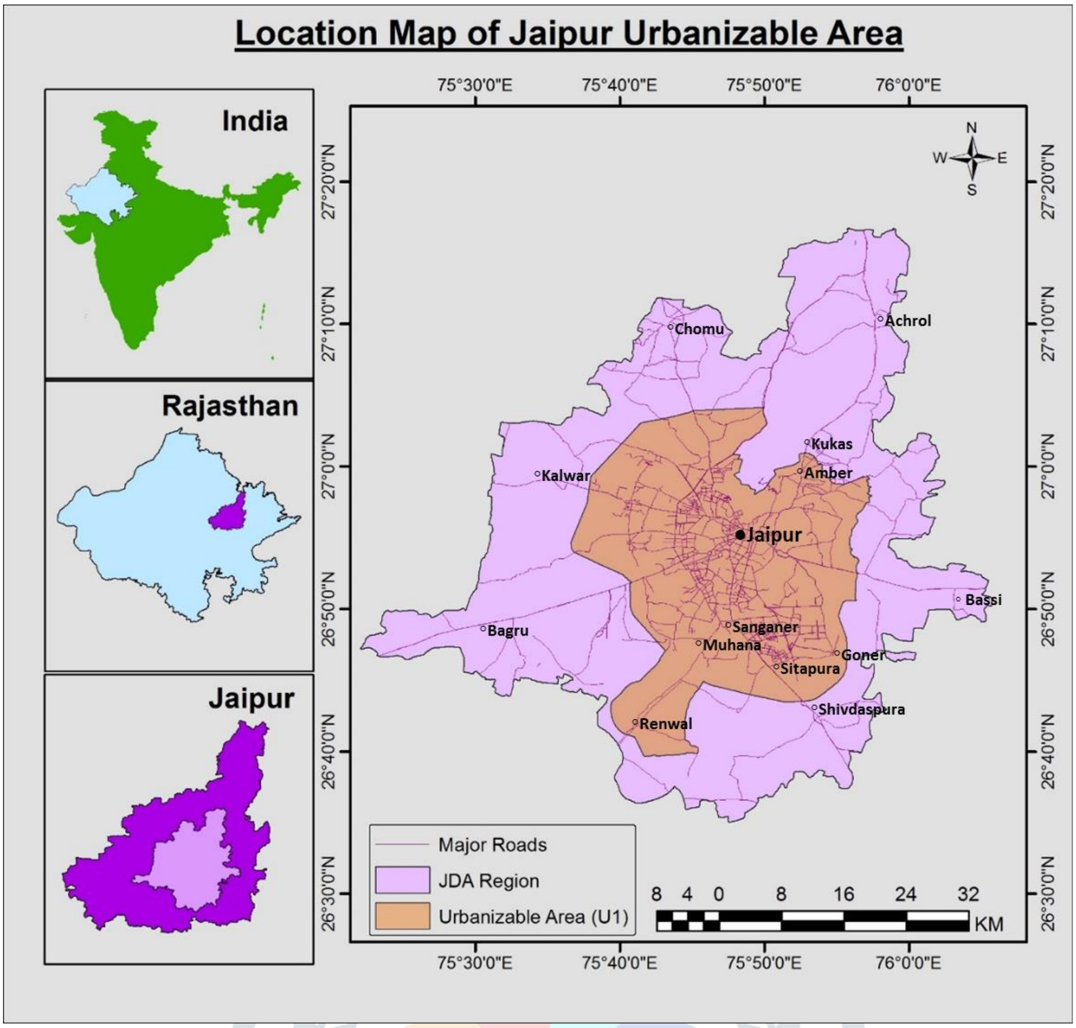

Figure 1: Location map of the study area.

The Jaipur urbanizable area envelops municipal corporation region of Jaipur city and 351 revenue villages with an areal extent of around 945 Km^2 (Master Development Plan-2025 JDA, n.d.). Out of 351 revenue villages, 117 villages of Jaipur tehsil, 162 villages of Sanganer tehsil, 40 villages of Amber tehsil, 14 villages of Jamwa Ramgarh tehsil, 02 villages of Bassi tehsil, 11 villages of Phagi tehsil and 05 villages of Chaksu tehsil are included in Jaipur urbanizable area (U1). Geographically, the whole area is located between $26^0 39' 38.26''$-$27^0 04' 67.66''$ north lat. and $75^0 36' 36.59''$- $75^0 57' 25.10''$ east long. The government of Rajasthan declared it as a "Metropolitan Area" on 10^{th} September, 2010.

MATERIAL AND METHODOLOGY

The methodology used in this research work for extracting built- up area and its dynamism in the study area is described in the following steps:

1. Preparation of boundary and base layer map by delineation of urbanizable area (U1) boundary, using ArcMap software with the help of Survey of India (SOI) toposheets and JDA Master Plan – 2025 (Master Development Plan-2025 JDA, n.d.).

2. Image pre-processing (a) Ortho-rectification: Geocoded image in WGS84, UTM Zone no. 43 (b) Radiometric correction and enhancement. (c) Subset and mosaic process.
3. Adoption of suitable land use/land cover classification system (Anderson & Witmer, 1976). As this study is mainly related to evaluating the change in the built-up area, therefore only three class classification

system was adopted for this case study. It includes water body, built-up area and other class. The third one i.e. other class includes all the classes like bare soil/fallow land, agriculture cropped land, natural vegetation, bare rock/hill surface etc. except water body and built-up.

4. Mapping of various land cover classes by Semi-automated supervised classification using maximum likelihood classifier (Bhandari, 2010) and visual image interpretation using various reference data.
5. Computation of various spectral indices (NDBI, NDWI etc.) and masks (masks for the cloud, water body, shadows, bare rocks, hills, etc.) (Stephan Pauleit, 2005) to refine the classification result.
6. Geo-correction, ground validation and accuracy assessment. Generation of the error/confusion matrix and computation of overall, user's and producer's accuracy with the help of field visit date –captured using GPS.
7. Computation of trend, rate, magnitude of change in the built-up area, Land Consumption Rate (LCR) and Land Absorption Coefficient (LAC).
8. Post-classification, comparison and calculation of various statistics to quantify the built-up area change in the region using Urban Landscape Analysis Tool (ULAT) developed by the Centre for Land Use Education and Research (CLEAR), Natural Resources Management and Engineering, the University of Connecticut in ArcGIS environment.

Due to dynamic nature of the built-up area of a region, a time series of built-up area patterns has been generated by using satellite imageries of the different time period. A set of four Landsat 8 OLI, Landsat 7 ETM+ and Landsat 5 TM land surface reflectance product images having high spatial and radiometric resolution were chosen to map and extract the dynamics of built-up area change in the region.

In total 4 imageries of the Landsat sensor were selected for this study. The required imageries were downloaded in L1TP land surface reflectance data type and GeoTIFF format from the USGS's Earth Explorer website (http://earthexplorer. Usages. Gov)

S No	**Landsat Scene Identifier**	**WRS Path/ Row**	**Sensor Identifier**	**Date Acquired**
1	LC81470412017055LGN00	147/ 041	OLI_TIRS	24/02/2017
2	LT51470412009033KHC00	147/ 041	5_TM	02/02/2009
3	LE71470412000049SGS00	147/ 041	7_ETM	18/02/2000
4	LT51470411992067ISP00	147/ 041	5_TM	07/03/1992

Table 1: List of Satellite images used for land cover change study and their specifications.

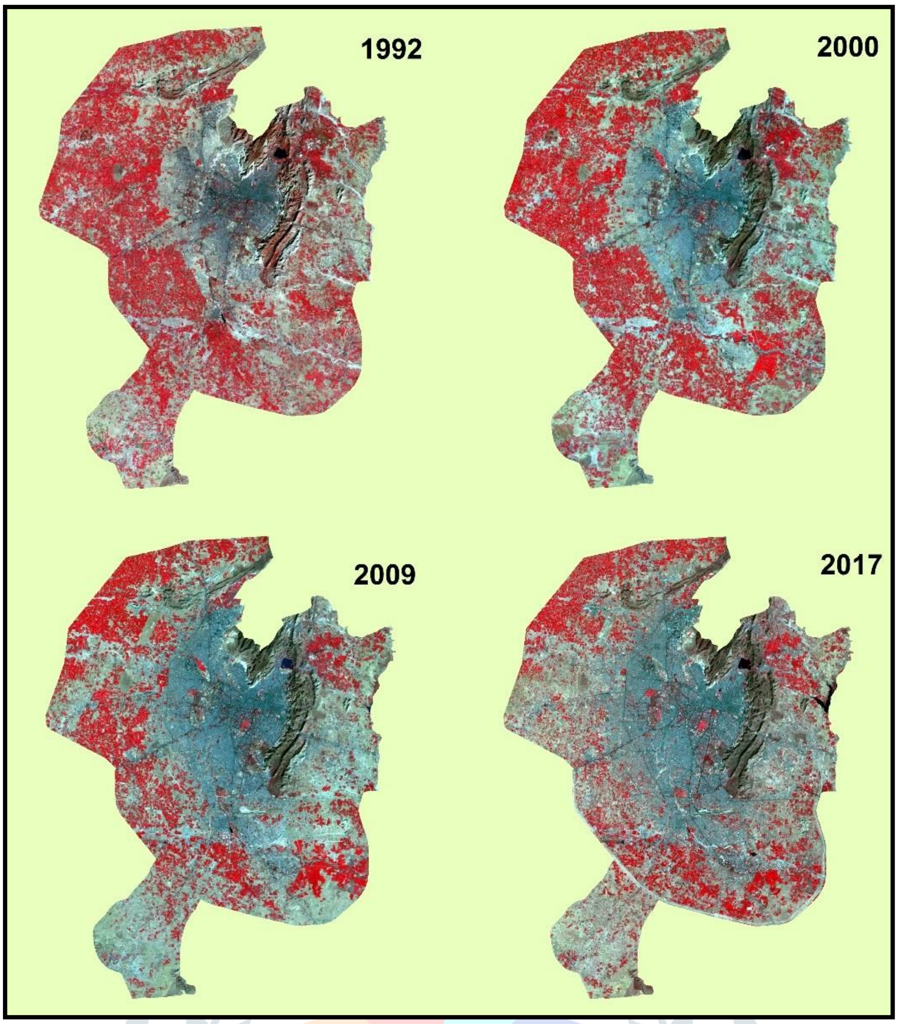

Figure 2: Landsat land surface reflectance data product subset of urbanizable area (U1) of Jaipur city in false colour composite.

For ground truthing, interpretation and verification of the information extracted from remotely sensed data, the reference data were also used. The reference data were obtained from field visit data –captured using GPS and other sources like Google Earth Pro, the United States Geological Survey website, Bhuwan website, Toposheets of the survey of India etc.

RESULTS AND DISCUSSION

Urban Landscape Analysis

To understand the dynamics of urban built-up area, change and to compute various matrices, Urban Landscape Analysis Tool (ULAT) developed by the Centre for Land Use Education and Research (CLEAR), Natural Resources Management and Engineering, University of Connecticut was used during this case study. Classified maps for the year 1992, 2000, 2009 and 2017 of the study areas were used as input land cover maps in this software. For each input land cover map, two output maps were generated: 1) The urbanized area map and 2) The urban footprint map. For every two consecutive land cover maps, a map of the new development classifications was also generated.

Category	Description
Built-up area	Impervious surfaces including buildings, transportation network, infrastructures etc.
Urbanized area	Impervious surfaces as well as heavily influenced open space.
Urban footprint	Impervious surfaces and any open space likely to be impacted, to some degree, by the city.

Table 2: Terminology used in ULAT to measure the urban extent and its nature.

The Urban Landscape Analysis Tool (ULAT) classified the urban landscape into classes indicating built-up density and the open land that is likely to be affected by close proximity to the built-up. The urbanized area map generated through this tool, classified the whole study area into seven categories (i) Urban built-up, (ii) Suburban built-up, (iii) Rural built-up, (iv) Urbanized open land, (v) Captured open land, (vi) Rural open land and (vii) Water. These categories were demarcated on the bases of the urbanness of the cells/pixels. The criteria for designating a land parcel to these categories has been mentioned in the table 3.

Source: Angel, S, J. R. Parent, and D. L. Civco. http//clear.uconn.edu/tools/ugat/index.htm)

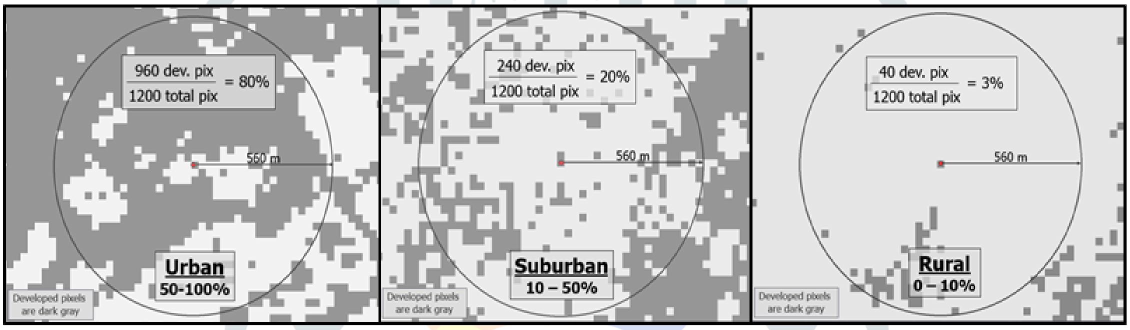

Figure 3: Computation of "urbanness" of a given built-up pixel in ULAT and various built-up categories based on this urbanness.

In this developed land cover or built-up area approximates impervious surface area. Developed pixels are classified based on the percentage of land within 560 meters that is developed. A roving neighborhood center on each developed pixel and % developed land is calculated for estimating urbanness.

Category	Criteria
Urban built-up	Built-up with more than 50% urbanness
Suburban built-up	Built-up with 10 – 50% urbanness
Rural built-up	Built-up with less then10% urbanness
Fringe open land	Undeveloped but within 100 m of developed area
Captured open land	Undeveloped patches (size less than 200 ha), completely surrounded by urban built-up/ suburban built-up/ fringe open land
Rural open land	Undeveloped, neither fringe nor captured open land
Water	Water in land cover classification

Table 3: Land use/land cover category scheme and criteria for their categorization adopted in Urban Landscape Analysis Tool (ULAT).

Seven land categories and their respective areal extent during 1992, 2000, 2009 and 2017 are summarized in the table and shown in Figure . The result gives an insight that during the study period, i.e. from 1992 to 2017, the urban built-up area (core) which has the urbanness index more than 50% has been increasing continuously over the time. The urban built-up area reported 3.60% in 1992 which increased to 14.37% of the total study area in 2017, hence gives an indication of urban growth over the time in the region. With urbanness index between 10% to 50%, sub-urban built-up land also increased by 2.13 km2, 3.98 km2 and 29.18 km2 during 1992–2000, 2000-2009 and 2009–2017 period respectively.

The considerable increase in sub-urban built up from 2009 to 2017 provides an insight that after 2009 the region experienced the phenomenon of intense sub-urbanization which refers to the migration of a population from populated towns and cities core for low density residential development over more and more rural land with the end result is the spreading of a city and its suburbs over more and more rural land. Urbanization of rural settlements and towns resulted in an increase in rural built-up area from 3.18 km2 in 1992 to 9.46 km2 in 2017. Over the 25-year time span, the rural built-up area remained almost unchanged, it could be due to continuous conversion of rural built-up to suburban and urban built-ups.

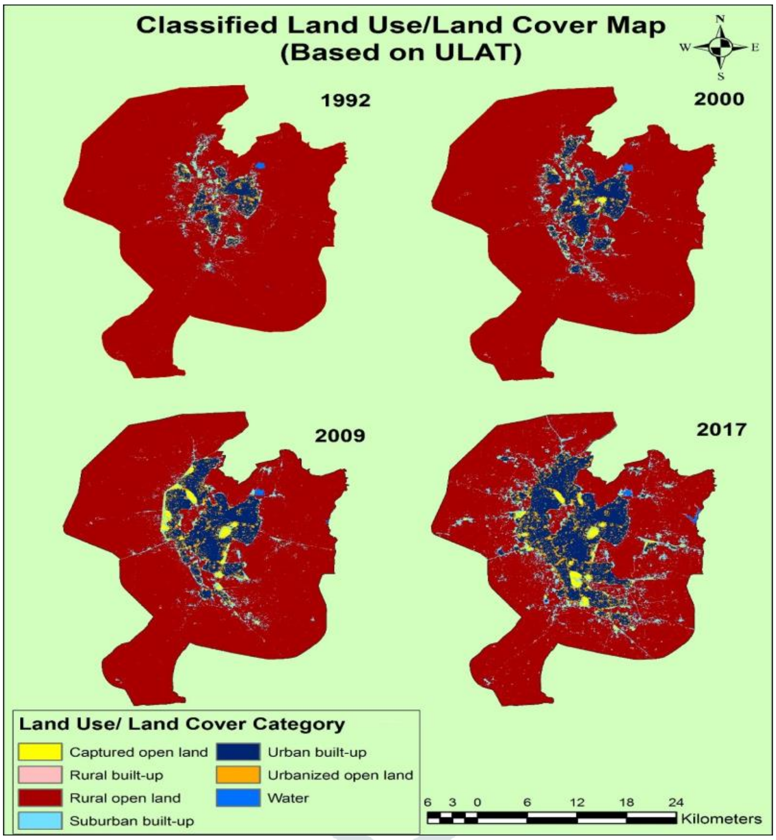

Figure 4: Spatial extent of the urbanized area in Jaipur Urbanizable Area (U1) obtained from ULAT for 1992-2017.

The urban to sub-urban ratio (urban built-up/Suburban built-up) for all the base year were estimated as 1.558, 2.0826, 3.023 and 2.379 respectively. The data reveals that up to 2009, this ratio reported a gradual increase which indicates that during this period compact urban growth took place in the region. But after 2009 the ratio decreased, which indicates the condition of urban sprawl in the region.

Urbanized open land and captured open land also experienced many folds increase during the reported time period. Contrary to this, rural open land category, following reverse trend witnessing a continuous decrease from 873.67 km2 in 1992 to 690.43 km2 in 2017. It indicates that rural open land is continuously consumed by other land use/land cover categories. Water body area was more or less same during the reported time span.

The classified urbanized area map revealed that built- up areas are situated in both large and small clusters and patches form. Most built-up areas are contiguous and clearly associated with the main urban cluster of the city, but some are found along intercity roads and some in scattered rural settlements and towns throughout the study area.

S. No.	**Land Category**	**Year**											
		1992			**2000**			**2009**			**2017**		
		No. of Pixel	Area (Sq. Km)	Area (%)	No. of Pixel	Area (Sq. Km)	Area (%)	No. of Pixel	Area (Sq. Km)	Area (%)	No. of Pixel	Area (Sq. Km)	Area (%)
1	Urban Built-Up	37809	34.03	3.60	55651	50.09	5.29	94073	84.67	8.95	151018	135.92	14.37
2	Sub-urban Built Up	24281	21.85	2.31	26649	23.98	2.54	31064	27.96	2.96	63491	57.14	6.04
3	Rural Built-Up	3537	3.18	0.34	3627	3.26	0.35	5846	5.26	0.56	10510	9.46	1.00
4	Urbanized Open Land	10714	9.64	1.02	15387	13.85	1.46	25339	22.81	2.41	41974	37.78	3.99
5	Captured Open Land	2865	2.58	0.27	3577	3.22	0.34	12112	10.90	1.15	14962	13.47	1.42
6	Rural Open Land	970740	873.67	92.35	944878	850.39	89.89	881485	793.34	83.86	767149	690.43	72.98
7	Water Body	1240	1.12	0.12	1417	1.28	0.13	1267	1.14	0.12	2082	1.87	0.20

Table 4: Temporal variation in area of various land use/land cover categories computed by ULAT (1992-2017).

Urban footprint map

Urban footprint maps for 1992, 2000, 2009 and 2017, were generated through ULAT consisted of seven categories based on pixel level urbanness values and their land cover attributes (Figure 6.8). These maps include impervious surfaces (built-up area) and an open space which is presently not a part of the built-up area, but likely to be impacted, to some degree, by the city. These maps represent the least conservative analysis of the impact of built-up land on open land around the city. It is appropriate to use for issues involving urban and scenario planning.

Urban footprint categorizes spatial density of built-up in three categories, i.e. urban built-up, sub-urban built-up and rural built-up. The share of sub-urban built-up gives an insight into open land degradation perspective as sub-urban built-up with low spatial density have a greater impact with respect to open land degradation.

Another important category identified by footprint mapping is fringe open land, which acts as an edge-disturbance zone. These are the regions at an edge that are prone to degradation by neighborhood built- up conditions. The result indicates that over the study period fringe open land experienced rapid increase. Whereas in 1992 only 55 Km2 area was covered under this category, this figure increased up to 156 Km2 in 2017. In 2017 it occupied an area of 16.49% of the total study area, which provides an insight of enhanced land degradation conditions prevailing in future.

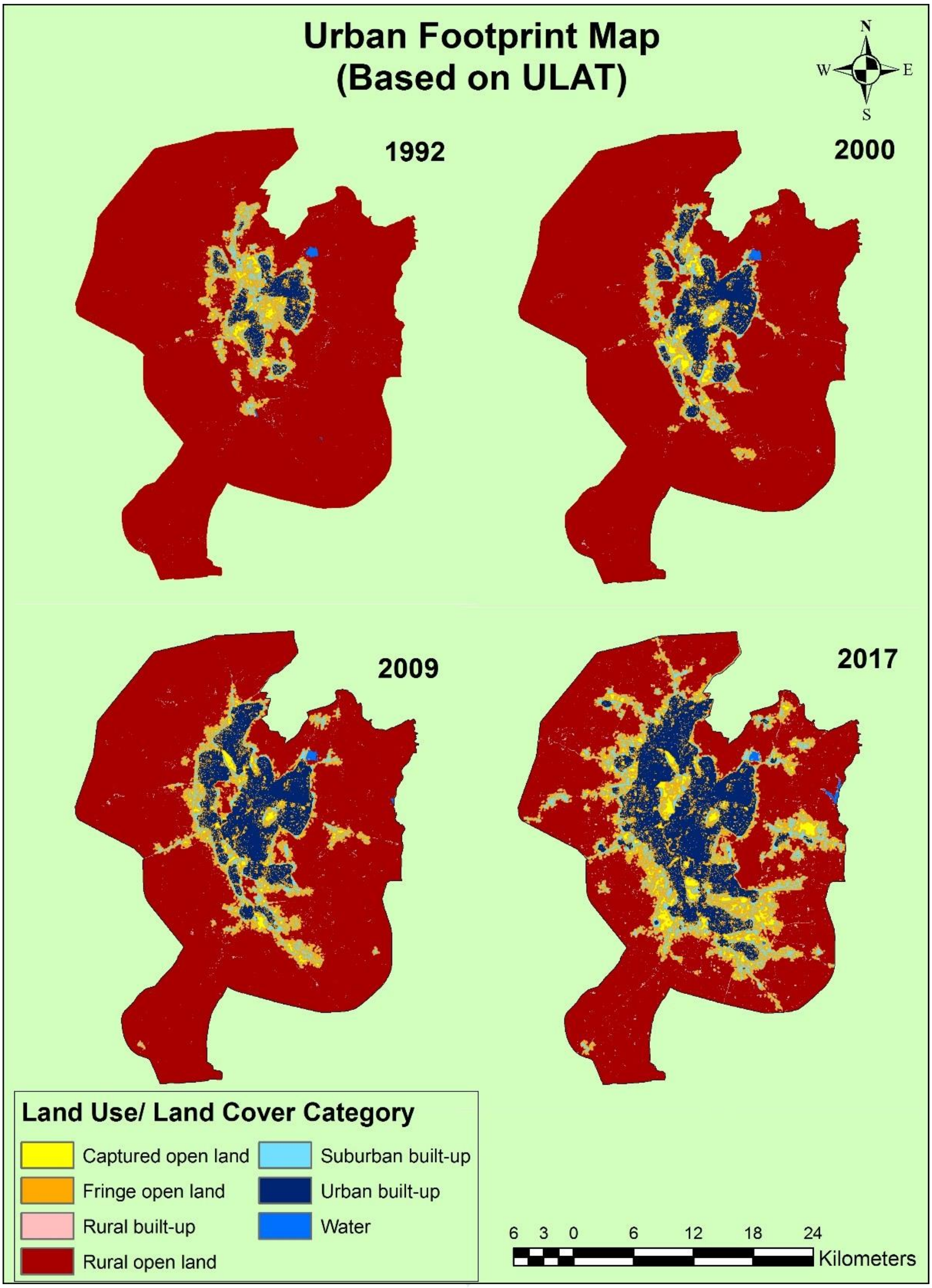

Figure 5: Spatial extent of the urban footprint area in Jaipur Urbanizable Area (U1) obtained from ULAT for 1992-2017

S. No.	Land Category	Year											
		1992			2000			2009			2017		
		No. of Pixel	Area Km2	Area (%)	No. of Pixel	Area Km2	Area (%)	No. of Pixel	Area Km2	Area (%)	No. of Pixel	Area Km2	Area (%)
1	Urban Built-Up	37809	34.03	3.60	55651	50.09	5.29	94073	84.67	8.95	151018	135.92	14.37
2	Sub-urban Built Up	24281	21.85	2.31	26649	23.98	2.54	31064	27.96	2.96	63491	57.14	6.04

3	Rural Built-UP	3537	3.18	0.34	3627	3.26	0.35	5846	5.26	0.56	10510	9.46	1.00
4	Fringe Open Land	61844	55.66	5.88	65718	59.15	6.25	92502	83.25	8.80	173352	156.02	16.49
5	Captured Open Land	4674	4.21	0.44	7058	6.35	0.67	7437	6.69	0.71	22727	20.45	2.16
6	Rural Open Land	917801	826.02	87.31	891066	801.96	84.77	818997	737.10	77.91	628006	565.21	59.74
7	Water Body	1240	1.12	0.12	1417	1.28	0.13	1267	1.14	0.12	2082	1.87	0.20

Table 5: Urban footprint categories and their areal extent computed by ULAT.

The captured open land is land which is surrounded by built-up area. It has formed yet another important category of open land as this is more susceptible to degradation because of its isolation from other open areas. This land category also experienced an increasing trend over the time.

Urban footprint statistics reveal that beside of existing built-up area (21.41% of the total) area, huge chunk of land categorized under the fringe and captured open land (18.6% of the total study area) also faced degradation process due to urbanization. Hence, 40% of the total study area was affected with the direct or indirect impact of intense urbanization in 2017.

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