

MONITORING URBAN GROWTH PATTERN OF DELHI USING REMOTE SENSING AND GIS TECHNIQUES

Rupesh Kumar Gupta

Assistant Professor, Dr. Bhim Rao Ambedkar College, University of Delhi, Delhi, India
Email: gisrs2004@gmail.com

Abstract: *This research is focused on the land use land cover changes and urban expansion in megacity; Delhi, and highlights the major impact of the rapid growth of population and urbanization on the LULC changes for the period of thirty-four years, which need immediate attention. The multi-temporal satellite data and visual interpretation methods were used through Arc GIS Software. The results show that the built-up land has increased by 14.41 km²/annum whereas agricultural, waste, barren and scrub land shrink by 9.59 km²/annum, 4.29 km²/annum respectively, during this period. The built-up area expanded from 298 km² to 773.59 km² during 1985 to 2018 on the cost of agricultural, waste, barren, and scrub land. The increment of forest 2.92 percent during this period shows a healthy sign. The findings would provide insight to the planners and policy makers; for the management of urban land, and problems related with the growth of city regions.*

Key words: Urban Growth, LULCC, Built-Up Area, GIS, Remote Sensing

Introduction

Urbanization is one of the most important global change processes. As the share of people in, and the footprint of, urban areas continue to grow globally and locally, understanding urbanization processes and resulting land use both their patterns and intensity is increasingly important with respect to natural resource use, socio-demographics, health, and global environmental change (Seto and Reenberg, 2014). For decades, urban studies have been grappling with the question of how to define “urban”; the definition of urban includes comparatively straightforward official definitions, such as those that use the administrative unit with a set minimum number of inhabitants (McIntyre et al. 2000), but, in some cases, it also includes such factors as population density, built-up area (urban landscape), commuting density, travel distance (Nilsson et al. 2014), and proportion of workforce engaged in non-agricultural economic activities (Census of India 2011).

Urbanization has been a megatrend of global land-use change that can be observed in all parts of the world. By 2050 close to 70 percent of the global population will live in cities (Eurostat, 2016). The present trend of the urbanization in developing countries is especially due to rural-urban migration, the geographic expansion of urban areas through annexations, and the transformation and reclassification of rural villages into small urban settlements (United Nations, 2017). As has been observed in the rest of the world, India had similar impacts of urbanization and land use land cover (LULC) change. The independence of the country gave further impetus to the urbanization in Indian cities such as Delhi, Mumbai, Kolkata and Chennai (Delhi Census Handbook 1991). The economic liberalization policy of 1991 opened up the Indian economy to the international market, which saw incoming of a large share of foreign direct investment (FDI) in

metropolitan cities. Delhi region received a maximum share of FDI compared to other regions of the country. Along with this allowance of 100 percent, FDI in real estate and infrastructure by the Indian government has made Delhi susceptible to rapid urban growth (Namperumal et al. 2011).

Delhi is one of the many megacities struggling with rapid urbanization and gigantic levels of pollution from industrial, residential and transportation sources (Mohan et al.2007). After independence, when Delhi witnessed a large influx of migrants, within a very short time the population of Delhi was approximately doubled. In a large migrating population, the city has expanded in a very unplanned and uncontrolled manner (Rahman, 2007). Such types of unplanned expansions have a direct impact on the quality of the urban environment affecting the efficiency of the people and their productivity in the overall socio-economic development (Netzband and Rahman,2007). In light of its past experiences and current trends of development, the emerging future of Delhi is one of the most important issue gaining focus from the authorities to improve the overall quality of life. Land use which is a highly dynamic entity in nature is one of the key parameters to quantify development (Gupta, 2014, 2006). The dynamic land-use database has a vital application to many diverse fields like Biodiversity-Environment, Forestry, Hydrology, Agriculture, Geology, Urban sprawl, etc.,

Location of the Study Area

The present study has been carried out on Delhi, the capital city of India located between the 28°24'17" and 28°53'00"N latitudes and 76°45'30" and 77°21'30"E longitudes. The elevation of the city ranges between 213 and 290 m. Delhi, the National Capital Territory situated near the western bank of river Yamuna which spreads over an area of around 1,490 km² is surrounded by the Himalayas in the North and the Aravali ranges in South-West. Delhi is one of the fastest-growing cities in the country. Due to the rapid pace of urbanization, the landscape of Delhi has undergone a change from a rural majority to urban. Delhi has 11 districts with 33 Tehsils/Sub-Divisions.

Research Question

The purpose of the study is to evaluate the impact of the rapid growth of population on the land use/land cover. To see the spatial pattern of land use/ land cover change over the last 34 years. It is also interesting to investigate the land transformation of different category. The study area witnessed of high population growth over the time periods, and the area drastically changes in last two decades. The horizontal growth of different land-use categories was evaluated through satellite data.

Methodology

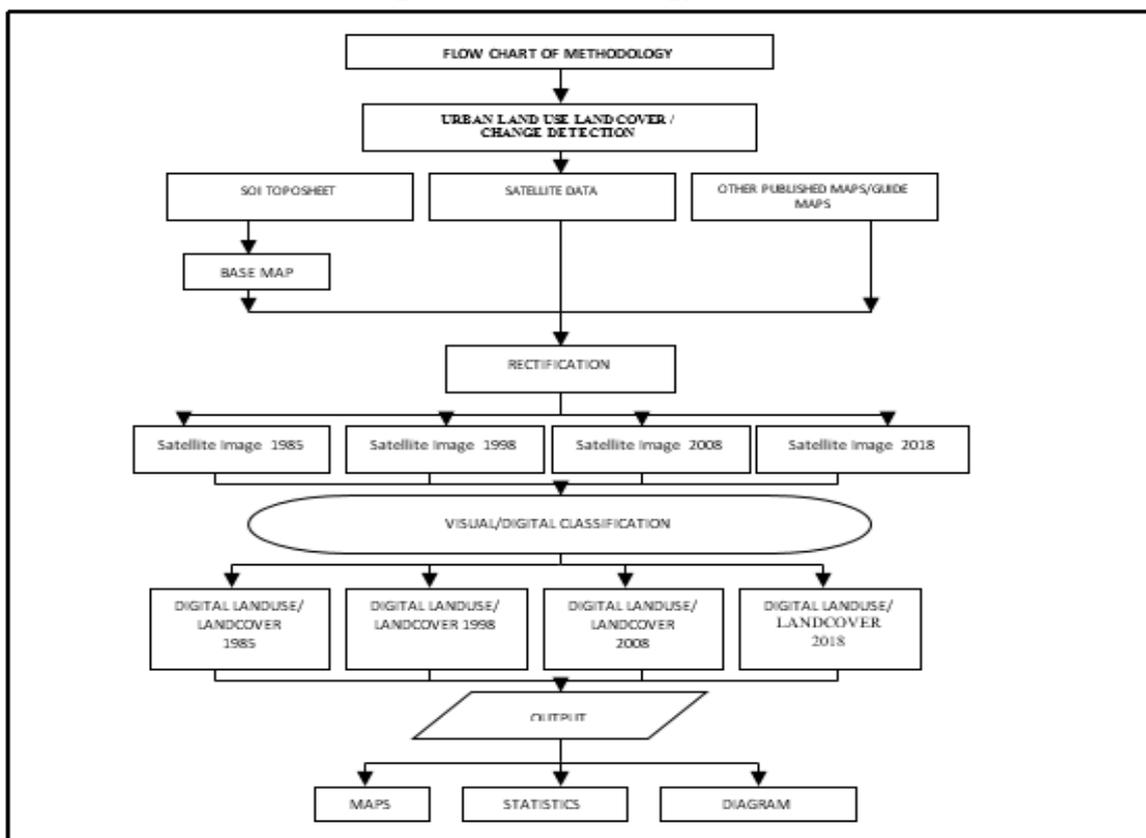
The work has been based on census and satellite data, map sheets and village maps. The data has been processed through Arc-GIS software. The data collection involved satellite Image, secondary published data and limited primary data. To understand the complexity of dynamics of the pattern of land-use change of the city and land transformation, a few indicators were examined. The indicators such as land use, roads, railway network and the agricultural area were captured from map sheets and imagery and each of the layers were digitized. The extension of agriculture land during the last four decades (1985-2018) is determined by computing the area from the digitized map sheets, imagery and compared it with the areas of different time periods. The land use classification is shown in Table-1. To find out the growth of the city and its built-up area; we used Google Earth Image data with limited ground truth verification, Survey of India data, topo sheets, Other data: Census of India 1981,1991, 2001 & 2011, Planning Commission, Master Plan 2001, 2021 of DDA etc. other Ancillary Data provided basic information of the study area. With the help of topographic map (1:50,000), we prepared a base map of the study area, and then rectified all data through base map and proceed for visual classification (figure 1).

Table 01: Land Use Classes Considered in Image Classification

Land use class	General description/Subclass
Built-up Land	Include Dense, Moderate, Sparse as well as Rural settlements, Industrial, Institutional, Commercial, Recreational, Transportation and utilities.
Agricultural Land	Cropland, Fallow land
Forest	Trees, green cover, Plantation
Wasteland	Scrub land, Water logged, hills / barren rock
Water Bodies	River, Pond, tank/lakes
Transport Network	Railway, Metro Rail, Expressway, National Highway, Major and Minor Road

Source: prepared by Author

Figure 01: Methodology Chart



Source: prepared by Author

With the help of Arc GIS software, we completed visual classification and remove all error like undershoot, overshoot as well as removed some error through reference map and field visit. The spatial framework of GIS database was organized in GIS as per the topographical maps coordinates and projection system. A grid was generated in Arc-Info with four-tic points for each map/sheet covering entire NCT Delhi Area. All these layers of different time periods were transferred to the above grid for commonality. Thematic map drafts were prepared on a sheet-by-sheet basis for digitization. On each sheet, all the required themes were drawn (all land use categories-different road, and built-up land). Four different time period land use maps (1985, 1998, 2008 & 2018) were prepared on the basis of Image data (figure 1).

RESULT AND DISCUSSION

Population Growth in Delhi

As per this census, the population of Delhi, as of 1st March 2011, was 16.78 million as against 13.85 million on 1st March 2001. According to Census 2011, about 97.50 percent of the population of Delhi lives in urban areas and the remaining 2.5 percent in rural areas. The total population of Delhi was nearly 0.4 million in 1901, which increased slowly and reached 1.74 million in 1951 (4.35 times in half-century) and 13.78 million in 2001 (census of India, 2001) implying about 34.45 times increase in one century. As per this census, the population of Delhi, as of 1st March 2011, was 16.78 million as against 13.85 million on 1st March 2001.

The growth in the urban area during 2001-2011 was observed at 20.44 percent. This pace of urbanization has reduced the number of villages in Delhi from 300 in 1961 to 165 in 2001 and 112 in 2011. The number of urbanized villages has increased from 20 in 1961 to 135 in 2011. The number of census towns has increased from 3 in 1971 to 29 in 1991 and 110 in 2011. The decadal growth rate of the population during 2001-2011 was recorded at 21.2 percent. This is a peculiar feature of Census 2011, as in all censuses since 1951, the decadal growth rate of the population was more than 50 percent and 47 percent in 2001 (Table 2 & 3, figure 2). The sequence of growth through the four phases, particularly the present day phase has set the base for the growth dynamics of the city. The growth has been analyzed taking both the demographical dynamics of the city as well as areal dynamics of the city. The demographic structured much more changes in Delhi for the last 110 years. If we go through the following data (Table-2, figure 2), it seems that the population of Delhi increased more than forty-one fold during 1901-2011.

Phase 1. 1901-1941-low to medium growth- during this period the growth rate was slow and after that, the decadal growth was from 1.98 to 18.03, 30.26 and 44.27 percent during 1901-1941. It may be the cause of shifting of British Indian Capital from Calcutta to Delhi in 1931. The announcement made in 1911 and name of New Delhi declared 1927 and capital inaugurated on 13 February 1931. The population grew rapidly from 4.13 lakh to 9.17 lakh from 1911 to 1941.

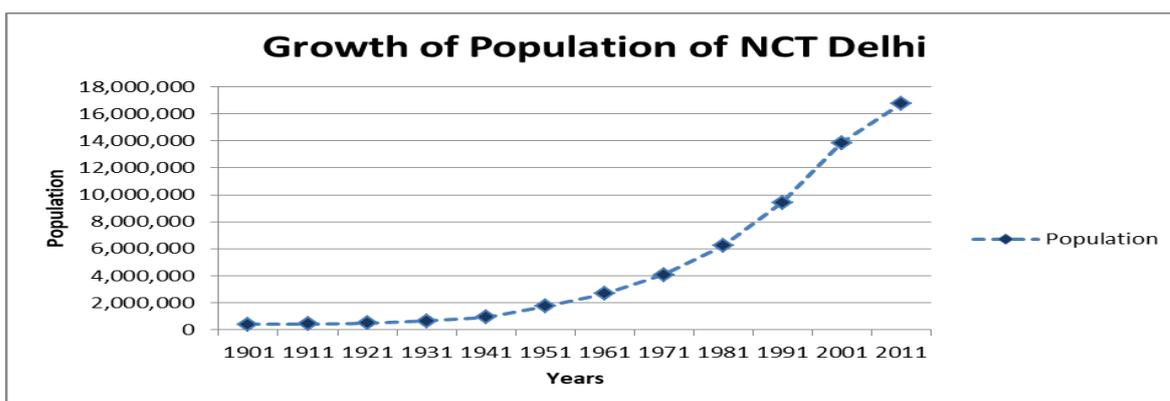
Phase 2. Very high growth rate-during 1941 to 1951, the decadal growth rate was 90 per cent, this is a very high growth rate ever in Delhi. All this happened due to India got independence and country divided in two-part, so most of the people attracted towards Delhi, and that's the reason for the suddenly highest growth of population.

Table 02: Decadal Population Growth & Trend of Urbanization in Delhi: 1901-2011

Census Year	Total Population	Percentage Decadal Growth	Average Annual Exponential Growth	Total Urban Population	Total Urban Area (sq. km.)	Percent Urban Population
1901	405,819	-	-	214115	-	52.76
1911	413,851	1.98	0.20	237944	43.25	57.50
1921	488,452	18.03	1.67	304420	168.09	62.32
1931	636,246	30.26	2.68	447442	169.44	70.33
1941	917,939	44.27	3.73	695686	147.31	75.79
1951	1,744,072	90.00	6.63	1437134	201.36	82.40
1961	2,658,612	52.44	4.31	2359408	326.55	88.75
1971	4,065,698	52.93	4.34	3647023	446.26	89.68
1981	6,220,406	53.00	4.34	5768200	540.78	92.73
1991	9,420,644	51.45	4.24	8471625	685.34	89.93
2001	13,850,507	47.02	3.93	12905780	924.68	93.18
2011	16,787,941	21.21	1.94	16368899	1113.65	97.50

Source: Census of India 2001, 2011, Economic Survey of Delhi: 2008-2009

Figure 02: Growth of Population of NCT Delhi (1901-2011)



Source: Census of India 1991, 2001, and 2011

Phase 3. High Growth Rate during 1951-1991-in this phase the population growth is high, and the decadal growth was more than 50 percent. Due to development of health sector, the birth rate was high but the death rate continues decline, resulting in a high growth of population. The other factor was the migration of population from other states to Delhi is to search for Job Opportunities, career advancement, safety-security and a better life.

Phase 4. Slowly decline growth rate during 1991-2020-in this period the decadal growth rate below 50 percent, it was 47.02 percent in 2001 and 21.21 percent in 2011. The decline of growth rate only causes of education, awareness among people, single-family system, job opportunity, urbanization, urban lifestyle, and high and expensive living standard of the people of urban area.

Table 03: Estimates of Natural Growth and Migration in NCT Delhi: 1991-2016 (Figures in lakh)

Year	Estimated Mid-Year Population	Annual Increased Population	Total birth	Total Death	Natural increase	Increase due to migration
1991	95.50	3.89	2.72	0.61	2.11	1.78
1994	107.50	4.12	2.62	0.68	1.94	2.18
1997	120.57	4.47	2.89	0.71	2.18	2.29
2000	134.60	4.78	3.17	0.80	2.37	2.41
2001	139.50	4.90	2.96	0.81	2.15	2.75
2004	152.79	4.36	3.06	0.85	2.21	2.15
2007	156.45	2.98	3.22	1.01	2.21	0.77
2010	165.74	3.16	3.59	1.24	2.35	0.81
2011	168.96	3.22	3.53	1.12	2.41	0.81
2014	179.00	3.41	3.74	1.21	2.53	0.88
2016	186.01	3.54	3.79	1.42	2.37	1.17

Source: Office of Chief Registrar, Births & Deaths, Government of NCT Delhi
(Compiled from: Economic Survey of Delhi: 2008-2009 and Economic Survey 2017-18).

In 1951, there were 304 villages in Delhi, but in 2011 it reduced to stand 105, the rural area also reduced sharply along with rural population and it's almost around 300 km². The major reason of migration from other states to Delhi may be the economic, social, political or better opportunities, infrastructure, technological advancement, law and order, social security, career security, good institution and good health Centre etc. (Table-3).

Land Use Land Cover Pattern

For any comprehensive study of the growth of cities over time and space, it is not sufficient if a researcher examines only the general structure of the cities. Rather, it is essential to understand land use arrangement and the population patterns existing within them (Gupta & Singh, 2012). For this purpose, the present study, the land use maps of 1985, 1998, 2008 and 2018 were prepared. The study covered almost a period of 35 years i.e., from 1985 onwards in the spatial pattern of land use and land cover.

Land Use/Land Cover of 1985

For the preparation of land use/land cover map, the boundary covered almost 1484 km² and result of this much area show that out of the total area, cropped area was 47.50 percent, Fallow Land was 1.61 percent, Barren and Scrub land was 14.56 percent, the forest was 14.08 percent, the plantation was 3.62 and water bodies 2.15 percent respectively. Only 20.08 percent of the total study area was built-up land (Table 4, Figure 3, & 4). In this period the rate of growth as well as, land transformation was slow. This shows that the area exhibits a low growth rate during this period.

Land Use/Land Cover of 1998

After the gap of thirteen years since 1985, the following changes occurred in land use categories, the crop land decline from 37.49 percent to 10.01 percent of its previous year 1985 due to utilization of cropland for settlement and commercial purpose or other requirements to meet the demands of this land. The fallow land decreased by 1.61 to 1.05 percent but the forest increased, from 14.08 to 14.25 percent respectively (Table 4, Figure 3, & 4). The areal extent of Built-up land indicates that the development of the city during this period, which has occupied 31.88 percent of the total study area under built-up, comprises of high density (11.73 percent), medium density (6.89 percent), and low density (11.61 percent). 11.80 percent of the total area comes under land under transformation, thus indicating the developmental process of the city.

Table 04: Land Use Land Cover Area Statistics of 1985-2018

Year/LULC Category	1985		1998		2008		2018		1985-1998	1998-2008	2008-2018
	km ²	%	Area	%	km ²	%	km ²	%	Growth km ² per annum		
Built Up Land	298	20.08	472.98	31.88	692.50	46.67	773.59	52.13	13.46	21.95	8.10
Agricultural Land	729	49.12	572	38.54	485.91	32.74	412.41	27.79	12.07	8.60	7.35
Forest	209.02	14.08	211.42	14.25	153.96	10.38	197.34	13.29	0.18	5.75	4.34
Barren & Scrub Land	215.98	14.56	196.31	13.23	121.55	8.19	74.23	5.01	1.51	7.47	4.73
Water Bodies	32	2.16	31.29	2.10	30.08	2.02	26.43	1.78	0.05	0.12	0.36
Total Area	1484	100	1484	100	1484	100	1484	100			

Sources: based on multi temporal Satellite Data

Land Use/Land Cover of 2008

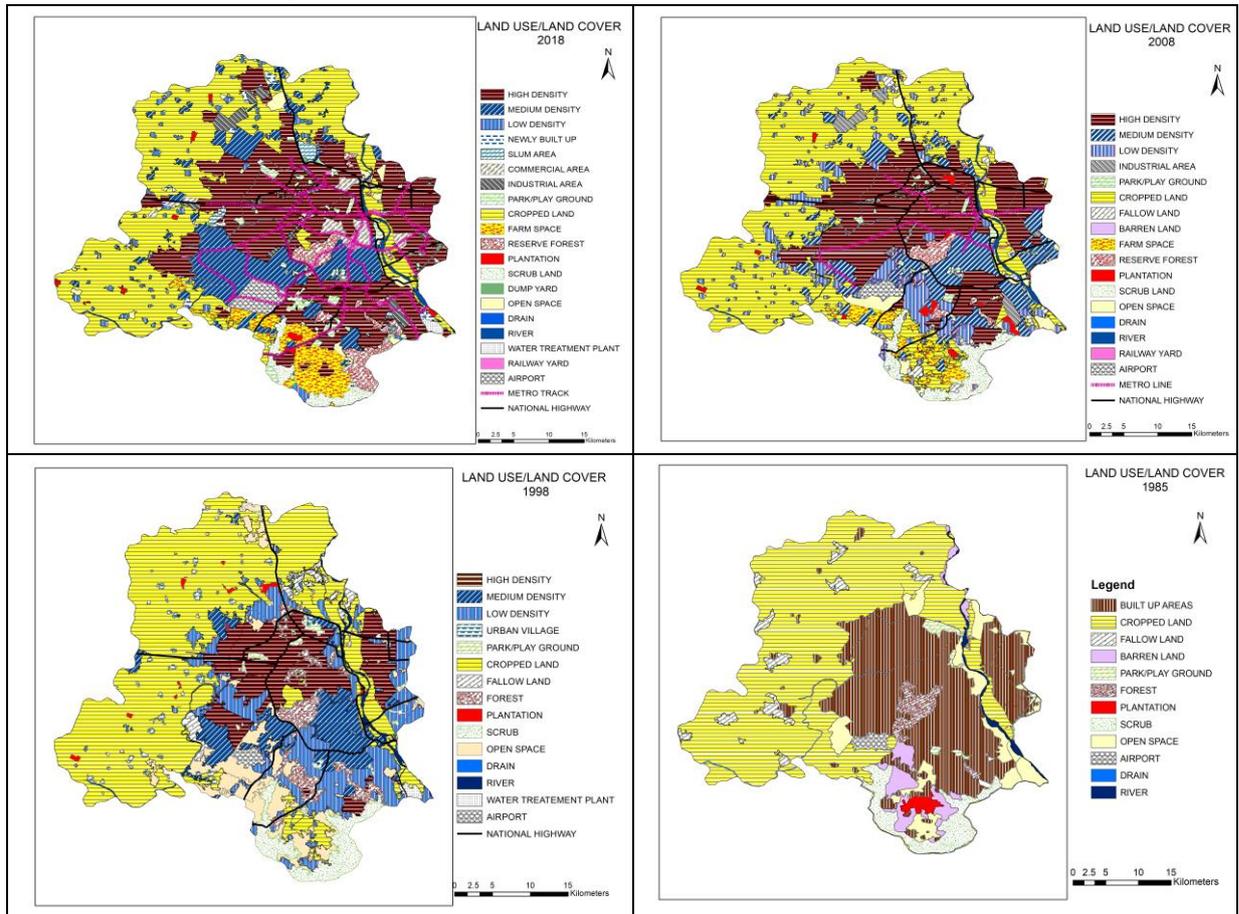
During 2008 the built-up land has grown from 31.88 percent to 46.67 percent registering an increase of 14.79 percent area of built-up land. During this period Agricultural Land shrink by 38.54 to 32.74 percent and the built-up area increased 14.79 percent respectively, which indicates the areal expansion of the city (Table 4, Figure 3, & 4). Another category like Fallow land has decreased from 1.05 percent (in 1998) to 0.74 percent (in 2008) due to utilization of fallow land for growing vegetables or converted into a new settlement. Similarly, crop area decreased by 7.3 percent.

Land Use/Land Cover of 2018

During 2008 to 2018 the high-density built-up land increased (31 percent) by around 461 km² whereas the total built-up land reached 773.59 km² within 10 years. In a little span of time, the land use rapidly changed especially in fallow land, waste or barren land, scrub

land which was either converted into low or medium density settlement or urban slum. During this period most of the land converted into medium to high or low to high density (Table 4, Figure 3, & 4). A large number of villages merged in the municipal area and lost their identity and living style. Ultimately it will change their ecology and environment of the surrounding.

Figure 03: Land Use Land Cover Map of 1985-2018



Sources: based on multi temporal Satellite Data

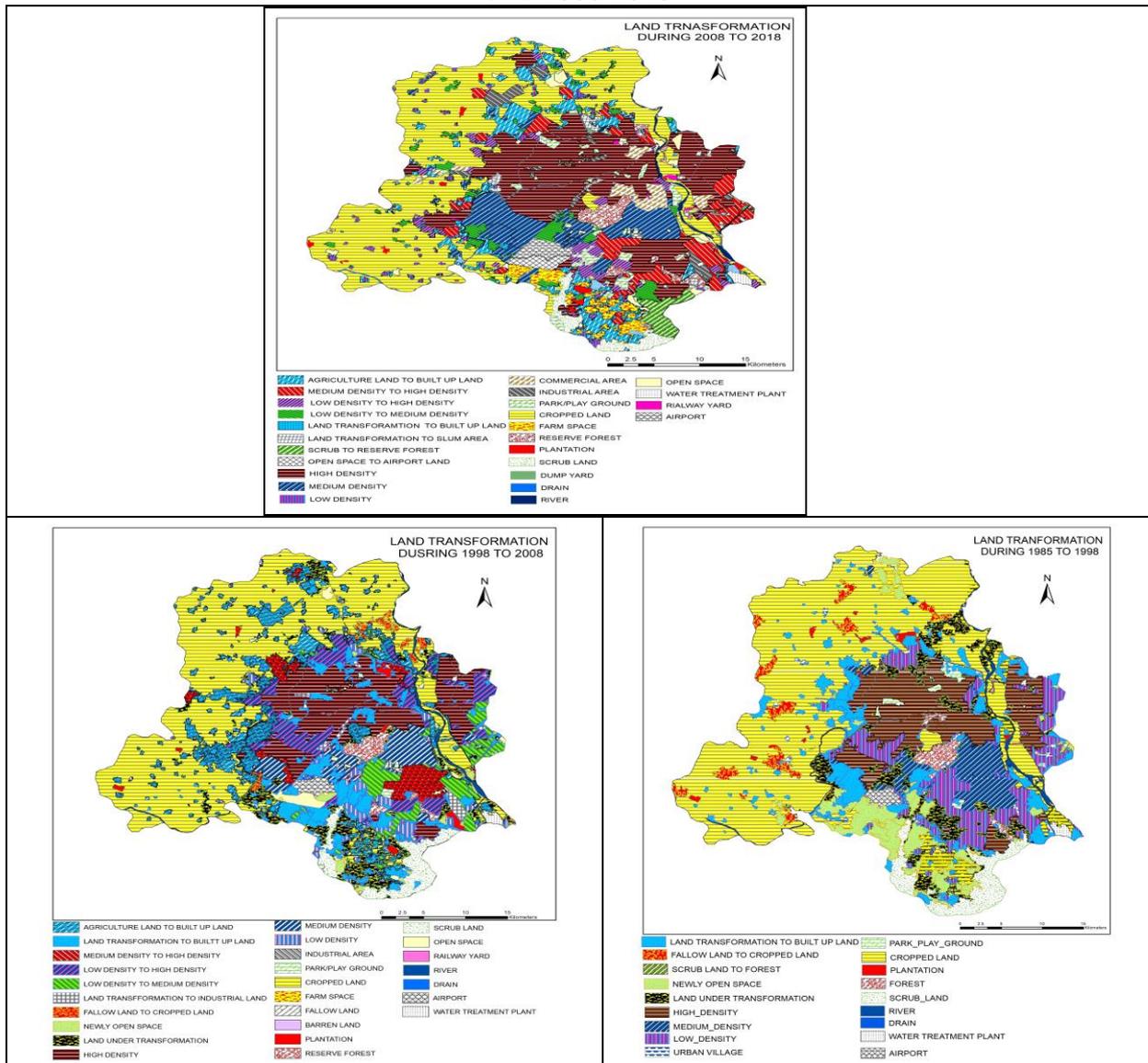
Land Transformation and Change Detection

In 1985, the Built-up land covered 298 km² or 20 percent of the study area, where agricultural land stand with 49.12 percent, 209 km² area covered by forest, 215.98 km² area under scrub, waste and barren land, as well as water bodies stand with 2.16 percent of the area. The cropped area covered by 47.50 percent, whereas fallow land 1.61 percent, forest 10.46 percent, and plantation 3.62 percent respectively. In 1998, after the gap of 13 years, a massive change observed in this categories and built-up land rapidly increased to reached 31.88 percent of the study area, and agricultural land shrinks by 729 km² to 572 km², and forest slightly increased 209 km² to 211 km², waste-barren and scrub land stands with 13.23 percent (earlier in 14.56 percent) of the area, where water bodies have no major changes and it still stands on 2.16 to 2.10 percent respectively (Table 4, Figure 3, & 4). The built up land comprises the high density built up area covered 11.73 percent, medium density 6.89, and low-density 11.61 percent. In 2008, after 10 years of gap, there was a major change seen in built-up land, and it covered 46.67 percent or 692.50 km², where 372 km² or 25.07 percent high density, 160.57 km² or 10.82 medium, and 126.17 km² or 8.50 percent low-density area, and this expansion is in the cost of agricultural land; which shrink from 38.54 to 32.74 percent, forest; 14.25 to 10.38 percent and waste-barren-scrub land; 13.23 to 8.19 percent, respectively. The change which has taken place during this period is mainly based on fallow land, cropped

land, forest, barren and scrub land. The fallow and cropped land shrink by 37 to 30 percent, forest from 14.25 to 10.38 percent and degraded-waste-barren and scrub land shrink decreases by 13.23 to 8.19 percent area respectively (Table 4, Figure 3, & 4).

In 2018, the rate of growth was slow, and the urban built-up area cover 773.59 km² or 52.13 percent, in which high density built-up area increased by 372 km² to 461 km² or 25 to 31.45 percent, medium-density from 160.57 km² to 181 km² or 10.82 to 12.19 percent and low density decrease by 2 percent area. In the other side, the agricultural area shrinks by 485.91 km² to 412.41 km². The positive changes observed in the forest area, which extended from 153.96 km² to 197.34 km², which is almost 13.29 percent of the study area. Other categories of land like scrub, waste, barren continue decline from 121.55 km² to 74.23 km² which has almost 5 percent of the study area (Table 4, Figure 3, & 4). The development of infrastructure and migration of people (Table-3) from a different state made it highly populated region and the explosive population growth (Table-2), created many problems, among them, the land use is prominent, which is challenging for the sustainability of urban ecology and environment of this region.

Figure 04: Land Transformations/ Change Detection Map of 1985-1998, 1998-2008, and 2008-2018



Sources: based on multi temporal Satellite Data

Major Finding and Conclusion

Figure 3 and 4, depicts the land use pattern in and around of Delhi in 1985, 1998, 2008 and 2018 and Figure-4 shows the land-use changes during the last decade (1985-2018) which is still continuing. The urban villages in Delhi region can broadly be classified into three categories based on the process of their transformation: Rural – dominated with agricultural land and primary activities; urban slum and unauthorized colonies converted into urban built up, and transitional semi-rural to semi-urban dominated with built-up land and territory activities. Figure 3 & 4 (urban land-use change 2008-2018, & land use 2018) highlights the following:

- Major conversion of agricultural land into urban built-up: commercial, residential and institutional land. The built-up area is largely added in peripheral areas rather than along transit.
- The built-up land increased during 1998-2008 that is 21.95 km²/annum, compared to 1985-1998 (13.46 km²/annum) and in 2008-2018 (8.10 km²/annum). This is found that the most of the built-up area expanded during 1998-2008, on the cost of fallow, crop, barren and scrub land.
- Similarly, the agricultural land rapidly declines in the rate of 12.07 km² per annum during 1985-1998, 8.60 km² in 1998-2008, and 7.35 km² per annum in 2008-2018, respectively. The waste, barren and scrub land shrink by 1.51, 7.47, and 4.73 km² per annum during this period.
- The open areas, greenery-forest and scrub land, agricultural-crop land, water body are more vulnerable due to land-use changes.
- The rapid population growth, urbanization, economic reform and development of physical infrastructure has triggered effect the land-use changes.
- The increase in population size has simultaneously led to the areal growth and spatial changes in the city thus, altering the landscape. Robust implantation strategies are required for sustainable intervention.

The rapid growth of population, migration and changing economy has major forces behind land-use changes in the city. The rapid population growth, created many problems like pollution, groundwater level decline, decreased green cover, and urban heat island etc. There is a requirement to developed infrastructure and services according to the thirst of the master plan of Delhi 2021 to cope with the demand for rapid growth. For the future point of view, to check the population, and try to encourage vertical growth instead of spatial, and the high rise building also opt the green roof to protect from heat during summer, it will help to address the problem of the urban area.

References

1. Census of India, (1991, 2001, 2011). Delhi Census Handbook (1991,2001) Directorate of census operations, Delhi <http://www.censusindia.gov.in>. New Delhi
2. Delhi Human Development Report (2006). Planning Commission of India, http://planningcommission.nic.in/plans/stateplan/sdr_pdf/shdr_del06.pdf.
3. Delhi Development Authority, The Master Plan for Delhi (1962, 2001 & 2021). <http://dda.org.in/planning/mpd-1962htm>
<http://dda.org.in/planning/mpd-2001htm>
<http://dda.org.in/planning/mpd-2021.htm>
4. Eurostat (2016). Urban Europe. Statistics on Cities, Towns and Suburbs. Edited by European Commission. Luxembourg. Available online at: <http://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-01-16-691>
5. Govt. of India. (1991, 2001,2011). Census of India, 1991, 2001 and 2011. Registrar General and Census Commissioner (1993), Census of India, (1991), Census of India, (2011). Census Atlas, Directorate of Census Operations, Government of India, New Delhi. <http://censusindia.gov.in/>

6. Govt. of India. (2010, 2018). Economic Survey of Delhi: 2008-2009 & 2017-18, Economic Division, Ministry of Finance, Government of India, New Delhi.
7. Government of NCT Delhi (2017). Directorate of Economics & Statistics (2017), *Delhi Statistical Handbook, 2017*, Directorate of Economics & Statistics, Government of NCT Delhi, Delhi.
8. Government of NCT Delhi (2009, 2011, 2018). Planning Department (2009), *Economic Survey of Delhi, 2008-09, 2010-2011, & 2017-2018*, Planning Department, Government of NCT Delhi, New Delhi.
9. Government of NCT Delhi (2011). Office of Chief Registrar, Births & Deaths, Government of NCT Delhi
10. Gupta, R. (2014). The Pattern of Urban Land Use Changes: A Case Study of the Indian Cities, *Environment and Urbanization ASIA*, Vol.5, No 1, pp 83-104. Sage Publication.
11. Gupta, R., Singh. R.B. (2012). Environmental Implications of Land Use Change in Jaipur City Using Satellite Data, *Indian Journal of Regional Science*, Vol. XXXXIV, No.2,2012 pp 141-154
12. Gupta, R. (2006). Study of Population Change and Urban Land Use relationship using an integrated Remote Sensing and GIS Approach, *Deccan Geographer*, Vol.44, Pp 1-12.
13. McIntyre, N.E., Knowles-Yanez, K., and Hope, D. (2000). Urban Ecology as an Interdisciplinary Field: Differences in the Use of "Urban" between the Social and Natural Sciences, *Urban Ecosystems*, 4: 5–24.
14. M. Mohan, Lalit Dagar and B. R. Gurjar, (2007). "Preparation and Validation of Gridded Emission Inventory of Criteria Air Pollutants and Identification of Emission Hotspots for Megacity Delhi," *Environmental Monitoring and Assessment*, Vol. 130, 2007, pp. 323-339. doi:10.1007/s10661-006-9400-9
15. M. Netzband and A. Rahman, (2007). "Urban Remote Sensing for a Fast-Growing Megacity: Delhi, India," *SPIE Inter- National Society Advancing an Interdisciplinary Approach to the Science and Application of Light*, Berlin, Germany, 2007. <http://spie.org/x17987.xml>
16. Nilsson K., Nielsen T. S., Aalbers C., Bell S., Boitier B., Chery J-P, Fertner C., Groschowski M., Haase D., Loibl W., Pauleit S., Pintar M., Piorr A., Ravetz J., Ristimaki M., Rounsevell M., Tosics I., Westerink J., Zasada I. (2014). Strategies for Sustainable Urban Development and Urban-Rural Linkages, Research brief, March 2014, European Journal of Spatial Development.
17. Namperumal S, Taubenbo"ck H, Jain M (2011). Seamless urbanization and knotted city growth: Delhi metropolitan region. In: Proceedings real CORP 2011 Tagungsband, 18–20 May 2011. ISBN:978-3-9503110-1-3
18. Rahman, A. (2007). "Application of Remote Sensing and GIS Techniques for Urban Environmental Management and Sustainable Development of Delhi, India," *Applied Remote Sensing for Urban Planning, Governance and Sustainability*, Springer-Verlag Publishers, New York, 2007, pp. 165-197.
19. Seto, K., and Reenberg, A. (2014). Rethinking Global Land Use in an Urban Era. Strungmann Forum Reports, (eds.) vol. 14, Julia Lupp, series editor. Cambridge, MA: MIT Press.
20. United Nations (2019). World Population Prospects 2019: Highlights. United Nations. Available online at: https://population.un.org/wpp/Publications /Files/ WPP2019 _Highlights.pdf.
21. United Nations (2018). Sustainable Development Goal 11–Make Cities and Human Settlements Inclusive, Safe, Resilient and Sustainable. Available online at: <https://sustainabledevelopment.un.org/sdg11>.
22. United Nations (2017). World Population Prospects. [ww.un.org/ development/ desa/publications/world-population-prospects-the-2017-revision.html](http://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html)