REMOTE SENSING OF URBAN DEVELOPMENT AND ENVIRONMENTAL LANDSCAPE: A STUDY OF GREEN COVER LUNGS OF DELHI AND SURROUNDING CITY REGIONS

Madan Mohan

Professor of Geography
Centre for the Study of Regional Development, School of Social Sciences – III,
Jawaharlal Nehru University, New Delhi, INDIA.
drmdnmohan@gmail.com; madanmohan@mail.jnu.ac.in

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ABSTRACT:

The remote sensing satellites have now a days been used for creation of geospatial databases of the earth surface features and natural resources as the land use land cover mapping and monitoring periodically at the local, regional, and global levels using geospatial technologies. The Land cover consider to the type of features present on the surface of the earth. Whereas, the land use considers to the human activity or the economic function associated with a specific piece of land. The supervised classification based on the maximum likelihood classifier technique has been applied to process the digital multi-spectral imagery for LULC classification. The built-up area was about 11.95 per cent in 1977 which increased to 19.74 per cent in 1999 and further increased to about 24.54 per cent in 2009. So, the urban landscape's urban built-up land was composed by areas of intensive use with much of land covered by built-up structures. The cities, towns, villages, strip development along highways; transportation, power, and communication facilities; shopping centres, industrial and commercial complexes, and institutions found located in the urban areas have been developed over the periods. The forests cover area accounted to about 1.43 per cent in 1977 which increased to about 10.04 per cent in 1999. The forest cover regeneration over the Delhi Ridge recognized as a significant contributor to carbon sequestration, micro-climate change, biodiversity restoration for the Delhi's urban development and rejuvenation of environmental landscape. So, the remote sensing imagery have commonly been used for urban landscape monitoring and environmental modelling for sustainable development of Delhi and adjoining city regions.

1. INTRODUCTION

1.1 Introduction

The remote sensing, digital photogrammetry, geographical information systems, global positioning systems are some of the efficient technologies for the study of land use land cover mapping and monitoring for urban landscape and its surrounding environment development. In other words, the remote sensing satellites have now been used for creation of geospatial databases of the earth surface features and natural resources as the land use land cover mapping and monitoring periodically at the local, regional, and global levels. The Land cover consider to the type of features present on the surface of the earth. Whereas, the land use considers to the human activity or the economic function associated with a specific piece of land (Lillisand et.al., 2007; DiGregorio, 2000; Martinez and Mollicone, 2012). So, the urban built-up land is composed of areas of intensive use with much of land covered by built-up structures for residential and commercial usages. The cities, towns, villages, strip development along highways; transportation, power, and communication facilities; shopping centres, industrial and commercial complexes, and institutions found located in the urban areas have generally been developed over the periods which are confirming to the urban and the environmental landscapes development.

The terms 'land cover' and 'land use' are sometimes used interchangeably. But it is widely acknowledged that both these terms denote to different notions (Comber, 2008). The land cover refers to the physical surface characteristics of land, such as the type of vegetation covers or the presence of water bodies and so on natural resources. Whereas, the land use defines the economic and social functions performed on land to meet demands for food, fibre, shelter, and so on. Both these two concepts are apparent to be largely linked, with complexity of the linkages between them. For instance, the land cover as forests, grassland may support many land uses, including recreational activities development. Whereas, a single land use, as mixed farming, may take place in a number of different land cover types including grassland, cropped and fallow land areas (Haines-Young, 2009). Nevertheless, despite the fact that their exits the distinction between the land cover and the land use; but these are considered often blended in classification schemes (Di Gregorio and Jansen, 2000).

The Land cover is the observed bio-physical cover consisted by biotic and abiotic components on the earth's surface ecosystem. The Land use is characterized by the arrangements, activities, and inputs that people undertake in a certain land cover type to produce, change, or maintain it. Several detailed researches were conducted to formalize a methodology that automates land use mapping process for urban areas in which an approach was that land use objects can be distinguished based on semantic and spatial information of land cover objects (Lo and Yang, 2002). The land use and land cover always change with the passage of time of which significant drivers of change are the man and climate (Mannion, 2002).

Over the periods there have been observed a lot of changes in the land use land cover which resulted into the concrete jungle sprawl in the surrounding city regions of Delhi, on the one hand; and there have been lot of changes in the urban built-up environment which is particularly resulting into the encroachment of green lungs and removal of green covers, on the other hand, over the Delhi Ridge. So, there is a need for the sustainable urban development and environmental restoration based on digital image processing of the satellite imagery through the application of the geospatial technological and latest methodological approaches for the present study.

2. OBJECTIVES

The present study is based on the integrated geospatial remote sensing databases and their digital processing using latest tools and techniques for urban development and environmental monitoring for the study region over the periods. The main objectives of the study are mentioned as follows:

i. to identify urban development process based on geospatial trends and patterns of urban land use land cover over the periods;
ii. to outline changes occurred in environmental landscape and their restoration and management in the city regions over the periods.
iii. to suggest suitable strategies for sustainable development of urban environmental landscape.

3. STUDY REGION

The study primarily focusses on the urban development and environmental landscape of Delhi and its surrounding city regions. The study area geographical extent are as 69.06^0 to 73.39^0 East longitudes and 31.96^0 to 31.96^0 North latitudes. The geographical area based on processed satellite imagery accounted for about 2,98,012 hectares in 2009. The study area comprises by the Delhi NCT and the surrounding urban centres and cities as the Bahadurgarh town, Gurugram city, Faridabad city, Noida city, Ghaziabad city and so on as of the Delhi's urban landscape. The geographical details of the study area are presented in the Figure 1 and Figure 2 below:

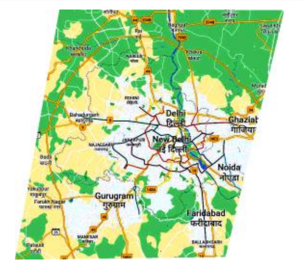


Figure 1. Google map, Delhi.

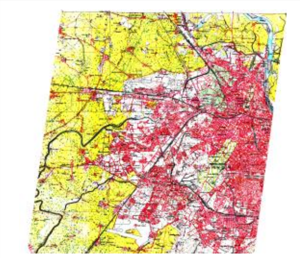


Figure 2. Delhi NCT.

Besides this, the Delhi NCT geographical area was accounted for about 4,613 sq. kms. The geographical extent of the Delhi NCT were as 76.84^0 to 77.35^0 East longitudes and 28.41^0 to 28.88^0 North latitudes. The Delhi NCT comprised by 9 administrative divisions as the North East, North, North West, East, New Delhi, Central, West, South West and West districts as evidenced by the Figure 2. The study area physiographic terrain height was ranging between 213 to 219 meters above sea level.

4. DATABASE

Over the periods, the digital remote sensing data products have been generated for urban development and environmental landscape mapping at different scale for the local, national, regional, and global levels. The present study is based on the primary data generated from the field as well as the ancillary and collateral data collected from the different sources. The Landsat satellite imagery have been acquired from the earth explorer portal i.e., https://earthexplorer.usgs.gov/ of the United States Geological Survey (USGS). In other words, the Landsat-2, 5 and 7 satellites imageries for different periods of 1977, 1999 and 2009 were downloaded from the earth explorer portal of the USGS. The imagery spatial resolution was of 80 meters of the MSS sensor. Whereas, the imagery spatial resolution was of 30 meters of the TM sensor. The panchromatic imagery spatial resolution was of 15 meters of the ETM+ sensor of the Landsat satellite-7. The imagery different spatial resolution cause awkward in comparison of the results. The other details of the database given below in the Table 1.

Acquisition Date	Path	Row	Sensor	Satellite	Spectral Bands	Resolution (meters)
08/03/1977	157	040	MSS	LSat-2	1-4	80
22/10/1999	146	040	ETM+	LSat-7	1-8	30 & 15
19/06/2009	146	040	TM	LSat-5	1-7	30

Note: Image courtesy of the United States Geological Survey (USGS), United States of America.

Table 1. Landsat satellites imagery details.

In addition to this, the large scale 1: 25,000 and 1: 50,000 topographic sheets of the Delhi and its surrounding city regions have also been obtained from the Survey of India (SOI), Dehradun, Uttaranchal, India, through a web portal i.e., https://surveyofindia.gov.in/ However, the digital remote sensing and geospatial vector databases have been used and processed for mapping of urban development and environmental landscape monitoring for the different periods for the study region.

5. RESEARCH METHODOLOGY

5.1 Geospatial Methodological Approaches

Since 1970s, the remote sensing database have been used for land use land cover classification system devised by the USGS, of which basic concepts and structure are still valid to present (Mannion, 2002; Wolter, et.al., 2006). So, the land use land cover digital info used in many urban development and regional planning and environmental resources management activities which also considered as an essential element for modelling and understanding the earth as a system. The Land use land cover classification developed to the widespread use of satellite imagery and computer-assisted classification techniques and algorithms as supervised and unsupervised classification algorithms to get the consistency and accuracy of results when mapping land use land cover over large, complex geographic areas and regions (Lillisand, et.al., 2007; Campbell, 2007; Sangawongse, 2006). The multilevel system devised to contain different degree of details obtained from imagery depending on sensor system and image resolution.

The levels of LULC classification devised for use with low to moderate resolution of satellite imagery as the Indian Remote

Sensing Satellite (IRS) multispectral scanner (LISS-3) and Landsat multispectral scanner (MSS) images and other satellite systems of which image resolutions ranging between 20 to 100 meters are appropriate for mapping (Lu, et.al., 2012; Wolter, et.al., 2006). So, the Landsat satellite Thematic mapper (TM) and Enhanced Thematic Mapper (ETM+), SPOT satellite (HRV), Indian Remote Sensing satellite (LISS and PAN) imagery are representative sources for many levels of mapping and monitoring of land use land cover resources of the earth. The LULC digital classification requires database for digital imagery processing which needs computational algorithms and faster processing with higher accuracies for the sustainable mapping and monitoring of urban landscape and urban environment for sustainable development.

5.2 Research Methodology

The artificial intelligence (AI) computer based intensive digital image processing of satellite imagery requires sophisticated classification techniques and algorithms as the unsupervised classification algorithm, supervised classification algorithm, hybrid classification algorithm, mixed pixels classification algorithm, accuracy assessment algorithm and so on. However, in the present study the supervised classification algorithm and accuracy assessment algorithm have been used for digital image processing for land use land cover mapping and environmental monitoring. So, the research methodology developed and applied for the present study is schematically presented in the Figure 3 in which each of the digital image processing (DIP) steps through the workflow diagram are illustrated.

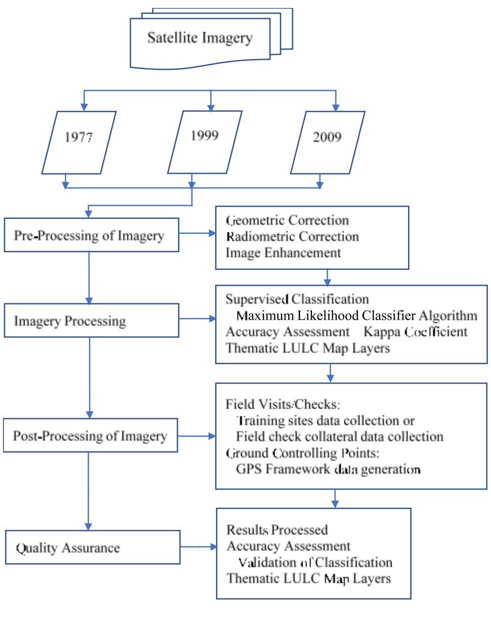


Figure 3. Research methodology flow diagram.

The digital image process performed using ERDAS Imagine software which widely used for spatial and spectral patterns recognition of the imagery using the broad digital image processing (DIP) techniques and algorithms (Mas, et.al., 2014). The study region imagery were georeferenced on UTM projection using the WGS 84 datum. The land use land cover classes identified were as the built-up area, open space, cultivable area, Delhi Ridge, forest area, river/waterbody, and road/rail based on the Survey of India topographic sheet, google earth map and ground truth/field check data used for imagery processing using the ISO (iterative self-organising) clusters algorithm of the unsupervised classification. In this case, the image processing algorithm iteration used in which all samples assigned to existing cluster centre for which new means computed for each of the classes. The unsupervised classification process is simple calculation process (Liu and Mason, 2009; Camps-Valls, et.al., 2011). So, it was applied to work out to check the land use land cover classification scheme and for the comparison of the results with the supervised classification.

5.2.1 Supervised Classification

The Supervised classification using the maximum likelihood classifier technique to process the multiband imagery used for digital image processing for LULC classification in the present study. The maximum likelihood decision rule allocates each pixel having pattern measurement of features 'X' to the class 'c' whose units are most probable to have given rise to feature vector 'X'. The decision rule applied to the unknown measurement vector 'X' computed using the following equation (Jenson, 1996; Weng, 2010; Cracknell and Hayes, 2009; Lu and Weng, 2005):

Decide X is in class c, if and only if,

$$P_c\,(a_c) \geq Pi\,(a_i),$$

Where:

$i = 1, 2, 3, \ldots$, m possible classes

and

$$P_c\,(a_c) = \log_e(a_c) - \{0.5 \log_e[\det(V_c)]\} - [\,0.5\,(X - M_c)^T\,(V_c^{-1})(X - M_c)]$$

So, to classify the measurement vector 'X' of an unknown pixel into a class, the maximum likelihood decision rule computes the value 'P_c' for each class. It allocates the pixel to the class that has the maximum value. The maximum likelihood classification for remotely sensed imagery encompasses considerable computational effort. It computes a large volume of data on the class membership characterization of each pixel. However, the supervised classification algorithm uses the field checks, ground truth training samples to identify thematic classes based on the spectral signatures. However, the supervised classification algorithm used for digital image processing in the present research; because, it is comparative more accurate than the unsupervised classification algorithm.

5.2.2 Accuracy Assessment

The accuracy assessments for land use land cover classification require to prepare the classification error matrix which is also known as confusion or contingency table. The error matrix comprises by the omission errors, commission errors, producer's accuracy, user's accuracy, and overall accuracy (Foody, 2002; Jenson, 2005 & 2009). So, it supports to compare the relationship between known reference data i.e., the ground truth data and the corresponding results of an automated classification. Generally, it is recommended that at least of 50 samples of each land use category, can be included in the error matrix.

The statistical approach of the accuracy assessment consists of different multivariate statistical analyses. A commonly used measure is Kappa coefficient. The Khat statistic is computed by the equation given below (Jension, 1996; Schowengerdt, 2009). However, the digital image processing is a computer-based algorithm operation on raw satellite imagery for enhancement of imagery and to extract useful geospatial information.

$$K_{hat} = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}$$

Where:

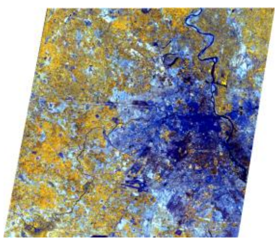
r	=	is the number of rows in the matrix,
x_{ii}	=	is the number of observation in row i and column i, and
x_{i+} and x_{+i}	=	are the marginal totals for row i and column i, respectively'
N	=	is the total number of observations

The image processing methods and techniques are rapidly growing for computation of better and precise results. So, the above mentioned geospatial methodological approaches have been used for the land use land cover mapping and environmental monitoring based on the satellite digital multispectral imagery for the present study.

6. RESULTS ANALYSES AND DISCUSSIONS:

6.1 Geospatial Patterns of LULC Classification: 1977

The Geospatial patterns of land use land cover classification (LULC) worked out using multi-spectral Landsat satellite imagery with the application of supervised classification algorithm for the periods of 1977, 1999 and 2009. The imagery was classified into six thematic land use land cover classes as the built-up area, open space, cultivable area, Delhi Ridge, forest area, river/waterbody, and road/rail as presented in the Figure 4 and Figure 5 for the period of 1977 for the study region, the Delhi and its adjoining city regions.



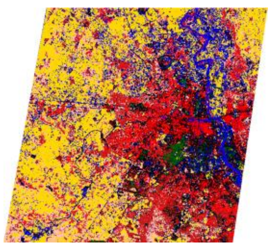


Figure 4. Raw imagery 1977. **Figure 5.** LULC 1977.

The multispectral imagery pixel-based land use land cover classification computed using the maximum likelihood supervised classification algorithm for the period of 1977 which is presented in the Table 2. The computed results reveals that the cultivable area accounted for the largest proportion of 26.38 per cent of the total geographical area. Besides this, the built-up area and open space together accounted for 24.91 per cent of the total geographical area. On the other hand, a small proportion of 1.43 per cent is accounted by the forest area. It is comprised by the green vegetation cover areas as the protected and reserved forests, gardens, and planted trees all along the roads and rails in the urban landscape of the Delhi and its surrounding areas as is evidenced by the Figure 5. So, in general, the forest's green cover is mainly spread over the Delhi Ridge area which is accounted for about 7.58 per cent in 1977 as evidenced by the above Table 2.

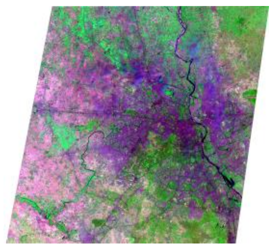
Index Color	Class	Area (Hectare)	Area (in %)
	Builtup Area	19938	11.95
	Open Sapce	21618	12.96
	Cultivable Area	44010	26.38
	Delhi Ridge	12641	7.58
	Forest Area	2393	1.43
	River/Waterbody	43974	26.36
	Road/Rail	22266	13.35
	Total	166839	100.00

Table 2. Land use land cover classification, 1977.

Whereas, the River Yamuna channel and water bodies as lakes and ponds together comprises about 26.36 per cent of the total geographical area. Apart from this, the road and rail transport network spread in the study region accounted for about 13.35 per cent of the total geographical area.

6.2 Geospatial Patterns of LULC Classification: 1999

The Geospatial patterns of land use land cover patterns found changed over the time, as evidenced by the processed multi-spectral satellite imagery for the period of 1999 for the Delhi's urban and environmental landscape as presented in the Figure 6 and Figure 7.



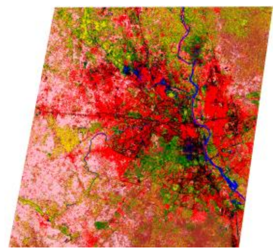


Figure 6. Raw Imagery 1999. **Figure 7.** LULC 1999.

The Maximum likelihood supervised classification worked out for the period of 1999 presented below in the Table 3. The computed land use land cover results statistics proved for the significant change in comparison to the previous results statistics of 1977 as is presented in the above Table 2.

Index Color	Class	Area (Hectare)	Area (in %)
	Builtup Area	56354	19.74
	Open Sapce	52036	18.22
	Cultivable Area	34179	11.97
	Delhi Ridge	46388	16.25
	Forest Area	28676	10.04
	River/Waterbody	3387	1.19
	Road/Rail	64531	22.60
	Total	285551	100.00

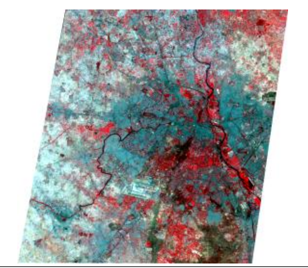
Table 3. Land Use Land Cover Classification, 1999.

The built-up area and open space together accounted for about 37.96 per cent of the total geographical area in 1999. It is evidenced by the Figure 7 that the built-up area expanded in the central business district (CBD) of the Delhi NCT, on the one hand; and the urban sprawl also took place in the neighbouring urban centres and cities as the Bahadurgarh town and the Gurugram city, Noida city, Ghaziabad city and so on. The notable fact is that the built-up area accounted for about 19.74 per cent of the total geographical area. This indicates to the expansion of built-up area in the urban centres and peripheral city regions of Delhi. The cultivable area accounted for about 11.97 per cent which is particularly occurring in the periphery of Delhi NCT particularly in the rural-urban fringe.

The Delhi Ridge area accounted for about 16.25 per cent of the total geographical area. Whereas, the forest area accounted for about 10.04 per cent. The forests cover has particularly been grown over the Delhi Ridge as well as over the community parks, open spaces and all along roads and railway tracks in the urban fringe zone of Delhi and its surroundings city regions. The road and railway network accounted for about 22.60 per cent. Such land use land cover class comprises by both the feature of urban network which evidenced phenomenal increase over the 22 years during 1977 to 1999. The River Yamuna and water bodies accounted merely 1.19 per cent. It could be due to drying of the river channel and water bodies during 1999.

6.3 Geospatial Patterns of LULC Classification: 2009

The satellite imagery for the Delhi's urban landscape and the land use land cover classification (LULC) based on multi-spectral Landsat satellite imagery processed by use of the supervised classification algorithm is presented in the Figure 8 and Figure 9, respectively for the period of 2009.



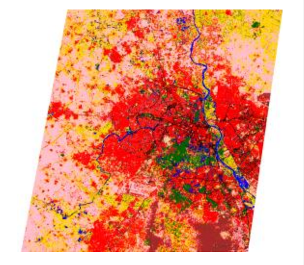


Figure 8. Raw imagery 2009. **Figure 9.** LULC 2009.

The land use land cover digital image processed statistics for the period of 2009 is presented in the Table 4. It is clearly evidenced that the built-up area and open space together accounted for about 49.60 per cent of the total geographical area. There was phenomenal urban development in the Delhi NCT and urban sprawl in the surrounding urban centres and cities as evidenced by the built-up area increase to about 24.54 per cent in 2009. The open space particularly in town and city centre kept for future urban expansion. The cultivable area accounted for 17.38 per cent. It is noteworthy to mention that the Delhi Ridge area is about 4.21 per cent in 2009. Such decrease in value could be due to the encroachment over the Delhi Ridge over the periods by the slum dwellers and shanty settlements since 1977.

It is noteworthy to mention that the forest area accounted for about 7.53 per cent in 2009. The vegetation green cover is protected and also drive for tree plantation implemented by the different govt. agencies as the Municipal Cooperation of Delhi (MCD) and the Delhi Development Agency (DDA); both these agencies primarily focussed for the Delhi Ridge's green cover regeneration and development of recreation areas over the periods over the Delhi Ridge.

Index Color	Class	Area (Hectare)	Area (in %)
	Builtup Area	73130	24.54
	Open Sapce	74689	25.06
	Cultivable Area	51789	17.38
	Delhi Ridge	12541	4.21
	Forest Area	22434	7.53
	River/Waterbody	53762	18.04
	Road/Rail	9667	3.24
	Total	298012	100.00

Table 4. Land Use Land Classification, 2009.

So, the Delhi Ridge is functioning as the green lung for the Delhi's urban environment landscape for sustainable development. The river channel and waterbodies accounted for about 18.04 per cent. Whereas, the road and rail network accounted for about 3.24 per cent. Such a decrease in value could be due the hidden of road and rail network under the green tree covers which have been expanded over the periods particularly in the urban built up areas of the Delhi NCT and the urban centres and cities located in the peripheral city region.

6.4 Geospatial Comparative Patterns of LULC Classification: 1977, 1999 and 2009

The Geospatial comparative patterns of land use land cover classification based on the multi-spectral Landsat satellite digital imagery processed by using of the supervised classification algorithm for about 32 years from 1977 to 2009 for the Delhi NCT and its surrounding city regions.

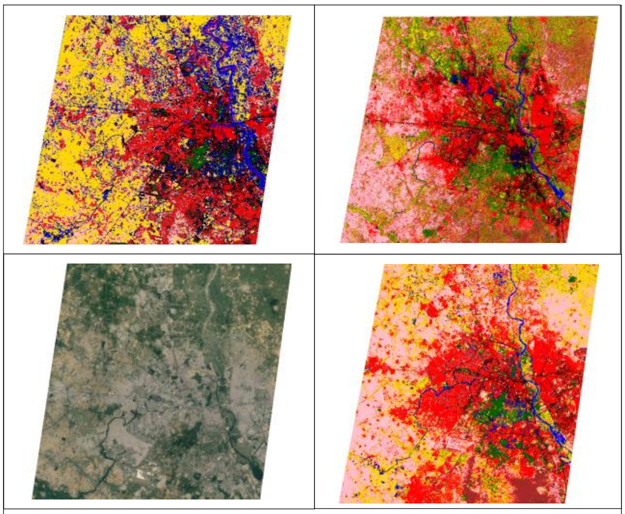


Figure 10. Geospatial Patterns of Comparative LULC Classification of 1977, 1999 and 2009 and Google map, clockwise, upper left.

The Geospatial patterns of land use land cover classification presented above for clockwise comparison from the upper left corner to the right and then downwards of the processed satellite imagery for the study region. The digital imagery processed results showed noteworthy changing trends of the urban development from the city centre of the Delhi NCT towards the surrounding urban centres and cities located in the rural-urban fringe as well as the comparative scenario of environmental landscape of the study region. Such geospatial comparative trends of the urban development and environmental landscape are also evidenced by comparison of the land use land cover classification statistics as presented below in the Table 5.

Index	Class		Area (in %)	
Color		1977	1999	2009
	Builtup Area	11.95	19.74	24.54
	Open Sapce	12.96	18.22	25.06
	Cultivable Area	26.38	11.97	17.38
	Delhi Ridge	7.58	16.25	4.21
	Forest Area	1.43	10.04	7.53
	River/Waterbody	26.36	1.19	18.04
	Road/Rail	13.35	22.60	3.24
	Total	100.00	100.00	100.00

Table 5. Comparative LULC Classification, 1977 to 2009.

So, it is clearly evidenced by the computed digital imagery results that the cultivable area accounted for about 26.38 per cent in 1977 of which value decreased to about 11.97 per cent in 1999. This class value was about 17.38 per cent in 2009. Whereas, the built-up area and the open space together accounted for about 24.91 per cent in 1977 which increased to 37.96 per cent in 1999 and further increased to 49.60 per cent in 2009. Moreover, the built-up area was about 11.95 per cent in 1977 which increased to 19.74 per cent in 1999 and then further increased to about 24.54 per cent in 2009. The built-up area development was largely concentrated in the Delhi NCT's CBD centre, on the one hand; and the urban sprawl in the adjoining city regions as the Bahadurgarh town, Gurugram city, Faridabad city, Noida city, Gahaziabad city and so on comprising to the urban landscape of Delhi.

Besides this, the Delhi Ridge area was accounted for about 7.58 per cent in 1977 which decreased to about 4.21 per cent in 2009. This decrease could be due to the large encroachment over the Delhi Ridge over the periods, on the one hand. And, the green cover generation through plantation drives initiated by the govt. agencies as MCD, DDA and so on, which resulted to partially cover-up the Delhi Ridge area over the periods from 1999 to 2009, on the other hand. Whereas, the forest area was about 1.43 per cent in 1977. Because, the wooded area was cleared over Delhi Ridge by the locally settled village dwellers in the surrounding areas of the Delhi Ridge. Thereafter, the forests area was increased to about 10.04 per cent in 1999.

Whereas, the river and waterbodies accounted for about 26.36 per cent in 1977 and about 18.04 per cent in 2009. So, the River Yamuna and lakes and ponds as the Hauz Khas tank/lake, Sanjay lake, Roshanara lake, Rohini lake are some of the rejuvenated waterbodies which are still largely found dominating over the periods. The road and rail network area were accounted for about 13.35 per cent in 1977 which decreased to about 3.24 per cent in 2009. So, such areal decrease in value of road and rail transport networks could be due to concealment of the of road and rail network under the tree covers generated all along the road and rail network in the Delhi NCT and in the surrounding urban centres and cities regions over the periods.

6.5 Accuracy Assessment of LULC Classification

The accuracy assessment compares the LULC classification based on satellite's multispectral imagery with the other kinds of accurate data i.e., the ground truth data. The ground truth data collected during the field checks of the study region. So, accuracy assessment validates to the classification data with the actual data. The land use land cover overall classification accuracy was about 88.96 per cent. The Producer's accuracy was about 76.87 per cent in case of the open space located in the settlements. Whereas, the producer's accuracy was about 94.67 per cent in case of the cultivable land. The User accuracy was about 78.34 per cent and 96.88 per cent for the open space and cultivable land, respectively. The Kappa coefficient computed value was about 82.56 per cent which represented to the overall accuracy. The Kappa coefficient value for forest area i.e., the green vegetation cover was 0.8845. Whereas, the Kappa coefficient value of the built-up area was 0.9825. The Kappa coefficient computation considers all elements of the confusion matrix. However, the accuracy assessment results proved that the land use land cover classification based on the multi-spectral Landsat satellite imagery processed using the supervised classification algorithm was good. The accuracy assessment result also proved that the training samples were spectrally separable. So, the LULC classification was worked well in the training areas of the Delhi's urban development and environmental landscape and adjoining city regions.

7. CONCLUSIONS AND SUGGESTIONS

There has been occurred a continuous change in the geospatial trends of land use land cover during 1977 to 2009, within a span of 32 years, over the Delhi's urban development and environmental landscape and its adjoining city regions. It is noteworthy to mentioned that the built-up area accounted for about 11.95 per cent in 1977 which increased to about 19.74 per cent in 1999 and further increased to about 24.54 per cent in 2009 in the study region, which comprises by the Delhi NCT and neighbouring urban centres and cities as the Bahadurgarh town, Gurugram city, Faridabad city, Noida city, Ghaziabad city and so on. The Delhi Ridge area continuously encroached over the periods.

The Delhi Ridge area accounted for about 7.58 per cent in 1977 which decreased to about 4.21 per cent in 2009. Thereafter, the forests area increased to about 10.04 per cent in 1999. It is a clear sign for environmental protection particularly the restoration and regeneration of the green vegetation cover over the Delhi Ridge which is functioning as a green lung for the Delhi's urban landscape. Whereas, the built-up area was increased over the periods from 1977 to 2009. The urban development and urban sprawl occurred from the city centre to the rural-urban fringe region was due to the implementation of various state govt. urban development plans and policies. So, the urban built-up area development and urban sprawl are to be planned in the open space comprises by the wasteland areas and the non-fertile lands largely available in the Delhi's rural-urban fringe region.

Whereas, there has been increased in the forests cover which is contributing to the carbon sink, on the one hand and; the restoration of the biodiversity of the Delhi's urban landscape and environmental development, on the other hand, over the periods particularly over the Delhi Ridge. However, the urban development and urban sprawl should be planned in such a way that it should not disturb to the fragile natural green cover ecosystem developed over the Delhi Ridge, on the one hand; and it should not worsen to the condition of the other land covers and land resources of the Delhi's urban landscape, on the other hand.

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Consequently, the sustainable urban development process can help to mitigate deterioration of urban environment as well as to help into the sustainable urban and environmental development of the Delhi's urban landscape. So, the geospatial technological methodology developed and applied for urban land development and environmental landscape's resources mapping and monitoring in the present study will be helpful to the urban planners, policy makers and govt. agencies for its application into the other such areas for their urban and regional development at the local, national, and global levels.

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