Spatial-temporal Analysis of Population, Land use-Land cover and Environment: A study of seven most populated city-regions of India

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Introduction

In today's increasingly global and interconnected world, over half of the world's population (54 percent) lives in urban areas, although there is still substantial variability in the levels of urbanization across countries. The coming decades will bring further profound changes to the size and spatial distribution of the global population. The continuing urbanization and overall growth of the world's population is projected to add 2.5 billion people to the urban population by 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa. At the same time, the proportion of the world's population living in urban areas is expected to increase, reaching 66 per cent by 2050 (United Nation, 2014).

According to the World Urbanization Prospects, 2014 there is great diversity in the characteristics of the world's urban environs: close to half of urban dwellers reside in relatively small settlements of less than 500,000 inhabitants, while nearly one in eight live in the 28 mega-cities of 10 million inhabitants or more. The number of mega-cities have nearly tripled since 1990; and by 2030, 41 urban agglomerations are projected to house at least 10 million inhabitants each. Whereas several decades ago most of the world's largest urban agglomerations were found in the more developed regions, today's large cities are concentrated in the global South, and the fastest-growing agglomerations are medium-sized cities and cities with 500,000 to 1 million inhabitants located in Asia and Africa.

In India, rapid population growth and expansion of developmental activities have both greatly aggravated resource depletion and degradation of the environment (Shaw 1989; Jodha 1990; Harte 2007).The extent of environmental degradation varies across countries and regions of the world (Shafix & Bandhyopadhyay 1992; Holtz-Eakin & Seldon 1995). For example, poverty has been the major cause of depletion of natural resources and environmental degradation in Africa (Kalipeni, 1992), but in the Asia Pacific region both rapid population growth and continued economic development are found to be the major causes of environmental pollution (Duraiappah 1996; Dewaram 2007). In contrast, in the United States, where population density is much lower than in India, the main cause of environmental damage has been the extremely high per capita consumption of resources and the consequent high carbon emissions (United Nations 1997).

According to the Registrar General of India, 2011 and the Indian Institute for Human Settlement, 2012 the top ten cities of India account for almost 8% of India's population and occupy approximately 0.1% of the total land area of the country. Similarly, the 53 million plus cities are estimated to account for 13% of the population and occupy approximately 0.2% of

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the land. The top 100 cities are estimated to account for 16% of the population and occupy approximately 0.26% of the land.

While the extent of land under cities remains small, the effect of population increase on land dynamics may be more significant. The areas where higher scope and opportunities are available have experienced a huge population increase and as a consequence of this there are significant changes in land use and land cover particularly in built-up land. Change in built-up land is one of the most widespread anthropogenic causes of the loss of arable land (Lopez, *et al*., 2001), habitat destruction (Alphan, 2003), and the decline in natural vegetation cover. To understand these processes of environmental change in developing countries, it is critical to analyze land-use changes and the factors underlying them. In this context, the question about the impact of population growth with limited and often degraded resources is most relevant for developing country like India.

Keeping the above mentioned challenges in mind, in the current study an attempt has been made to study and analyze the population dynamics, changes in Land use- Land cover (LULC) and environmental conditions of the top seven city-regions of India for last two decades. The study has also focused on linkages among these aspects. The city-regions studied in this paper are Delhi, Mumbai, Kolkata, Bangalore, Ahmedabad, Chennai and Hyderabad. The study has focused on changes in key population parameters such as total population, population density, no. of households, migration, slum population, population growth rate, etc. For the same time period spatial changes in LULC has been studied in the city-regions. To analyze the environmental conditions in selected parameters such as weather conditions[3], river pollution[4], air pollution[5] (PM10, Sulfur Dioxide SO2, Nitrogen Dioxide NO2) etc. have been taken into consideration.

Background

Global context

Human beings have altered the face of the earth for the last few centuries, but with the introduction of modern technologies, the land cover of the earth has changed drastically in the last three centuries. The debate about the relationship between human population dynamics and the availability of natural resources dates back to more than 200 years when Malthus (1798) put forward his argument that population growth would eventually outstrip the production capacity of the land. Population pressure on farmland has long been a concern in the demographic literature. A more recent interest is tropical deforestation. In the past, research on population growth and land use was hindered by lack of adequate data (Bilsborrow and DeLargy 1991).

As seen from space, land cover change is far and away the signature imprint of human habitation on the surface of the Earth. What is driving changes in land use and the environment?

[3] Includes maximum temperature, minimum temperature and average annual rainfall
[4] Includes pH, conductivity, Biological Oxygen Demand and Dissolved Oxygen
[5] Includes Particulate Matter 10, Sulfur Dioxide and Nitrogen Dioxide

What is the role of population? In addressing these questions, "*Population, Land Use, and Environment"* by Barbara Entwistle and Paul C. Stern, presents light on land use or land cover change where the population is a prominent driving force.

According to Anne R. Pebley (1998), several recent studies by demographers are an important break from past research (Foster, Rosenzweig, and Behrman 1997; Rindfuss, Walsh, and Entwisle 1996; Rosero- Bixby and Palloni 1996; Shivakoti et al. 1997). Their much effective methodologies include analyzing of panel data for large samples of local areas (such as, villages, neighborhoods, or land parcels), linking with spatial data from satellite images and/or other sources with socioeconomic and demographic survey or census data, and examining the role of other social and economic changes that may cause or mitigate land-use change.

Indian Perspective

In the recent time few researchers from India and other parts of the world have done the analysis link and relate spatial changes in environments with various factors, primarily demographic, in different areas of the Indian subcontinent.

Singh Bijender and Singh Joginder, 2014 in their study have stated that in India, unprecedented population growth coupled with unplanned developmental activities has resulted in urbanization, with the loss of agricultural land. According to Sunil Sankhala and B. K. Singh (2014), in India, with an unparalleled population growth and migration, an increased urban population and urbanization is involuntary. More and more towns and cities are affluent with the spatial changes in the land use along the highways and in the instantaneous vicinity of the city. C.M. Lakshamana (2013) has assessed the impact of population pressure on India's environment, with particular reference to the degradation of natural endowments like land and water resources and the resultant environmental pollution in the six regions of India. Anjana Vyas et al, (2014) has analysed land use land cover change in the in the Ahmedabad City in the study related to Urban Heat Island in the same area. They used spatial and temporal analysis of the city and depicted the changes in LULC, vegetation and temperature and explained these changes by classifying the city into different zones.

In major urban centers of India, as the processes of population increase and spatial transformation are moving from core areas to the periphery, it is essential to know the trend and magnitude of such changes. It is also important to explore at what degree population is affecting the spatial change and the environment.

Study Area

The top seven city-region in terms of population size are taken into consideration in this study (figure 1). These city-regions are Delhi, Mumbai, Bangalore, Hyderabad, Ahmedabad, Chennai and Kolkata. The

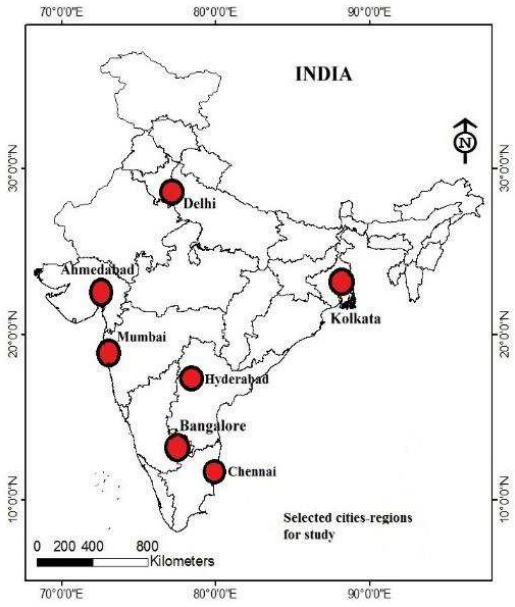

Figure 1 Selected city-regions for the study

administrative boundaries[6] of these city-regions are constructed as per the availability of spatial, demographic and environmental data.

Data sources and methodology

Variables used in the study and sources:

The variables and with sources are as mentioned below (table 1).

Table 1 Variables used in the study and sources

Sr. no.	Name of the variables/parameters	Data source
	Population Variables	
1	Total population	Registrar General of India, District Census Handbook, Census of India 1991, 2001 and 2011
2	Total no. of households	
3	Population growth rate	
4	Percent share of slum population	
5	Population density	
6	Inter-censal migration	Registrar General of India, Migration Tables, Census of India 1991, 2001. Projected for 2011[7]
	LULC parameters	
7	Built-up land	Calculated from supervised classification of LANDSAT images derived from United States Geological Survey (USGS)
8	Vegetation/forest cover	
9	Agricultural land	
10	Fallow land	
11	Water body	
	Environmental parameters	
	Weather condition parameters	
12	Maximum temperature	Registrar General of India, Town Directory, Census of India 1991,2001 and 2011
13	Minimum temperature	
14	Average annual rainfall	
	Air quality parameters	
15	Sulphur dioxide (SO2)	Central Pollution Control Board
16	Nitrogen dioxide (NO2)	
17	Particulate Matter (PM10)	
	Water Quality parameters	
18	Dissolved Oxygen (D.O.)	Central Pollution Control Board
19	power of Hydrogen (pH)	
20	Conductivity	
21	Biological Oxygen Demand (B.O.D)	

Land use- Land cover change analysis:

[6] The actual administrative (municipal) boundaries of cities may vary from the boundaries of the city-regions considered for the study

[7] Projection is done using National Growth Rate Method because of non-availability of data

To study the LULC analysis satellite data of LANDSAT-5 TM derived from United States Geological Survey (http://glovis.usgs.gov) for three time periods have been used. The study has used the software like Erdas imagine 9.2 and Arc GIS 10.2 for the supervised classification of LANDSAT images and final layout of the classified maps. The methodology involved in land use and land cover change detection is represented below with the flow diagram (figure 2).

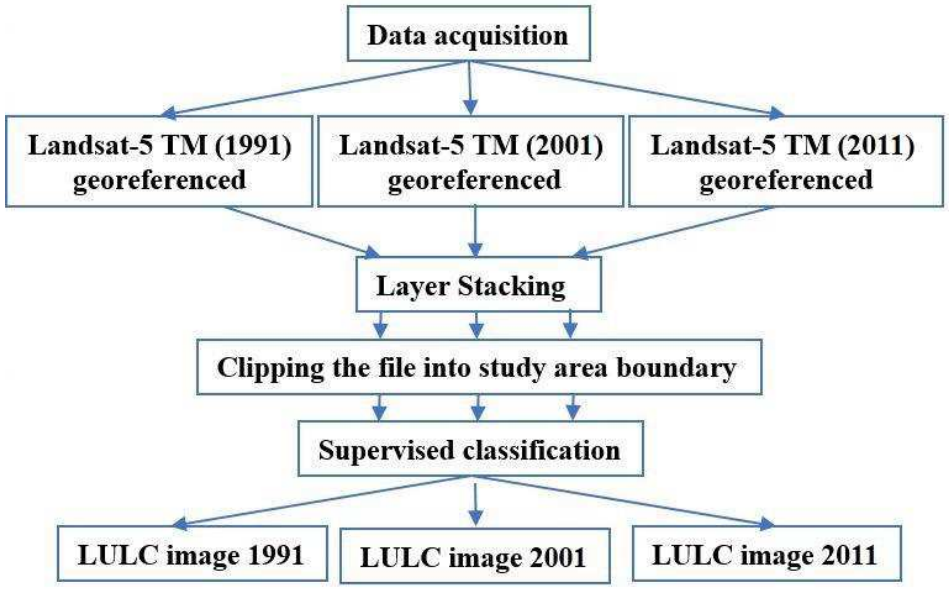

Figure 2 Process involved for the LULC change estimation.

The LULC is categorized into five classes as follow:

LULC class	Inclusion Description
Built-up land	Mainly including residences, commercial centers, Industrial zones, railways, highways, expressways and others
Agricultural land	Arable agricultural land, sparse forest and others
Vegetation/forest cover	Mainly including natural forest land, shrub lands, forest nursery, mangroves and others
Water body	Mainly including rivers, ponds, lakes, reservoirs, permanent and seasonal wetlands and others
Fallow land	Land without vegetation cover, exposed soil and landfill sites and others

To assess the changes in environmental conditions of city-regions, the levels of selected parameters have been compared to the standard levels set by the CPCB (Central Pollution Control Board).

To examine the relationship exists among selected spatial and population variables, correlation coefficients have been calculated and a correlation matrix has been constructed for all the city-region together.

Results:

Population dynamics in the selected city-regions

Population parameters of the city-regions have shown different patterns from 1991 to 2011 (Table 2).

Trend of total population and change

The total population for all cities have increased over the period of time, except in Kolkata where the total population has declined in the last decade. Among the city-regions, Mumbai and Delhi have crossed the 10 million mark in 2001. Bangalore has shown the highest percent change of population increase over last two decades i.e. 99 percent. Delhi and Ahmedabad have also experienced high percent change of 78 percent and 69 percent respectively. Kolkata has presented lowest percent change at the same time. Whereas the percent change in population for Mumbai, Hyderabad and Chennai range between 20 to 25 percent.

Trend of total no. of households and change

Total no. of households has shown an increasing trend for all the city-regions from 1991 to 2011. The no. of households have recorded in Delhi, Mumbai and Bangalore are very high with respect to the other four city-regions. From the case of Kolkata, it becomes clear that even the total population of the city is declining but the no. of households are increasing. Percent change in total no. of households has given the results that correspond to the percent change in the total population for all the city-regions. Furthermore, it is also found that the total no. of households are increasing with higher rate than the increase in population in all city-regions.

Trend of population growth rate

The population growth rate has declined for all the city-regions except for Bangalore and Ahmedabad. Furthermore, these declines are significant for Delhi, Mumbai and Hyderabad where the difference in growth rate is high with respect to the other city-regions in last two decades. Kolkata has shown a negative growth from 2001 to 2011.

Trend of percent share of slum population to total population:

The share of slum population to total population is varied across the city-regions and over time. Overall the highest slum proportion is found in Mumbai (40 percent) whereas Ahmedabad has accounted lowest slum proportion (4 percent) in 2011. In the case of Mumbai and Kolkata share of slum population has witnessed a significant increase from 1991 to 2001, but it has started declining in the last decade. Ahmedabad and Delhi presented declining trend in last two decades, whereas the reverse is true with Hyderabad, Chennai and Bangalore.

Table 2 selected population parameters at different time for the city-regions.

City	Total Population				Total no. of households				Population Growth Rate		Percentage of Slum population to total		
	1991	2001	2011	Percent change '91-'11	1991	2001	2011	Percent change '91-'11	1991-01	2001-11	1991	2001	2011
Ahmedabad	3250464	4173395	5490598	68.9	628892	869457	1168212	85.8	28.4	31.6	13	11	4
Delhi	9420644	13850507	16787941	78.2	1877046	2733383	3435999	83.1	47.0	21.2	19	13	10
Kolkata	4399819	4572876	4496694	2.2	848085	929586	1024928	20.9	3.9	-1.7	13	32	31
Bangalore	4839162	6537124	9621551	98.8	959654	1460697	2393845	149.4	35.1	47.2	2	7	7
Mumbai	9925891	11978450	12442373	25.4	2027243	2515589	2779943	37.1	20.7	3.9	24	54	41
Hyderabad	3145939	3829753	3943323	25.3	533748	695906	849051	59.1	21.7	3.0	13	17	30
Chennai	3841396	4343645	4646732	21.0	798279	962213	1154982	44.7	13.1	7.0	13	19	27

Population Density			Inter-censal migration			City
1991	2001	2011	1981-1991	1991-2001	2001-2011	
12747	16366	21532	373121	4758108	390152	**Ahmedabad**
6352	9340	11320	1681573	2353936	489319	**Delhi**
23783	24718	24306	160070	203836	-709270	**Kolkata**
2210	2985	4393	651707	929701	2064630	**Bangalore**
16461	19865	20634	1164405	1628430	-1452026	**Mumbai**
14497	17649	18172	204186	248041	-307083	**Hyderabad**
22077	24963	26705	328450	251997	-374944	**Chennai**

source: Census of India: 1991, 2001, 2011

Population density and net migration:

Population density and net migration have shown a reverse relationship for the city-regions. The city-regions showing high density of population have experienced a declining trend of net in-migration over time. Bangalore, accounted for the lowest population density among all the city-regions, has received highest no. of in-migrants between the periods of 2001 to 2011.

Estimation of Land use – Land cover (LULC) change in the city-regions

LULC analysis of Ahmedabad

The analysis indicates significant dynamism of LULC over time (table 3 and figure 3). These spatial changes are associated with each other. The most significant change is observed under built-up area that is accounting for 28 percent of the total area of Ahmedabad City Taluka in 1991 and increased around 76 percent of the total area in 2011. This rapid change is a result of the high level of urbanization. Rapidly increasing population and high inflow of migrants has resulted into the transformation of forested land into residential land. Also the new industries and factories are continuing to establish in the periphery areas of the city and have contributed in the process of land transformation.

The LULC category experiencing significant negative change is agricultural land. The area under agricultural land is accounting for 50 percent of the total area in 1991 and dropped around 7 percent of the total area in 2010. The possible contributing factors behind this change are penetration of the developmental activities from the urban areas to the rural and sub-urban area, where agriculture is the prime economic activity. Change in the area under vegetation/forest cover is associated with change in agricultural land and built-up area. The expansion of built-up land and agricultural land have occurred over the forested land that has been declined 32 percent within the considered time period. In rural areas the forested land is converted into the agricultural land and later transformed into the built-up area as a consequence of developmental processes. Whereas in the core areas of city, forested areas are directly converted in built-up area.

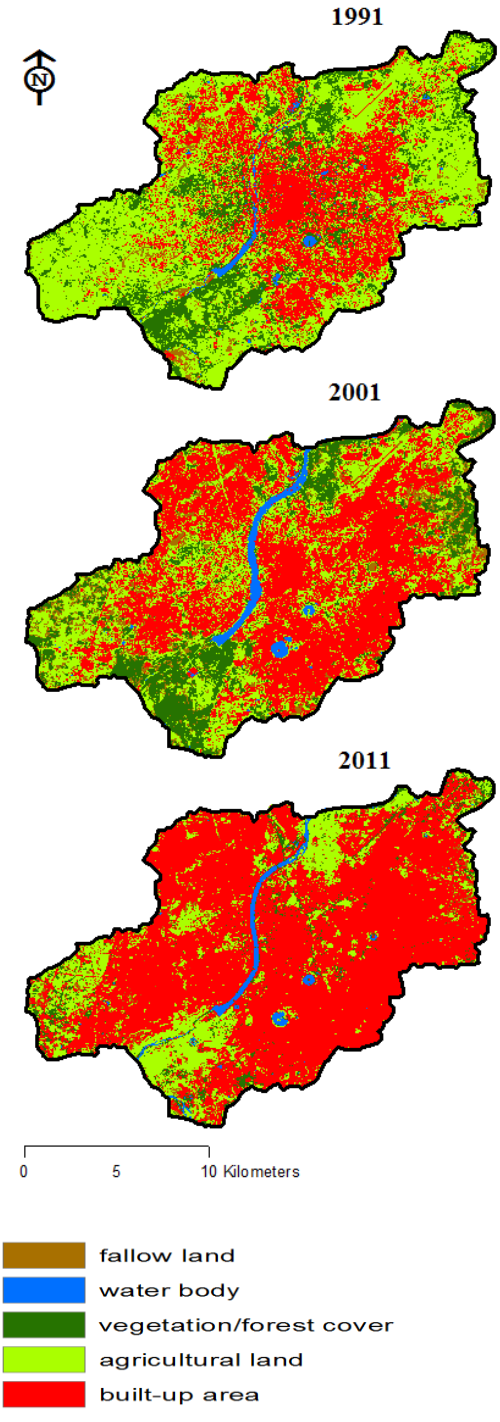

Figure 3 Satellite image analysis of Ahmedabad.

Table 3 Estimated LULC at different times and change in Ahmedabad.

LULC categories	1991		2001		2011		Change:1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	71	28	128	50	194	76	123	173
vegetation/forest cover	44	17	37	15	30	12	-14	-32
agricultural land	127	50	76	30	18	7	-109	-86
fallow land	10	4	8	3	5	2	-5	-50
water body	3	1	6	2	8	3	5	167
total	255	100	255	100	255	100		

LULC analysis of Delhi

In Delhi, the area under built-up land has increased from 442 km^2 in 1991 to 1046 km^2 in 2011. This expansion of 604 km^2 in the last 20 years has come from the reduction in the forest cover, agricultural land and fallow land (figure 4 and table 4). Till 1991, built-up land has been found on the eastern side of the city. The main reason behind this concentration may be the availability of water from the Yamuna River at the eastern side. Delhi, being the capital of India, have many pull factors to attract the immigrants from all over India. Employment opportunities, a good standard of living, infrastructure facilities, favorable geographical connectivity, educational environment, etc. have given rise to a huge inflow of migrants. To sustain the immigrant, built-up land has expanded with remarkable rate at the cost of reduction of other land uses.

Over time, the built-up land has been extended to western and southern parts of the city. The area under fallow land category has been declining from 306 km^2 to almost zero within the 20 year time span. The area under fallow land has mainly converted into built-up land and also, to some extent, into agriculture land. The vegetation/forest cover has also showed reduction of around 94 km^2 i.e. from 173 km^2 in 1991 to 79 km^2 in 2011. The forested land cover has concentrated in the central part of the city. Later it has been reduced in size and accounts only 5 percent of the total area of the city.

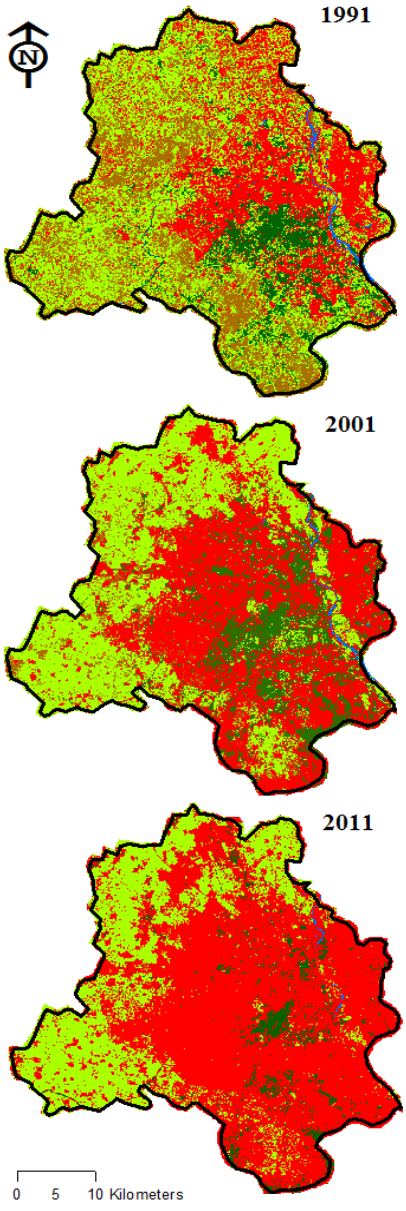

Figure 4 Satellite image analysis of Delhi.

Table 4 Estimated LULC at different times and change in Delhi.

LULC categories	1991		2001		2011		Change:1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	442	28	682	43	1046	66	604	137
vegetation/forest cover	173	11	225	14	79	5	-94	-54
agricultural land	658	41	591	37	464	29	-194	-29
fallow land	306	19	86	5	0	0	-306	-100
water body	13	1	8	1	3	0	-10	-77
total	1592	100	1592	100	1592	100		

LULC analysis of Kolkata

The LULC analysis of Kolkata city suggests that the built-up land has expanded mainly towards the southern part of the city (figure 5 and table 5). The built-up land has increased from 105 km^2 to 138 km^2 in last two decades. It has started expansion from the bank of the Hoogli River at the northwestern side of the city and extended gradually towards the southeastern side of the city. The change in built-up land has mainly come from the reduction of fallow land over the period of time. The forest cover has declined slightly from 11 km^2 to 7 km^2 from 1991 to 2011 respectively.

The most drastic negative change has been observed in the category of fallow land. The percent share of area under fallow land to total area has declined from 26 percent to almost zero percent from 1991 to 2011 respectively. In the case of Kolkata, it becomes clear that the fallow land is first reduced because of agricultural expansion and later the agricultural land reduced for the expansion of built-up land. The agricultural land has shown a significant increase from 1991 to 2001 i.e. 25 km^2 to 66 km^2 respectively. It is clear from the LULC analysis that the increase in agriculture has come from the reduction of fallow land. From 2001 to 2011 the area under agriculture has started declining. This decline has mainly contributed by the increase of built-up land from 2001 to 2011.

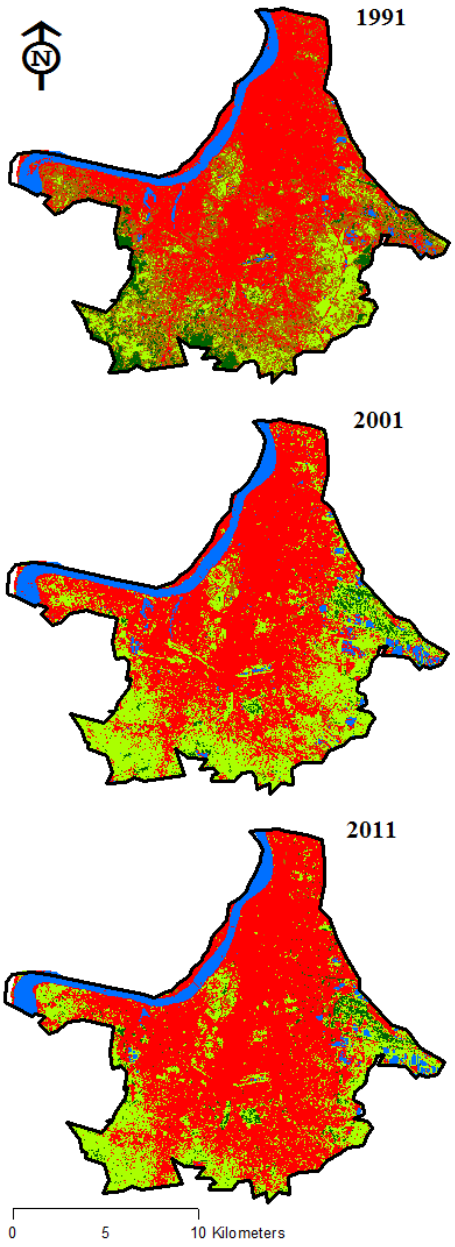

Figure 5 Satellite image analysis of Kolkata

Table 5 Estimated LULC at different times and change in Kolkata.

LULC categories	1991		2001		2011		Change:1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	105	50	118	56	138	66	33	31
vegetation/forest cover	11	5	5	2	7	3	-4	-36
agricultural land	25	12	66	32	49	23	24	96
fallow land	54	26	3	1	1	0	-53	-98
water body	14	7	17	8	14	7	0	0
total	209	100	209	100	209	100		

LULC analysis of Bangalore

The LULC analysis of Bangalore at different time has suggested very significant spatial changes (figure 6 and table 6). The built-up land has shown a very high rate of change, i.e. 208 percent in last two decades. The area under built-up land has increased from 250 km^2 to 769 km^2 from 1991 to 2011 respectively. The built-up land was concentrated in a small patch at the core and gradually extended towards the peripheral regions following the major transport line. These changes have mainly come from the deforestation process and conversion of the fallow land to the built-up land.

The agricultural land has shown a small increase over the period of time. The area under agricultural land has increased by 29 km^2 from 1991 to 2011. This increase has mainly come from the conversion of the forest cover and fallow land into the agricultural land use in the periphery areas.

The most significant contributor in the dynamism of LULC of Bangalore city is the fallow land. There has been a highest negative change of 70 percent observed in the area of fallow land in last two decades that may be considered as the responsible factor for the increase in the built-up land as well as in the agricultural land. The water body has remained unchanged over the time.

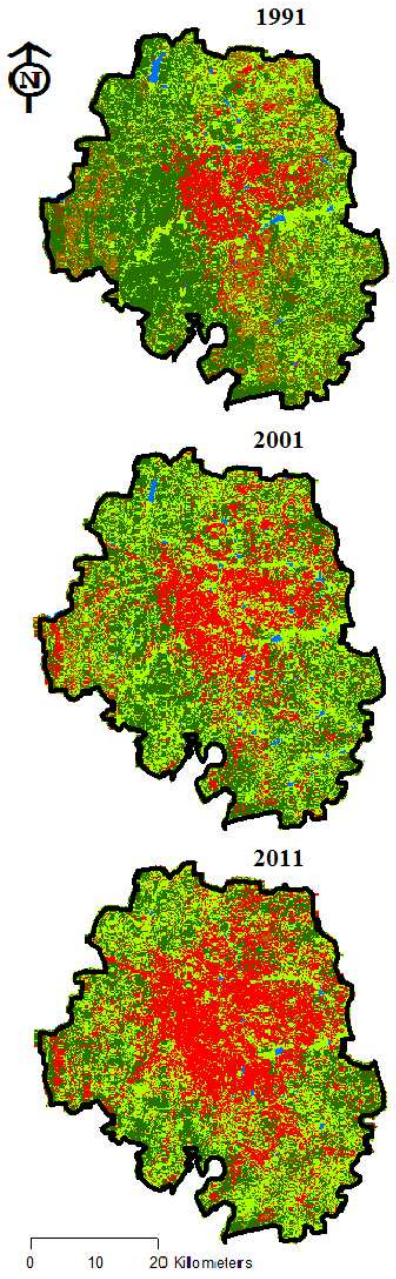

Figure 6 Satellite image analysis of Bangalore

Table 6 Estimated LULC at different times and change in Bangalore.

LULC categories	1991		2001		2011		Change 1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	250	11	527	24	769	35	519	208
vegetation/forest cover	1099	50	839	38	648	30	-451	-41
agricultural land	693	32	718	33	722	33	29	4
fallow land	121	6	80	4	36	2	-85	-70
water body	21	1	20	1	9	0	-12	-57
total	2184	100	2184	100	2184	100		

LULC analysis of Mumbai

The urban agglomeration of Mumbai is one of the largest and fastest-growing urban regions in the world, and this growth has unprecedented effects on urban sprawl and population dynamics (Chakrabarti 2001, United Nations 2012).

LULC, being the most important aspect of such urban sprawl, has shown significant spatial changes over the period of time. The built-up land has shown a significant positive change and other LULC categories have shown a negative change over the last two decades (figure 7 and table 7).

The most dynamic change has been observed in built-up land, i.e. increase from 142 km^2 to 316 km^2 from 1991 to 2011 respectively. This change has majorly come from agricultural land. The spread of built-up land has not shown any particular point from where it has started. Mumbai, the economic growth pole of India, has a large population base and very high migration flow and thus the built-up land has increased with very high rate to sustain the population. In 2011, as represented in the map, the built-up land has occupied almost 70 percent

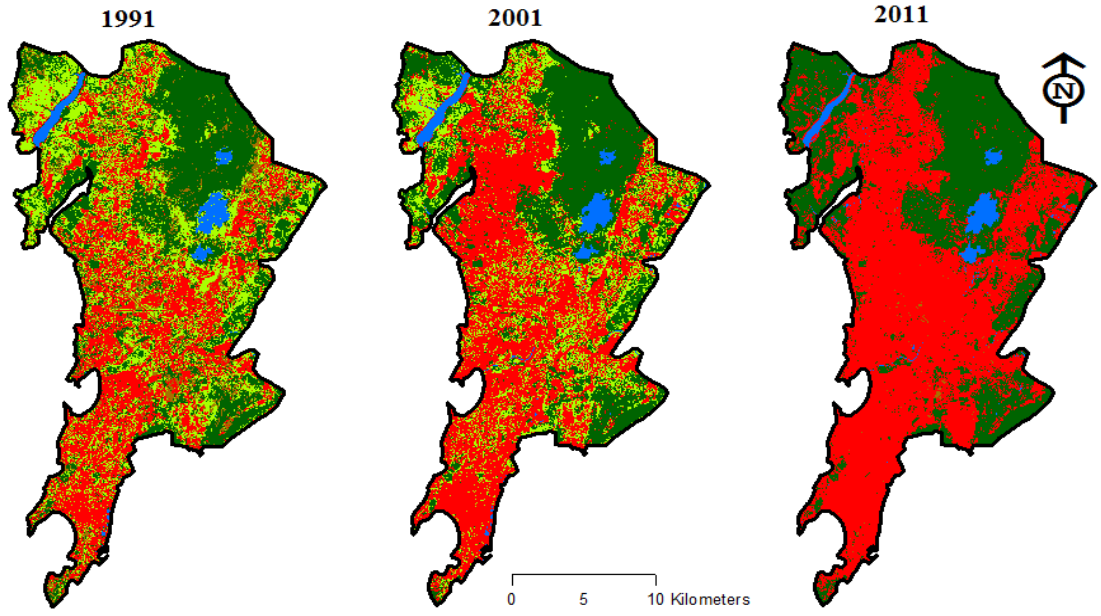

Figure 7 Satellite image analysis of Mumbai

Table 7 Estimated LULC at different times and change in Mumbai.

LULC categories	1991		2001		2011		Change:1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	142	31	251	55	316	69	174	123
vegetation/forest cover	146	32	140	30	131	28	-15	-10
agricultural land	124	27	46	10	0	0	-124	-100
fallow land	37	8	11	2	2	0	-35	-95
water body	11	2	12	3	11	2	0	0
total	460	100	460	100	460	100		

of the total area of the city. From the LULC analysis, it becomes clear that the expansion of the built-up land has reached to the threshold because there is no suitable land for the future extension.

The agricultural land has shown a remarkable negative change of 124 km^2 within the last two decades. The area under the agricultural category has declined from 124 km. sq. to zero. The main reason for these changes is the rapid expansion of the built-up land over the same period of time.

LULC analysis of Hyderabad

The LULC analysis of Hyderabad suggests substantial spatial changes in all the LULC categories (figure 8 and table 8). The built-up land has shown a significant positive change, whereas all the other LULC categories have declined from 1991 to 2011.

The built-up land has increased from 44 km^2 in 1991 to 106 km^2 in 2011. The built-up land was concentrated on the eastern side of the city on the banks of Musi River in 1991. Later the expansion took place with the reduction in agricultural land, forest cover and fallow land at the southern and western sides of the city. At 2011, the share of area under built-up land to total area has reached to 58 percent.

The vegetation/forest cover has shown a small decrease of four km^2 from 1991 to 2001. But the rate of change increased from 2001 to 2011 and the forest cover declined

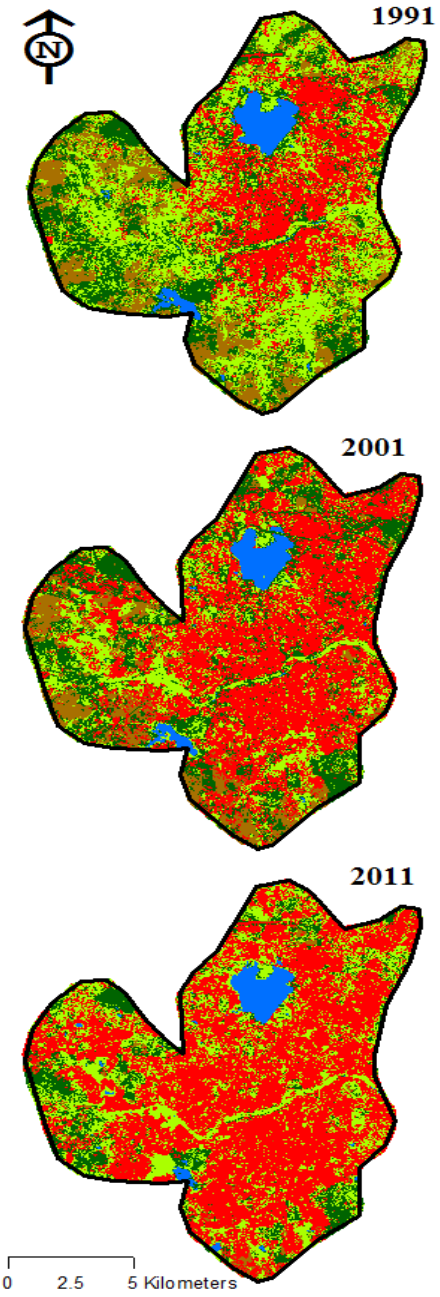

Figure 8 Satellite image analysis of Hyderabad

to half. This is related to the expansion of built-up land. From 1991 to 2001 the built-up land has expanded mainly over the agricultural and when the agricultural land has declined significantly, the expansion of built-up land started over the fallow land, i.e. from 2001 to 2011.

The agricultural land has decreased from 1991 to 2001and then increased in the next decade. The increase in the latter decade has mainly come from the conversion of fallow land to agricultural land.

The most significant negative change has been observed in the fallow land. The fallow land has reduced to the negative rate of change of 84 percent in last two decades. The area has declined from 25 km^2 to 4 km^2 from 1991 to 2011 respectively. The water body of the city has not shown any noticeable change.

Table 8 Estimated LULC at different times and change in Hyderabad.

LULC categories	1991		2001		2011		Change 1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	44	24	83	46	106	58	62	141
vegetation/forest cover	44	24	40	22	20	11	-24	-55
agricultural land	63	35	36	20	47	26	-16	-25
fallow land	25	14	18	10	4	2	-21	-84
water body	6	3	5	3	5	3	-1	-17
total	182	100	182	100	182	100		

LULC analysis of Chennai

As illustrated in the figure 9 and table 9, Chennai has experienced remarkable changes in the LULC over the last two decades. The built-up area has expanded from 87 km^2 in 1991 to 131

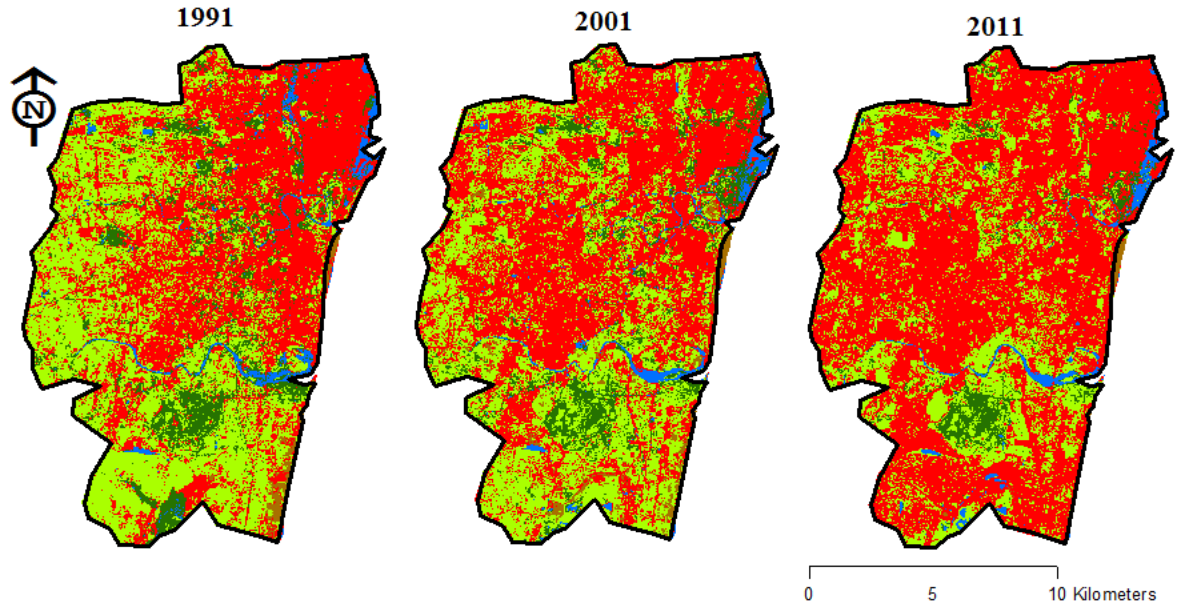

Figure 9 Satellite image analysis of Chennai

km^2 in 2011. This change of around 44 km^2, has come from the available forest, agricultural land and fallow land. From the LULC analysis it becomes clear that the built-up land was concentrated at the north-eastern corner of the city. Later, the built-up land has extended towards the southern and western parts of the city. In 2011 the built-up land has occupied almost 66 percent area of total area of the city.

The other LULC category important to discuss is the vegetation/forest cover. Although sharing only 10 percent of the total area of the city in 1991, the forest cover has experienced highest rate of negative change. The area under vegetation/forest cover has reduced from 20 km^2 to 9 km^2 from 1991 to 2011 respectively. This decline is mainly a consequence of the increase in the built-up land to fulfil the demand of infrastructural facilities for the increasing population and to provide the space to the industries, mainly the IT-industries. As illustrated in the LULC map, the forested land, although very less, was found in patches all-around the city and over time these patches have disappeared at the north part of the city and only a small patch has found in the southern part of the city.

Table 9 Estimated LULC at different times and change in Chennai.

LULC categories	1991		2001		2011		Change:1991-2011	
	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Area in Km^2	Percent share to total area	Absolute change (in Km^2)	Percent change (in %)
built-up land	87	44	98	50	131	66	44	51
vegetation/forest cover	20	10	15	8	9	5	-11	-55
agricultural land	81	41	72	37	52	26	-29	-36
fallow land	3	2	7	4	1	1	-2	-67
water body	6	3	5	3	4	2	-2	-33
total	197	100	197	100	197	100		

The LULC category of agricultural land has also experienced noticeable changes in last two decades. The share of agricultural land and to the total has declined from 41 percent to 26 percent from 1991 to 2011 respectively. The area under agricultural land has been reduced mainly because of the expansion of the built-up land. As shown in the maps, there was enough agricultural land in the western and southern parts of the city in 1991. Gradually, as the built-up land has started expanding to the western and southern sides, the area under agricultural land has declined.

Although the area under fallow land and water body is less in comparison to the other LULC categories it is essential to discuss the change of the same. Both the categories have experienced a negative change over the period of time. The Adyar River, at the south of the city, has significantly reduced its area in the last two decades.

Environmental changes in the city-regions

To study the environmental changes in the city-regions few selected environmental parameters have been analyzed. First, the trends in maximum and minimum temperature and average annual rainfall of all the city-regions have studied for last two decades. Second, air quality data have analyzed for all the city-regions for last decade i.e. 2001-2011. Third, to study the water quality status four rivers, namely Yamuna, Hoogli, Sabarmati and Musi have taken into analysis and selected water quality parameters have been studied over time.

Variability in temperature and rainfall

To study the changes in temperature the maximum and minimum temperature for the years 1991, 2001 and 2011 have taken into consideration for all the selected city-regions (figure 10, table 10). The maximum temperature has increased from 1991 to 2011 in all the city-regions. On the other side, the minimum temperature has shown decline for all the city-regions except in Chennai and Delhi. Ahmedabad has recorded highest maximum temperature, i.e. more than 40 centigrade in 1991, 2001 and 2011.

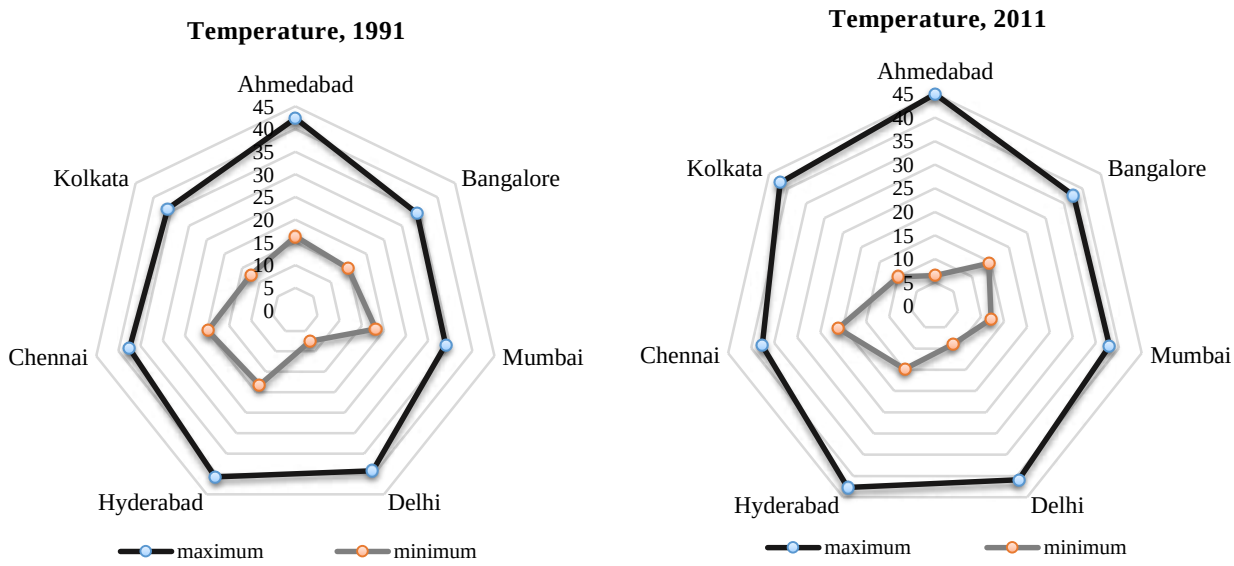

Figure 10 Maximum and minimum temperature records of city-region at 1991 and 2011.

In 1991, the difference between maximum and minimum temperature is found highest in Delhi when compared with the other city-regions. Thus, at that time Delhi was experiencing extreme weather conditions.

In 2011, except Chennai, the difference between maximum and minimum temperature has increased in all the city-regions. Ahmedabad has recorded the highest difference between maximum and minimum temperature. It indicates that all the city-regions have experienced extreme weather conditions in 2011. This kind of extreme weather conditions has adverse implications on the agricultural productivity of the area, the health condition of people and other living organisms.

Table 10 Maximum and minimum temperature records for the city-regions in 1991, 2001 and 2011.

City	Temperature in Centigrade (1991)		Temperature in Centigrade (2001)		Temperature in Centigrade (2011)	
	maximum	minimum	maximum	minimum	maximum	minimum
Ahmedabad	42.35	16.3	43.45	18.4	45	6.5
Bangalore	34.34	14.87	34.3	15.3	37.61	14.6
Mumbai	33.98	18.18	31.2	23.7	37.95	12.2
Delhi	39.2	7.5	31	19	40.9	8.9
Hyderabad	40.7	18.2	40.7	19.3	42.7	14.8
Chennai	37.5	19.8	37.5	19.8	37.6	21.1
Kolkata	35.99	12.6	38	12	42	10

Source: Census of India 1991, 2001 and 2011, Town Directory of respective city-regions.

The analysis of average annual rainfall for the years 1991, 2001 and 2011 has suggested that the amount of average annual rainfall has declined in all the city-regions except in Kolkata and Ahmedabad (table 11). The rate of decline from 1991 to 2011 is highest in Chennai. It has also observed that for Chennai, Hyderabad, Delhi and Bangalore the rate of decline in the amount of average annual rainfall is high in the period of 2001 to 2011 compared to the period of 1991 to 2001.

Table 11 Average annual rainfall in the city-regions in 1991, 2001 and 2011.

City	Average annual Rainfall (in mm.)			Percent change '91-'11
	1991	2001	2011	
Ahmedabad	559	781.95	834	49.2
Bangalore	824.6	836	784	-4.9
Mumbai	2367.7	2146.6	2182.7	-7.8
Delhi	705	745	617	-12.5
Hyderabad	834.5	839.6	757	-9.3
Chennai	1413.2	1413.2	1216.3	-13.9
Kolkata	1351.13	1650	1583	17.2

Source: Census of India 1991, 2001 and 2011, Town Directory of respective city-regions.

Air quality assessment

For the study of air quality in the city-regions data for Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2) and Particulate matter (PM_{10}) have studied for the years 2001 and 2011 and also compared with the National Ambient Air Quality standards (NAAQs).

Table 12 illustrates the level of Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2) and Particulate matter (PM_{10}) for the city-regions in 2001 and 2011 respectively. It has been observed that the levels of SO_2 are below the NAAQ standards for all the city-regions and the level are low. Except in Ahmedabad, the levels of SO_2 has declined from 2001 to 2011. This low level of

SO_2 concentration in all the studied city-regions is may be because of the effective environmental monitoring system in the city-regions.

In 2001, only Delhi and Bangalore have recorded lower pollution level of NO_2. Four city-regions, namely Ahmedabad, Delhi, Mumbai and Hyderabad have recorded mean annual concentration NO_2 within the Medium category of air pollution level. Kolkata has recorded critical level of concentration of NO_2. In 2011, only Chennai has recorded low level of NO_2. Ahmedabad, Bangalore, Mumbai and Hyderabad have recorded medium levels of NO_2. Delhi has moved to high level category. Kolkata, although the level has declined, still remains in the critical level category. From 2001 to 2011, the level of mean concentration of NO_2 has increased in Delhi, Bangalore and Mumbai.

In 2001, except Bangalore, all the city-regions have crossed the NAAQ standard level for PM_{10} mean annual concentration. Moderate level of PM_{10} has found only in Bangalore. Mumbai, Hyderabad and Chennai have recorded high level of PM_{10} concentration. The critical level of PM_{10} has recorded in Ahmedabad, Delhi and Kolkata.

In 2011, Hyderabad and Chennai remained in the high level category, whereas all the other city-regions have recorded critical levels of PM_{10} concentration. From 2001 to 2011, the level of PM_{10} has increased for Delhi. Bangalore, Mumbai and Hyderabad.

Table 12 Annual mean concentrations of SO2, NO2 and PM10 in the city-regions in 2001 and 2011 and NAAQS standards.

City	Annual Mean Concentration Range (µg/m3)					
	SO2		NO2		PM10	
	2001	2011	2001	2011	2001	2011
Ahmedabad	10	18	38	25	200	100
Delhi	20	10	40	52	150	286
Kolkata	20	15	75	70	110	100
Bangalore	20	18	20	30	50	103
Mumbai	15	8	26	40	75	136
Hyderabad	11	10	30	30	69	79
Chennai	18	15	19	17	80	70

Source: CPCB, 2012

Pollutant	NAAQs (in µg/m3)
SO2	50
NO2	40
PM10	60

Source: CPCB, 2012

Water quality assessment in the rivers of selected city-regions

This analysis is restricted to the four rivers i.e. Yamuna River in Delhi, Sabarmati River in Ahmedabad, Hoogli River in Kolkata and Musi River in Hyderabad for the time period of 2007 to 2012. To assess the quality of water in four selected rivers, water quality parameters have been selected i.e. Dissolved oxygen (D.O.), pH (power of Hydrogen), Conductivity, Biological Oxygen Demand (BOD) and compared with the standards set by the Central Pollution Control Board (CPCB) of India.

Table 13 represents the levels of D.O., pH, conductivity and B.O.D. for the selected rivers.

In 2007, all four rivers have shown the D.O. level above the CPCB standard (> 4 mg/l). This level has declined for Yamuna, Hoogli and Musi Rivers in 2012. Yamuna River has reduced D.O. level below the standard set by CPCB. All four rivers have shown a pH level within the range of 6.5 to 7.5. The levels of pH have increased in the case of Yamuna and Sabarmati Rivers.

Although, the levels of conductivity have increased for all four rivers from 2007 to 2012, the levels have not crossed the standard set by CPCB. In 2007, except Sabarmati, the rivers have shown B.O.D. levels below the standard (< 3 mg/l). In 2012, these levels have increased for Yamuna, Hoogli and Musi Rivers and declined significantly for Sabarmati River.

Table 13 Levels of water quality parameter for selected rivers and CPCB standards.

Water quality parameters	CPCB standard	Yamuna River		Sabarmati River		Hoogli River		Musi River	
		2007	2012	2007	2012	2007	2012	2007	2012
D.O. (mg/l)	> 4	7.4	2	5.6	8	6.7	6	7	5.3
pH	6.5-8.5	7.2	7.9	7.4	8.2	7.8	7.8	8.2	8
Conductivity (µmhos/cm)	< 2250	453	969	536	601	292	306	340	418
B.O.D. (mg/l)	< 3	1.9	22	29	5	1.4	2	1.5	11.3

Source: Central Pollution Control Board, India, 2007, 2012

Linkages between selected spatial, population and environmental parameters

Relationship among the selected variables of population, LULC and environment

To study the relationship among selected variables of population, LULC and environment Pearson Correlation Coefficient Matrix has been constructed for all the city-regions together (tables 14*).*

For the city-regions time has shown a significant positive relationship with the built-up land, total population, maximum temperature, and temperature range whereas it is negatively associated with forest cover. The built-up land has shown a strong significant negative relation with forest cover. The increase in built-up land is positively related to the increase in total population, maximum temperature and temperature range.

Increase in forest cover is positively associated with an increase in total population. This could be mainly due to reflection of cultivated land, dense grassland etc. that reflect in a similar way to that of the true forest cover. With population increase expansion of agricultural land is visible. Some areas of these farm lands may be classified as the forested area in LULC classification. Furthermore, in some of the city-regions afforestation might have contributed. It has also been observed that with the decrease in forest cover there is an increase in maximum temperature and temperature range (difference between maximum and minimum temperature).

The increase in total population is positively correlated with built-up land, forest cover, maximum temperature and temperature range.

Table 14 correlation matrix for selected parameters of all the city-regions.

	time	built-up land	forest cover	total population	max temp	temp range
time	1	-	-	-	-	-
built-up land	0.664**	1	-	-	-	-
forest cover	-.195*	-.654**	1	-	-	-
total population	.210*	.085	.173*	1	-	-
max temp	.236**	.311**	-.415**	.587**	1	-
temp range	.282**	.284**	-.415**	.314**	.808**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Relationship between built-up land and migration in the city-region

It has been observed that as the percent share of built-up land of a city-region increases, there is a decrease in net migration over time (figure 11). For the year 2011, highest no. of net migrants have observed in Bangalore where percent share of built-up land is low as compared to the other city-regions.

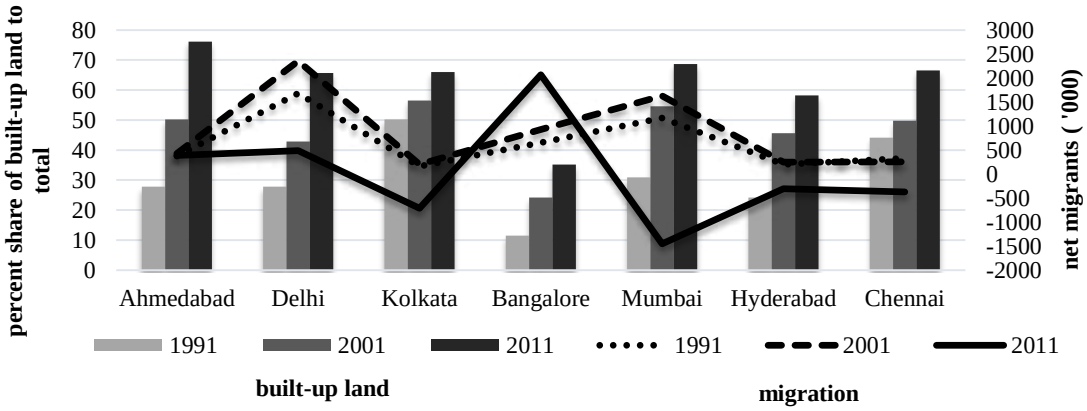

Figure 11 Association between built-up land and net migration.

On the other hand, lowest no. of net migrants found in Mumbai, where the built-up land has reached around 70 percent share to the total area of the city-region. For the rest of the city-regions, as the share of built-up land is increasing the no. of net migrants are decreasing over time.

Summary and Conclusion:

This study, while focusing dynamics and association of population, LULC and environment came to following conclusions:

It is found that population variables have experienced substantial dynamism in the city-regions. The total population has shown increasing trends over time, except in Kolkata. The growth rate of population from 2001 to 2011 is observed lower than it was from 1991 to 2001, except for Ahmedabad and Bangalore. Percent change in total number of households exceeds the percent

change in total population over time. Percent share of slum population to the total population has depicted increasing trend in the southern city-regions i.e. Bangalore, Hyderabad and Chennai. The number of net migrants is declining in five out of seven city-regions. Significant net out migration is found in the city-regions where population density is very high i.e. Kolkata, Mumbai, Hyderabad and Chennai.

All the city-regions have experienced expansion of built-up land from 1991 to 2011. The maximum percent increase is observed in Bangalore, whereas Kolkata has marked least percent change in the built-up land. Though the vegetation/forest cover is declining in all the city-regions, the rate of decline in vegetation/forest cover is found higher in Delhi, Hyderabad and Chennai. A common pattern of expansion of built-up land found in most of the city-regions is that the built-up land initially start concentrating around the water sources and over time starts expansion following the major transport lines in the city-regions.

The maximum temperature recorded for city-regions has increased over time. Also the difference between maximum and minimum temperature has widened for all the city-regions, except for Chennai. Over the period of time the average annual rainfall has declined for Delhi, Bangalore, Mumbai, Hyderabad and Chennai. The concentration of Sulphur Dioxide (SO_2) has remained within the standard limits for all the city-regions, except Ahmedabad. Whereas the concentration of Nitrogen Dioxide (NO_2) has crossed the standards for Mumbai, Kolkata and Delhi. Particulate Matter (PM10) is the most significant air pollutant in the city-regions. PM10 is found in critical[8] amount for five city-regions and for the other two it comes under high[9] category set by CPCB.

There is a decrease in the amount of Dissolved Oxygen for Yamuna, Hoogli and Musi River. The pH values have increased for Yamuna and Sabarmati Rivers. There is an increase in the levels of conductivity for all the rivers.

There exists an association among the variables of population, LULC and environment for the city-regions with varying magnitude. The findings suggest that the population, LULC and environment of the city-regions are linked with each other. Most of these city-regions have reached to the threshold level of expansion for built-up land and have started vertical expansion within the limited space. There is a strong need for afforestation activities in these city-regions. The city-regions like Bangalore and Delhi, have some green space available. The rest of the city-regions should strictly focus on effective planning and policies to create open space and to help environment to maintain its harmony with the population.

[8] Concentration of PM10 above 90 µg/m3 (set by NAAQs)
[9] Concentration of PM10 between 61 µg/m3 - 90 µg/m3 (set by NAAQs)

References:

Alphan, H. (2003). Land use change and urbanization in Adana, Turkey. *Land Degradation and Development*, 14(6), 575–586.

Bilsborrow, R. E., & DeLargy, P. F. (1990). Land use, migration, and natural resource deterioration: The experience of Guatemala and the Sudan.*Population and Development Review, 16*, 125-147.

Chakrabarti, P. G. (2001). Urban crisis in India: new initiatives for sustainable cities. *Development in Practice*, 11, 260-272.

Dewaram AN. (2007). Population growth and environmental degradation in India. *Asia Pac J Environ Dev*. 14:41–63.

Duraiappah A. (1996). Poverty and environmental degradation: a literature review and analysis [Internet]. CREED Working Paper 8. [cited 1996 Oct 1].

Entwistle B., Stern P.C. (2005). *Population, Land Use, and Environment: Research Directions.* Washington DC: The National Academies Press.

Harte J. (2007). Human population as a dynamic factor in environmental degradation. *Popul Environ*. 28:223–236.

Holtz-Eakin D, Seldon TM. (1995). Stroking the fires? CO2 emissions and economic growth. J Public Econ. 57:85–101.

Indian Institute for Human Settlement. (2012). *Urban India 2011: Evidence*. New Delhi. Retrieved from http://iihs.co.in/wp-content/uploads/2013/12/IUC-Book.pdf

Jodha NS. (1990). Depletion of common property resources in India: micro level evidence. *Popul Dev Rev*. 15:261–284.

Kalipeni E. (1992). Population growth and environmental degradation in Malawi. Africa Insight. [Internet]. [cited 2007 Aug 17]. 22:273–282. Available from: http://www.ncbi.nlm.nih.gov/pubmed

Lakshmana, C. M. (2013). Population, development, and environment in India. *Chinese Journal of Population Resources and Environment*, *11*(4), 367-374.

Lopez, E., Bocco, G., Mendoza, M., & Duhau, E. (2001). Predicting land cover and land use change in the urban fringe a case in Morelia City, Mexico. *Landscape and Urban Planning*, 55(4), 271–285. 1), 81–97.

Malthus, T. R. (1798). *An Essay on the Principle of Population Or a View of Its Past and Present Effects on Human Happiness, an Inquiry Into Our Prospects Respecting the Future Removal Or Mitigation of the Evils which it Occasions by Rev. TR Malthus*. Reeves and Turner.

Pebley A.R. (1998). Demography and the Environment. *Population Association of America*, pp. 377-389.

Rahman, A. (2007). Application of remote sensing and GIS technique for urban environmental management and sustainable development of Delhi, India. *Applied remote sensing for urban planning, governance and sustainability*. Springer Berlin Heidelberg. 165-197.

Registrar General of India. (2014). Census of India 2011. Urban Agglomeration and cities. New Delhi. Retrieved from http://censusindia.gov.in/2011-prov results/paper2/data_files/India2/1.%20 Data%20Highlight.pdf

Sankhala, S., & Singh, B. (2014). Evaluation of urban sprawl and land use land cover change using remote sensing and GIS techniques: a case study of Jaipur City, India. *Journal of Emerging Technology and Advanced Engineering*, *4*(1). 66-72.

Shafix N, Bandhyopadhyay S, (1992). Economic growth and environmental quality: time series and cross country evidence. Washington (DC): World Bank.

Shaw RP. (1989). Rapid population growth and environmental degradation: ultimate versus proximate factors. *Environ Conserv*. 16:199–208.

Singh, B., & Singh, J. (2014). Land Use/Land Cover Change in Fast Growing Urban Centre in National Capital Region (Ncr): A Case Study. Retrieved from https://scholar.google.co.in/scholar?q=Singh+Bijender+and+Singh+Joginder+&btnG=&hl=en&as_sdt=0%2C5

United Nations. (1997). Glossary of environment statistics in methods series F.67. New York (NY): United Nations.

United Nations. (2004). United Nations Human Settlements Programme (UN-HABITAT). Water and

United Nations. (2014). World urbanization prospects. The 2011 Revision. New York.

Vyas A., Shasrti B., Joshi Y. (2014). Spatio-Temporal Analysis of UHI Using Geo-Spatial Techniques: A Case Study of Ahmedabad City. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-8. Retrieved from: http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XL 8/997/2014/isprsarchives-XL-8-997-2014.pdf