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AN ASSESSMENT OF URBAN ENVIRONMENTAL ISSUES USING REMOTE SENSING AND GIS TECHNIQUES: AN INTEGRATED APPROACH. A CASE STUDY: DELHI, INDIA

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Abstract

India's cities are growing rapidly, resulting in a wide variety of environmental stresses. In this paper an integrated approach using satellite data and GIS techniques in conjunction with socio-economic data is used to assess urban environmental issues in Delhi. Delhi's current population of 13.8 million is growing rapidly, and is projected to reach 22.4 million by 2021. The issues addressed in this paper include: changes in land use/land cover

(1992-2004); changes in surface temperatures for 2001 and 2005; solid waste generation, collection and its management; and industrial pollution (i.e. air, waste water and noise). The results show that Delhi is developing very rapidly mainly in the west, south-west and eastern sides. The study shows that a 122% increase in highly dense residential area was recorded during last decade in Delhi. There was a reduction (17%) in agricultural land because of urban expansion in the fringe areas. The pollution load has increased in terms of air, water, noise, and solid waste generation and disposal, etc. The thermal infrared (TIR) satellite data of Delhi clearly shows that there was a 1-2°C increase in surface temperature in just 4 years that is a subject matter of concern.

Key words: *Population, development and environment; Geo-spatial approach; Delhi; India.*

1. Introduction

There is an unequal urban growth, which is taking place all over the world, but the rate of urbanization is very fast in the developing countries, especially in Asia. In 1800 A.D., only 3% of the world's population lived in urban centres, but this figure reached to 14% in 1900 and in 2000, about 47% (2.8 billion) people were living in urban areas. India no longer lives in villages and 79 million people were living in urban areas in 1961, but it went up to 285 million in 2001. In India and China alone, there are more than 170 urban areas with populations of over 750,000 inhabitants (United Nations Population Division, 2001). Statistics show that India's urban population is the second largest in the world after China, and is higher than the total urban population of all countries put together barring China, USA and Russia. In 1991, there were 23 metropolitan cities in India, which increased to 35 in 2001 (Census of India, 1991 and 2001). The prominent ones are Delhi (13.78 million), Mumbai (13.22 million), and Chennai (6.42 million). There is a mass migration of people from rural areas to cities and also from smaller to larger cities and then to metropolitan centres like Delhi, Bombay, Kolkata, Bangalore, and Chennai. The major cause is the search for better employment opportunities in these urban centres in comparison to neighbouring States. As urban population increases, the demand of land for various urban activities also increases. The process of urbanization in India gained momentum with the start of the industrial revolution in the 1970s followed by globalization in the

1990s. Forests were cleared, grasslands ploughed or grazed, wetlands drained and croplands encroached upon due to expanding cities, yet never as fast as in the last decade (Rahman, 2007a).

This exponential population growth has wreaked havoc on human life in the city environment. The doubling and tripling of urban population in practically all major cities and towns and the consequent strain on existing systems has manifested in environmental chaos. Every major city of India faces the same proliferating problems of urban expansion, inadequate housing, poor transportation, poor sewerage, erratic electric supply, and insufficient water supplies. An increasing number of trucks, buses, cars, three-wheelers and motorcycles all spewing uncontrolled fumes, all competing for space on city streets already jammed with jaywalking pedestrians, rickshaws and cattle. The phenomena of rapid urban economic growth and urbanization are the main culprits, which besides bringing higher standards of living, has also brought problems related to the growth of dense and unplanned residential areas, environmental pollution, lack of services and amenities, solid waste generation, and growth of slums. Population growth and in-migration of poor people, industrial growth, inefficient and inadequate traffic corridors, and poor environmental infrastructure are the main factors that have deteriorated the overall quality of the city environment. The future of Delhi in the light of its past experiences, current trends, and development initiatives is one of the important issues which shows different social and physical factors affecting the housing and quality of life in Delhi (Mishra *et al.*, 2001). After independence, when Delhi witnessed a large influx of migrants, within a very short time, the population of Delhi increased more than two fold. To house such a large migrant population, the city has to expand. The rate of expansion is very fast, unplanned, uncontrolled and most of them are illegal (Rahman and Agarwal, 2007). Mushrooming of illegal construction has become a day-to-day phenomenon in the fringe areas of all big and medium size cities in India.

The level of air, water, and land pollution has increased because of poor environmental management. This has a direct impact on the quality of the urban environment, affecting labour productivity and overall socio-economic development. India's urban air quality ranks among the world's worst. Vehicles are the major source of this pollution, today with more than 5 million cars, trucks, buses, taxis, and rickshaws already on the roads in the country's capital New Delhi alone. Each urban centre has a number of environmental problems with varying scale and scopes which are influenced by factors such as size of population and its density, climatic conditions, water resources and the flora and fauna in and around the urban centre (Hardoy *et al.*, 1997). The state of the urban environment all over India is deteriorating so fast that the sustainability of the cities is threatened. In metro cities like Delhi, the land environment is under stress due to the pressure of rapid urbanization. As the cities expand and population increases, the resources, which are limited, are shared. The lack of services such as water supply, sanitation, drainage of storm water, treatment and disposal of waste water, management of solid and hazardous wastes, supply of safe food, water and housing are all unable to keep pace with urban growth.

In Delhi three organizations, the New Delhi Municipal Corporation (NDMC), the Municipal Corporation of Delhi (MCD), and the Delhi Development Authority (DDA), are looking at different aspects of Delhi's growth and development under the overall supervision of the Delhi Government. But often one organization blames the other for deteriorating conditions and the growing threat to the city's sustainability (Tiwari, 2003). There are also Mayors, Municipal Commissioners, and ward Counsellors/Representatives who are responsible for managing their respective areas. However, even these people are not doing what has to be done to protect the city environment. This is mainly due to the lack of up-to-date spatial data, skill to use the data properly, and commitment to save and protect the environment (Raman, 2007b). There is no tax for environmental management. In fact it would be good to make some sort of environmental tax that can be levied on the industrial units and transport owners. This collected revenue can go directly to local administrators and environmental managers. It is fair to say that only one part of Delhi has a good level of services – namely the NDMC enclave – and rest of the huge area of Delhi suffers from the above mentioned problems. The increasing demands for information in urban planning and management sectors call for the application of remote sensing for sustainable development of urban areas.

So in this context integrated geo-spatial technologies such as remote sensing (RS), geographic information system (GIS) and global positioning system (GPS) can contribute to interactive operations that would be an asset for assessing, understanding, and mapping utility and service facilities, as well as solving complex urban environmental problems. By utilizing remote sensing data and implementing GIS mapping techniques, changes in urban extent can be monitored and mapped for specific developmental projects. Creating linkages between remote sensing data and socio-economic data obtained on the ground from household surveys has been recognized as one of the major challenges of land use/land cover change studies (Rindfuss *et al.*, 2003). Satellite remote sensing, with its repetitive coverage and multi-spectral (MSS) capabilities, is a powerful tool for mapping and monitoring the emerging changes in the urban core and peripheral areas. The loss of agricultural land because of rapid urbanization has been detected using remote sensing techniques in some cities of India, such as Hyderabad, Madras, and Nagpur (NRSA, 1994). The situation is severe in India due to unplanned growth of the cities in all directions. The spatial patterns of urban sprawl in all direction over different periods can be systematically mapped, monitored and accurately assessed from remotely sensed data along with conventional ground data (Lata *et al.*, 2001).

Keeping these above points in mind, in this paper an attempt has been made to assess some of the urban environmental issues which Delhi is currently facing with the help of geo-spatial tools, i.e. remote sensing (RS), geographic information system (GIS), and global positioning system (GPS).

1.1. Objectives

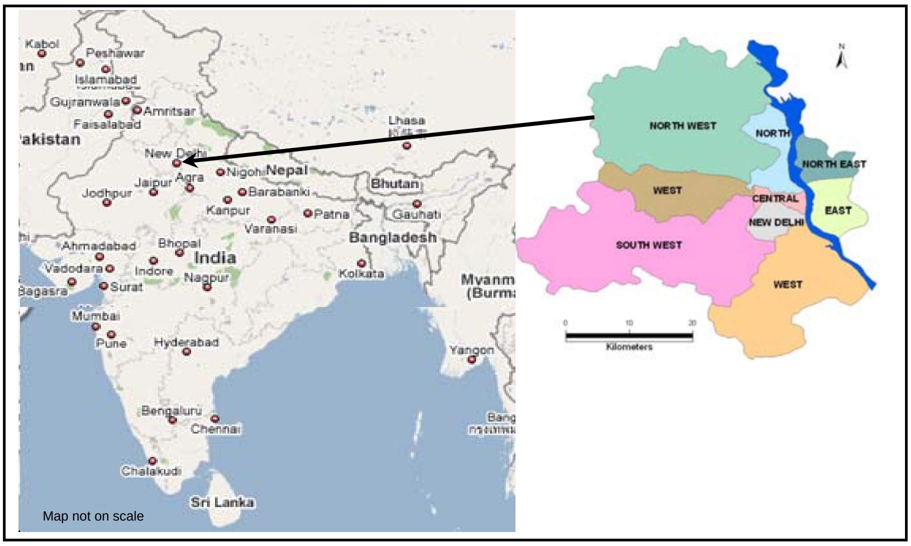
The specific research objectives of this paper are as follows:

- ✓ To assess the demographic profile of Delhi;
- ✓ To assess the land use/land cover of Delhi during 1992-2004;
- ✓ To assess the thermal environment of Delhi for 2001 and 2005 in order to assess the Urban Heat Island (UHI) effect;
- ✓ To find out the temperature variations associated with different land use/land cover types;
- ✓ To examine the spatial pattern of solid waste generation, collection and its management;
- ✓ To assess the pollution problems in terms of air, waste water and noise.

1.2. Study area

Delhi, the capital city of India, is located between the 28º 24' 17" and 28º 53' 00" N latitudes and 76° 45' 30" and 77 º 21' 30" E longitudes (Figure 1) and it spreads over an area of 1,463 km². It is situated on Aravali quartzite range of Rajasthan. The climate is semi-arid with maximum rainfall in the month of July (296 mm), October to December are dry. While the hottest months are May and June with temperatures reaching 48°C, the coolest time is at the end of December and early January, when temperatures fall to 4°C. In 1901, the total population of Delhi was nearly 0.4 million, which kept on increasing slowly until it reached 1.74 million in 1951 and 9.42 million in 1991. But a sharp rise in population was recorded in the most recent decade, such that in 2001 the population stood at 13.78 million (Census of India, 2001). The Registrar General of India (RGI) projects that Delhi's population will be 20.78 million by 2015. In Delhi about 79.5% of households have electricity connections and 63.4% of households have toilet facilities (Economic Survey of Delhi, 1991). About 60% of the households have both electricity and toilet facilities, 75.7% have piped water supply (individual plus sharing), while 20% depend on hand-pumps/tube-wells (Economic Survey of Delhi, 1999-2000).

Figure 1



2. Data source and methodology

2.1. Satellite data

The satellite remote sensing data utilized in this study are found in Table 1.

Table 1 – Details of satellite imageries used

S. No.	Satellites	Sensors	Date	Resolution	No. Bands	Path	Row
1	Landsat	TM	1992	28.5 m	4	146	40
2	IRS-P6	LISS-III	Feb. 2004	23.5 m	3	96	51
3	TERRA	ASTER	Sept. 2003	15.0 m	4	144	48
4	TERRA	ASTER	Oct. 2001	90.0 m	5	13	204
5	TERRA	ASTER	Sept. 2003	90.0 m	5	13	204

2.2. Secondary data

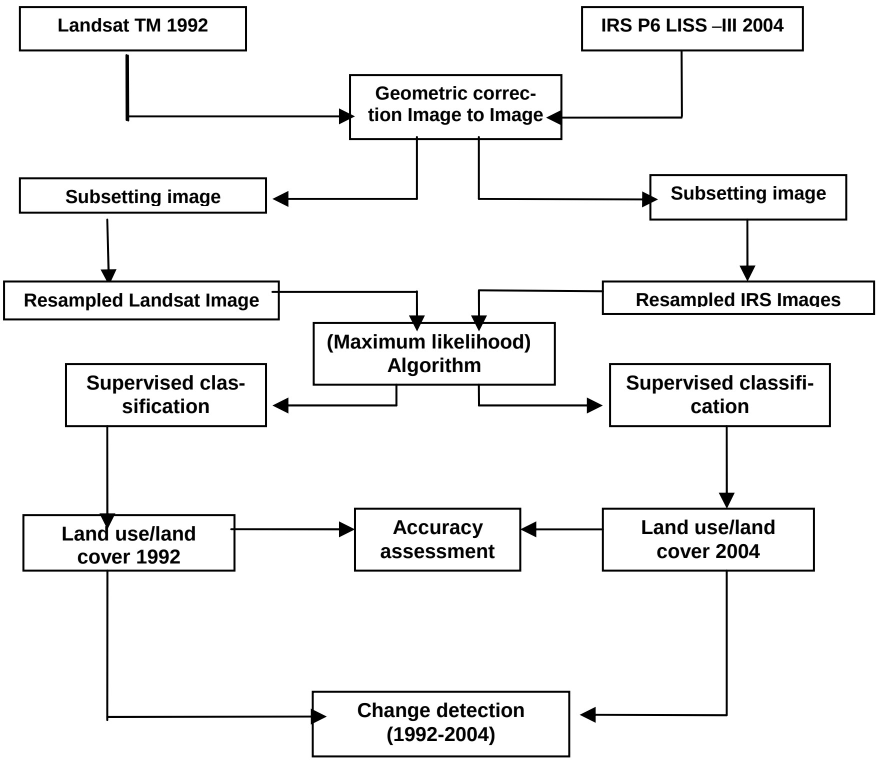
The following secondary data were used:

- Demographic data of Delhi, Census of India, Delhi;
- Air, noise and waste water pollution data, Central Pollution Control Board, (CPCB), Delhi;
- Garbage and solid waste data from CPCB, Delhi Pollution Control Board (DPCB) and Municipal Corporation of Delhi (MCD).

2.3. Methodology for land use/land cover classification and change detection

Landsat and IRS multi spectral (MSS) satellite images for 1992 and 2004 respectively were used for generation of a land use/land cover map (Figure 2). The satellite data was enhanced before classification using histogram equalization in ERDAS Imagine 8.7 to improve the image quality and to achieve better classification accuracy. Further both satellite data were rectified to a common Universal Traverse Mercator (UTM) projection/coordinate system on 1:50,000 scale. The data was re-sampled to a common spatial resolution of 23.5 m. Then a supervised classification was performed using a maximum likelihood algorithm, the classified data was recoded, and ground truthing was completed. Out of this an accuracy assessment matrix was generated. Two land use/land cover maps were prepared from (i) Landsat TM 1992, and (ii) IRS LISS-III satellite data of 2004, and afterwards changes in land use/land cover were assessed.

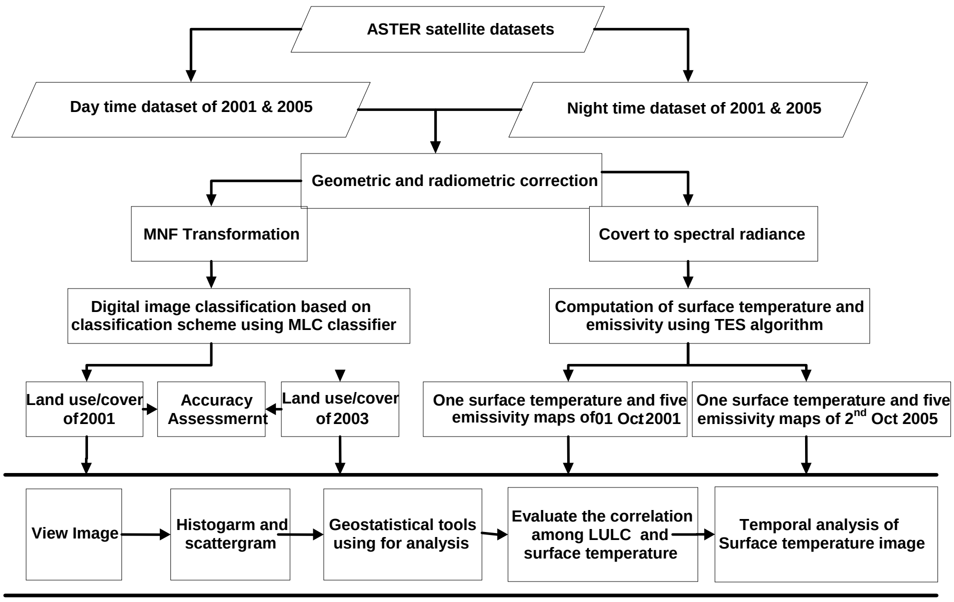
Figure 2 – Flow chart of methodology for land use/land cover and change detection



2.4. *Methodology for estimation of surface temperature from satellite data*

To assess the surface temperature of Delhi, the ASTER images were rectified to a common UTM (Universal Transverse Mercator) projection and WGS84 datum using Survey of India (SoI) topographical sheets and then were re-sampled using the nearest neighbour algorithm. The DN number of Landsat 7 ETM+ and ASTER datasets were converted into spectral radiance. Standard atmospheric and geometric parameters were estimated using FLAASH 4.1 and were applied to each of the images for atmospheric correction. The flow diagram of multi-spectral data processing and estimation of surface temperature is shown in Figure 3. The procedure involves successive steps that are described in the flow chart.

Figure 3 – Flow chart of methodology for surface temperature estimation



2.5. Methodology for solid waste, air, waste water and noise pollution

The map of Delhi collected from the Delhi Development Authority (DDA) was scanned, geo-referenced using Survey of India (SoI) topographical sheets at the scale of 1:50,000, and digitized in ArcGIS software. Various thematic layers were generated in the GIS using secondary data collected from Government departments like CPCB and MCD, etc.

3. Results and discussion

3.1. Demographic profile of Delhi

The national capital is attracting people from all parts of India. Delhi is a mini India with the largest number of immigrant communities of any city. Every day, 665 persons migrate to Delhi – a number that far exceeds migration to Mumbai (236), Bangalore (165), and Ahmedabad (121) put together (Delhi's First Human Development Report, 2006). Delhi has witnessed a phenomenal population growth during the past few decades. From a population of 4m in 1901, it increased to 13.8m in 2001. Since 1951, the population of Delhi has been increasing at an average rate of about 46% every decade (Table 2).

In the 1901 Census, more than 47% of Delhi's population lived in rural areas. This declined to 18% in 1951 and to 7% in 2001. The urban portion of the population has increased rapidly since 1911 when the capital of India was shifted from Calcutta (presently Kolkata) to Delhi. The pace of urbanisation was accelerated during 1941-51 when the country was divided into India and Pakistan and a large number of migrants settled in Delhi. With rapid urbanisation, the rural area is shrinking; it has been reduced to 592 km² in 2001 from 1158 km² in 1961, but urban population kept on increasing and it reached almost 14 million in 2001 (Figure 4). In 2001 the population density was 14,387 and 1,627 persons/km^2 in urban areas and rural areas, respectively. Villages of Delhi, which have coexisted with the sprawling urban settlements, still retain a great deal of rural tradition.

Figure 4

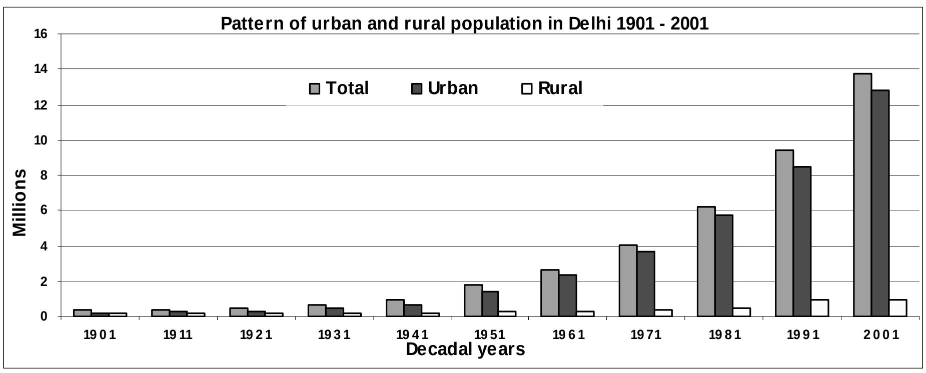


Table 2 – District-wise area and population of Delhi during 1991-2001

District	Area (km²)	% area to total area of State	1991			2001			Decadal growth 1991-2001
			Population	% to population of State	Density (pers./km²)	Population	% to population of State	Density (pers./km²)	
North-West	440	29.70	1,778,268	18.88	4,042	2,847,395	20.66	6,471	60.12
South	250	16.90	1,502,878	15.95	6,012	2,258,367	16.38	9,033	50.27
West	129	8.70	1,434,008	15.22	11,116	2,119,641	15.38	16,431	47.81
North-East	60	4.05	1,085,250	11.52	18,088	1,763,712	12.8	29,395	62.52
South-West	420	28.30	1,084,705	11.51	2,583	1,749,492	12.69	4,165	61.29
East	64	4.31	1,023,078	10.86	15,986	1,448,770	10.51	22,637	41.61
North	60	4.05	688,252	7.31	11,471	779,788	5.66	12,996	13.30
Central	25	1.68	656,533	6.97	26,261	644,005	4.67	25,760	-1.91
New Delhi	35	2.36	167,672	1.78	4,791	171,806	1.25	4,909	2.47
Total Delhi	1,483	100.00	9,420,644	100.00	6,353	13,782,976	100.00	9,294	46.31

Source: Census of India, 1991 and 2001.

The rapid urbanisation has led to the development of new settlement colonies in Delhi. These settlements are categorised by DDA in terms of civic infrastructure, types of houses, authorised, unauthorised settlement, unauthorised-regularised colonies, Jhuggis and Jhoparis (informal) resettlement colonies, etc. There has been tremendous slum growth in Delhi, from 12,749 in 1951 to over 500,000 in 2005. The current number of slum dwelling units is estimated to be about 0.6 million, and the population living in these slums and Yamuna clusters is about 3 million (Rahman, 2007b). More than three people are residing in a single room, which is 25% of Delhi's population, as compared with 56% for Mumbai, 43% for Kolkata, and 30% for Chennai. The Master Plan of Delhi 2001 suggested that 1.61 million new dwelling units should be made available during 2001 because housing demand is expected to increase further. The shortage of housing coupled with the large influx of migrant population leads to unplanned city expansion and change in land use/land cover over period of time.

The Delhi High Court ordered on 3 March 2003 the removal of all unauthorised structures, including *jhuggies*/slums. Though in theory all encroachments have to be removed, the Government only targeted *jhuggies*/slums. And about 75,000 families living in slums areas like Yamuna Pushta, Gautampuri, Koyela Plot, Kanchanpuri and Indira colony on West sides of the Yamuna River were cleared (Jamwal, 2004). Government claims to have resettled these families in 19,000 25-sq.m. plots all over Delhi at a charge of Rs. 7,000 ($ 175) per family. Another Government plan is for integrated slum development and providing to urban poor the basic services like housing and land at affordable price. This will include the Integrated Housing and Slum Development Programme (IHSDP), including provision of housing near the place of occupation (Basu, 2006).

3.2. Land use/land cover change detection

IRS-1C, LISS-III MSS, and PAN merged data products are very useful in urban analysis and urban land use/land cover mapping (NRSA, 2005). Digital mapping techniques can create up-to-date urban information (Rathi and Vatsvani, 1999). Land use/land cover maps were produced from Landsat TM and IRS-1C LISS-III satellite images from 1992 and 2004 respectively and the expansion of Delhi was mapped from 1992 to 2004. The study shows that out of Delhi's total area of 148,375 ha, agriculture constituted 65,114 ha in 1992, and this declined by 12% to 54,153 ha by 2004. The major cause of this unprecedented decline in area under agriculture was due to an increase in urban area (Table 3 and Figure 5. At the same time high density residential area more than doubled in the last twelve years. That is mainly at the cost of highly fertile agricultural land (Plate 1). Similarly land transformations have taken place all around Delhi in the fringe areas especially in East, South-West, and North districts of Delhi. Medium and low density residential areas have decreased at the cost of high density residential areas. That means the areas that featured low density development in 1992 have been converted into high density development in 2005. The Delhi ridge, which was once considered the lungs of Delhi, is fast degrading. There was a considerable decrease in the ridge area, from 6.7% in 1992 to 5.5% in 2004, because of continuous illegal tree cutting, quarrying and construction activity, especially in the S-E around Vasant Vihar, Vasant Kunj, and other areas.

Plate 1 – Encroachment of built-up area on productive agricultural lands

Figure 5 – Land use/land cover change in Delhi during 1992-2004

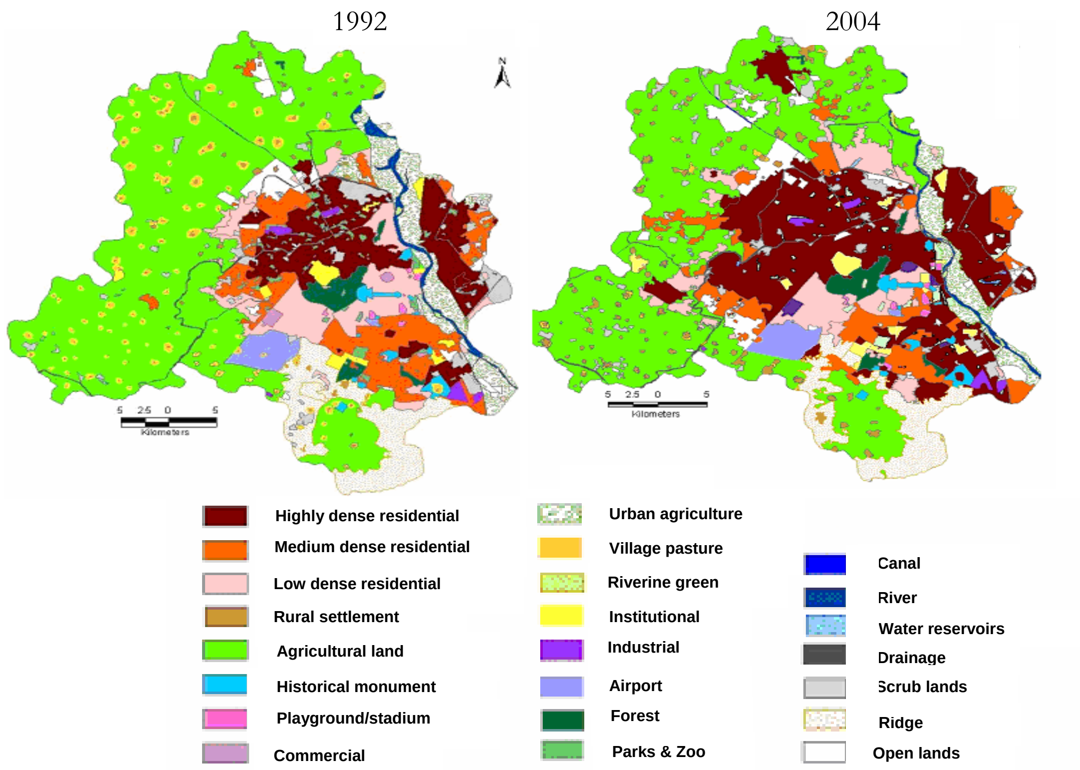


Table 3 – Land use/land cover change in Delhi during 1992-2004

Land use/land cover	1992		2004	
	Area (ha)	Area (%)	Area (ha)	Area (%)
High density residential	15,348.9	10.4	34,123.0	23.0
Medium density residential	12,039.8	8.2	10,706.8	7.2
Low density residential	10,661.8	7.2	10,324.3	6.9
Rural settlement	1,457.1	1.0	2,773.8	1.9
Commercial	396.9	0.3	527.9	0.4
Airport	2,261.7	1.5	2,160.0	1.5
Institutional	1,718.2	1.2	1,951.3	1.3
Industrial	689.7	0.5	576.0	0.4
Parks and Zoo	1,650.9	1.1	1,429.4	1.0
Stadium and playground	241.1	0.2	383.2	0.3
Historical monument	1,280.4	0.9	1,293.9	0.9
River	1,728.6	1.2	1,075.9	0.7
Drainage	920.3	0.6	1,088.4	0.7
Water body and reservoir	184.0	0.1	189.1	0.1
Canal	143.0	0.1	185.7	0.1
Agricultural land	65,114.2	44.9	54,152.6	36.9
Scrub land	3,521.4	2.5	3,615.6	2.4
Forest	2,331.1	1.6	2,127.3	1.4
Ridge	9,874.9	6.7	8,211.8	5.5
Pasture land	3,286.1	2.2	554.3	0.4
Urban agriculture	8,102.8	5.5	4,755.3	3.2
Riverine green	177.4	0.1	164.5	0.1
Open land	3,508.0	2.4	5,338.1	3.7
Total	148,375.7	100.0	148,375.7	100.0

3.3. Surface temperature assessment

Studies have been done on the relative warmth or "heat island effect" of cities by measuring the air temperature, using meteorological data. However, this method is time consuming and it leads to problems in spatial interpolation. Hence satellite sensors can provide quantitative physical data at high spatial and temporal resolutions and repetitive coverage is capable of measurements of earth surface conditions over time (Owen *et al.*, 1998). For example, temperature data derived from Landsat ETM$^+$, a Vegetation Index (VI) derived from high resolution IKONOS multi-spectral images, digitized data of the city urban infrastructure, and 3-D virtual reality models were integrated to assess urban environment quality of Hong Kong (Nichali and Wong, 2004). An infrared remote sensing satellite is now being used in estimating the surface physical properties and variables (Owen *et al.*, 1998, and Voogt and Oke, 2003). For the estimation of surface temperature, derivation of surface emissivity is important. Since the study area is a heterogeneous one, estimation of surface emissivity at the pixel scale was calculated. In the overall determination of surface temperature using Landsat 7 ETM+ thermal channel (10.4-12.5µm), more accurate emissivity values are obtained for the thermal band (band 6), which is in the 8-14µm wavelength region.

Figure 6 shows the night-time surface temperature using ASTER satellite data for 7 October 2001 at 22:35 hrs (local time). The estimated surface temperature ranges from 29.50 to 47.40°C. It is observed that in the image, the central and eastern parts exhibit a maximum surface temperature range that corresponds to built-up areas. The study shows that some parts of the north-west have lower surface temperature corresponding to wastelands, bare soil, and fallow lands. Water bodies exhibit a maximum surface temperature during night due to high thermal capacity. Fallow land, waste lands, and bare soil, due to their low thermal capacities, cool down faster than other land use/land cover features. Hence they, together with vegetated areas, are cooler as compared to other land use/land cover types during night time.

Figure 6 also shows the night time surface temperature using ASTER satellite data of 2 October 2005 at 22:35 hrs (local time). The estimated surface temperature ranges from 26.90 to 48.50°C. It is observed that in the image, the central and eastern parts exhibit high surface temperatures, corresponding to high density built-up areas. Some parts of north-west, north-east and extreme southern part of the image have lower surface temperature corresponding to agricultural cropland and bare soil. Table 4 shows comparative picture of the temperature data obtained from the satellite imageries as well as from the field observation. It shows higher surface temperature over concrete 1 (urban areas), i.e. 31.90°C and 32.96°C compared to vegetation 1, 29.64°C and 31.01°C and bare soil, 30.88°C and 31.05°C in 2001 and 2005 respectively. It is observed that the thermal gradient during night time decreases from high density built-up areas to fallow land.

Figure 6 – Spatial distribution of night time land surface temperature from ASTER data, 7th Oct. 2001 and 2nd Oct. 2005

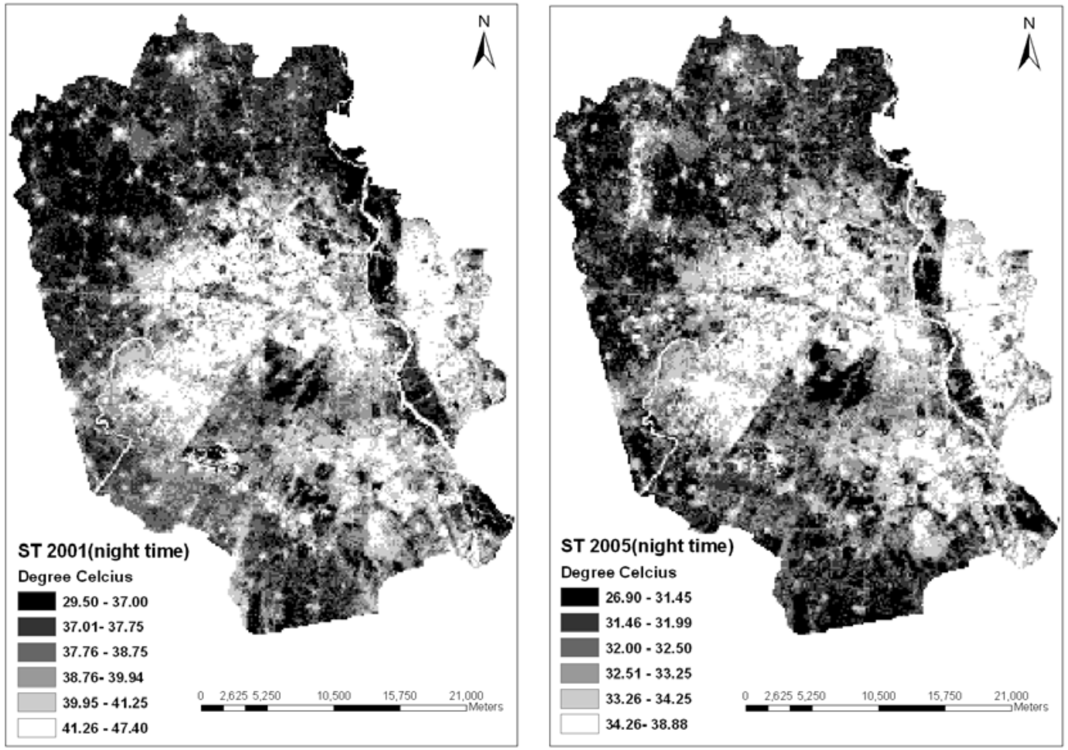


Table 4 – Comparison of satellite derived night time surface temperature with field measurement

Features	In the field observation on 3rd Oct. 2005 (21.30 to 23.00 local time) in °C*	Satellite observation		UTM coordinates (m)
		ASTER of 7th Oct. 2001 (22.35 local time) in °C	ASTER of 2nd Oct. 2005 (22.35 local time) in °C	
Vegetation	28.50	29.64	31.10	718935/3159479
Vegetation	29.00	30.25	31.30	719570/3169243
Vegetation	29.30	30.67	31.47	718365/3167032
Vegetation	28.00	28.95	30.20	717613/3160398
Average of vegetation	*28.70*	*29.88*	*31.02*	-----
Bare soil	28.50	30.88	31.35	700395/3158756
Concrete (Urban)	30.10	31.90	32.96	719871/3168740
Concrete (Urban)	28.30	31.42	32.34	717811/3169012
Total average	28.80	30.45	31.47	------

*This measurement is the mean value 5 to 10 reading.

Meteorological data was collected from the Delhi's Safdarjang Weather Monitoring Department for different dates in Oct. 2001 and Oct. 2005. This has been done in order to adjust the ASTER satellite derived measurement (Table 5). The table shows that the temperature observed night time on 7th Oct. 2001 was 22.1°C and on 2nd Oct. 2005, it was 23.0°C, compared to average temperature observed on different land use on the same dates by the satellite data was 30.45°C and 31.47°C respectively (Table 4).

The fact that, as mentioned previously, high density built-up areas have increased in Delhi has had implications for the UHI of Delhi. Although the data for the two dates in 2001 and 2005 cannot definitively prove that temperatures have increased over this time period based on two images, it is possible to say that based on the thermal signatures of different land cover types, there has undoubtedly been an increase in the overall surface temperatures in the Delhi metropolitan area. It is likely that on vegetative surfaces, bare soils, and concrete surfaces, the

Table 5 – Diurnal range of temperature in Delhi, 2001 and 2005

Dates	Temperature in 2001 (°C)		Temperature in 2005 (°C)	
	Minimum	Maximum	Minimum	Maximum
30th Sept.	21.6	32.8	23.8	33.8
1st Oct.	22.2	31.2	23.6	34.2
2nd Oct.	**21.0**	**32.2**	**23.0**	**34.2**
3rd Oct.	20.5	33.6	21.5	34.6
4th Oct.	19.6	32.2	21.7	34.2
5th Oct.	20.4	33.3	21.0	34.3
6th Oct.	21.3	32.1	22.4	35.1
7th Oct.	**22.1**	**31.8**	**23.2**	**34.8**
8th Oct.	20.4	30.5	21.0	33.9
9th Oct.	19.9	31.6	22.1	33.1

Source: Safdarjang Monitoring Station (IMD), Delhi.

increase of temperature is close to 1°C (Table 4). Thus, it seems likely that due to pressure of population and the increase in the built-up area, the vegetative area and agricultural land is decreasing, which leads to an increase in the surface temperature over different land cover classes.

3.4. Solid waste management

In India the increasing level of solid waste generation and its management is becoming a serious problem in urban areas. High population growth rates and increasing per-capita income have resulted in the generation of enormous amounts of solid waste, posing a serious threat to environmental quality and human health. Urban solid waste includes garbage or refuse discharged from residential, market, institutional and industrial activities. India produces about 75 million tons of waste every year, and in urban areas 40-50% remains uncollected. The quantity of solid waste generated depends on a number of factors such as food habits, standards of living, and the degree of commercial activities. In 1999 the estimated quantity of garbage generated in Delhi was 8,203 million tons (MT) based on 0.61 kg/capita per day, out of which only 4,885 MT is properly disposed of. However present consumption patterns are indicative of an increase to 11,899 MT by 2011. The quantity of solid waste substantially increases during the monsoon because the moisture content increases.

Remote sensing data can be an aid in identification and location of garbage dumping sites and in monitoring the changes in land use within and near hazardous waste and sanitary landfills (Radhakrishnan *et al.*, 1996). As part of this study, a land use/land cover analysis of a part of Delhi was carried out using IRS data to identify suitable sites for hazardous waste disposal in the national capital region (NCR) (Javed and Pandey, 2004). One of the objectives of this study is to assess the garbage generation and identification of hot spots using GIS and GPS. Table 6 shows zone-wise solid waste generation and disposal in Delhi during 1996-2005. It is seen that both garbage generation and disposal in the South and East districts of Delhi are highest, 750 tons/day and 528 tons/day respectively, followed by Central Delhi (Table 6 and Figure 7. This is mainly because of the high population density in these districts.

Table 6 – Zone-wise solid waste generation and disposal in Delhi (1996-2005)

Zone	Quantity of waste generated (tons/day)		Quantity of waste disposed (tons/day)	
	1996	2005	1996	2005
1 City	442.15	522.15	294.84	329.84
2 Civil lines	457.80	537.80	305.76	345.76
3 Shahdara (N)	415.00	485.05	276.64	306.64
4 Shahdara (S)	480.20	566.15	320.32	370.32
5 Sadar Paharganj	403.00	463.00	269.36	299.36
6 Karolbagh	269.37	339.36	269.37	289.36
7 West Delhi	241.62	311.63	241.62	291.63
8 Central Delhi	548.15	620.00	364.00	404.00
9 **South Delhi**	680.15	750.00	418.00	528.02
10 Najafgarh	397.15	465.15	265.74	305.72
11 Narela	147.50	207.50	98.28	148.28
12 Rohini	540.10	645.10	426.56	496.56
Total	5022.19	5912.89	3550.49	4115.49

Source: Central Pollution Control Board, Delhi, 30th Inspection Report (2006).

Figure 7

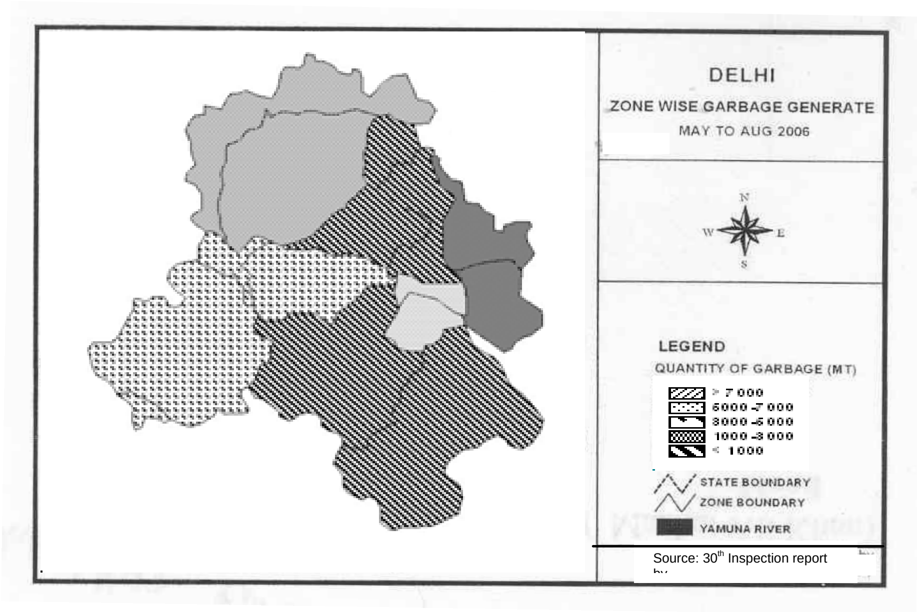


Figure 8

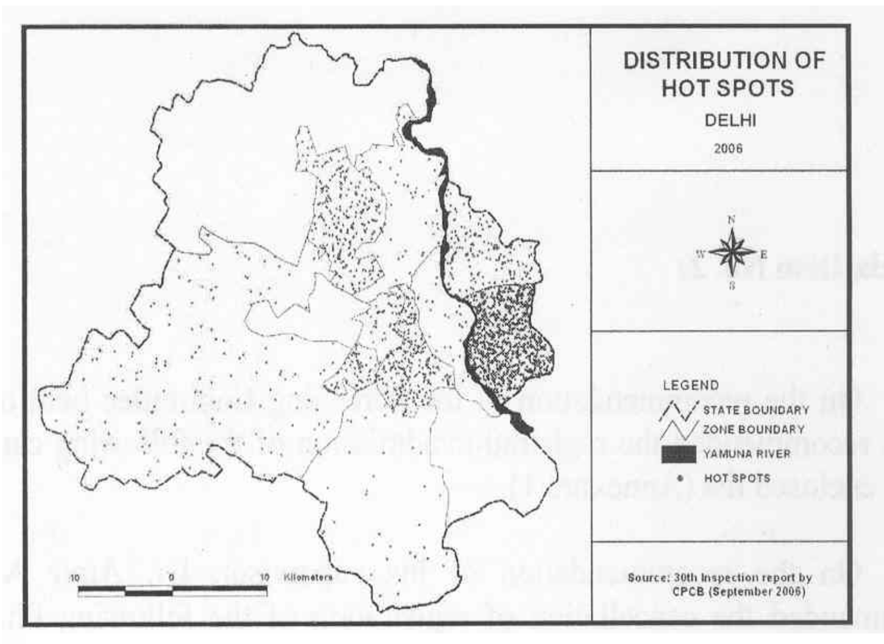


Figure 8 shows the hot spots which require immediate action with respect to sanitation and maintenance, areas characterized by open dumping of wastes commonly seen along streets, lanes, road divides, footpaths, open ground, open plots, and even in parks. It shows that there are 134 hot spots in the MCD zone of Delhi. The hot spots were identified using GIS and GPS field survey in conjunction with data from a survey conducted by Central Pollution Control Board (CPCB). Dustbins are very few in number and can't hold the volume of garbage that is being generated. The biggest cluster of solid waste hot spots is East district. This is because the higher the population, the larger the waste generated in an area. The population density in East district is 22,637 persons/km² followed by central district at 25,760 persons/km² and NE district at 29,395 persons/km² (Table 2). So, due to the huge solid waste generation in these densely populated districts, there are health related problems. In urban areas due to improper garbage dumps in residential colonies are directly responsible for breeding grounds for bacteria which lead to diarrhoea and measles. Flies also spread diseases such as salmonella by transporting bacteria from garbage to kitchen countertops or to the dinner table. There is a need to give due care on this issue by the municipal authorities especially in these hot spots.

3.5. Industrialization and air pollution

In recent times the growth of Delhi is characterized by increase in residential complexes, use of vehicles and rapid industrialization. The deficiencies in both planning and environmental regulation have led to health and environmental damages. Apart from being the capital of the country, it has become a centre for commercial, industrial, social, cultural, and educational activities. Figure 9 shows the major industrial areas of Delhi.

A white paper on Delhi by the Government of India addresses the state of urban environment of Delhi and worked out for assessing the pollution trends and the prescribed ambient standards (MEF, 1997). Major sources of air pollution in Delhi are vehicles (70%) followed by thermal power plants, industries, and domestic coal burning. Apart from automobiles, the two biggest sources of air pollution in Delhi are the Babarpur and Indraprastha (IP) thermal power stations (Table 7). The 705 MW Badarpur thermal power plant in Delhi alone produces

Figure 9 – Industrial areas in Dehli

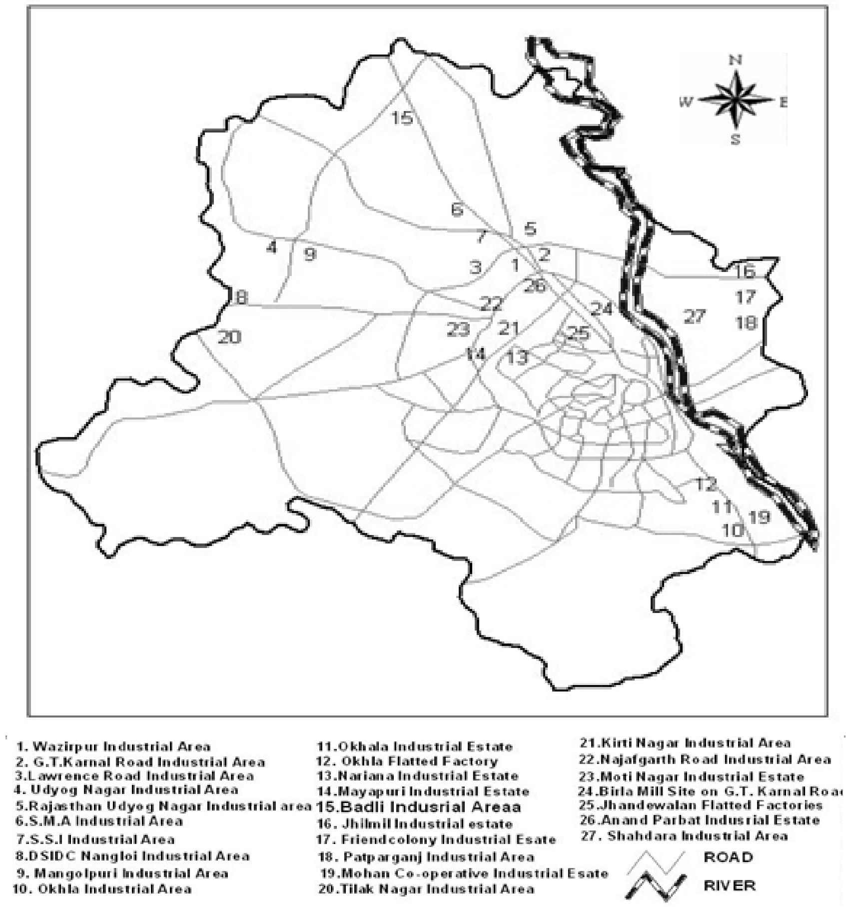


Table 7 – Fly-ash generation from the power plants in Delhi

Stations	Capacity (MW)	Fly-ash (tons/day)
Indraprastha (IP)	247.5	1200-1500
Rajghat	135	600-800
Badarpur	705	3500-4000

Source: CPCB, 2006.

about 4,000 tons of fly-ash on daily basis, i.e., about one kg per resident. It can be said today that the city lies under a permanent blanket of smoke. Fly ash coats every surface and a good deep breath is likely to wind up with a racking cough.

There was an increase in the concentration of all ambient air pollutants except in 2005, when all pollutants recorded a decline (Table 8). This is mainly due to the use of cleaner fuels in automobiles, i.e., compressed natural gas, unleaded petrol, phasing out of vehicles more than eight years old, and various other strict government policies combined with strong action from the judiciary for the enforcement of environmental and transport laws. Figure 10 shows the concentration of CO and SPM which is quite high in most of the districts of Delhi. This is mainly due again to the high number of vehicles. According to the Economic Survey of Delhi, there were 4,830,136 vehicles in 2005-06 and, in one year, Delhi added 30,630 vehicles (*The Times of India*, 2006).

Table 8 – Year wise annual mean ambient air quality levels in Delhi

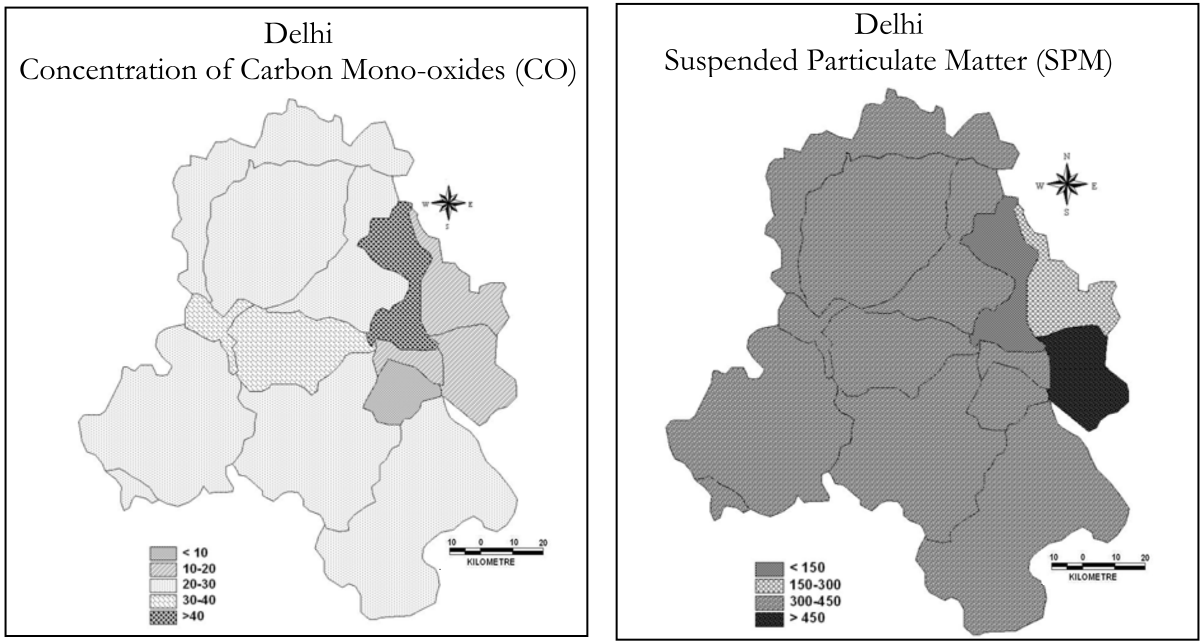
Year	Concentration in ambient air (in μg/m³)				
	SO2	NOx	CO*	SPM	RSPM
1999	18.68	44.85	4810	362.58	NA
2000	20.37	42.17	5450	377.92	NA
2001	19.46	40.11	4241	374.92	NA
2002	18.03	71.83	4686	430.83	191.00
2003	14.10	41.75	4183	381.67	150.08
2004	11.33	47.28	3258	455.92	192.25
2005	9.49	45.00	2831	352.30	148.86

Source: Department of Environment (Govt. of NCT of Delhi).
*At ITO intersection.
NA: Data not available.

3.6. Water pollution

The river Yamuna covers a 22 km stretch between Wazirabad and Okhla barrage in Delhi. Delhi represents only 2% of its catchments area, but it contributes about 80% of the river's total pollution load. Nineteen major drains (Figure 11) dispose of untreated municipal wastewater, amounting to daily flows of approximately 2,871 million

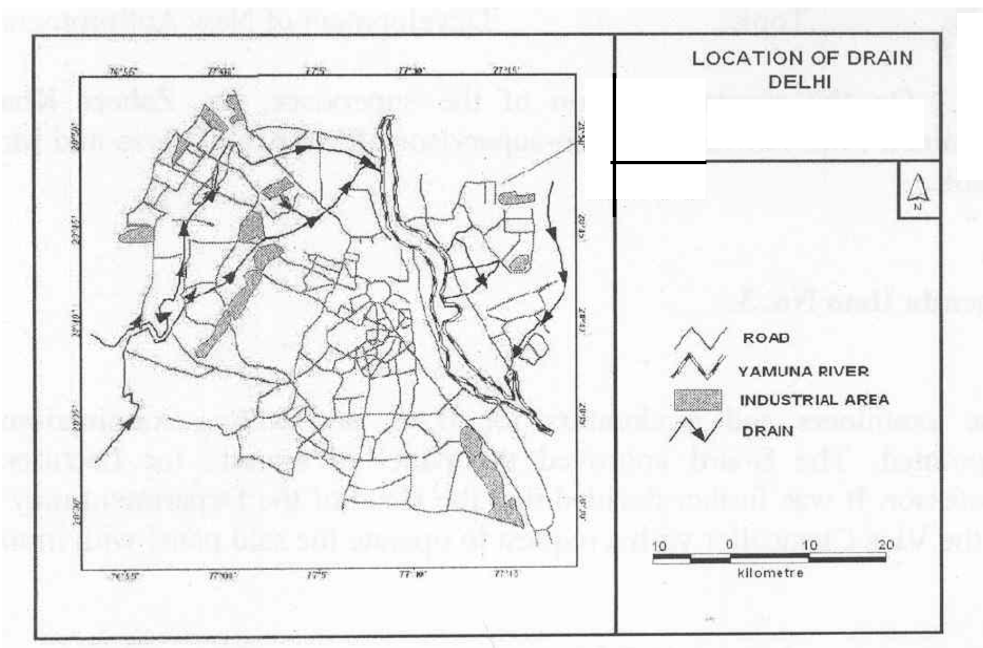
Figure 10



Delhi
Concentration of Carbon Mono-oxides (CO)
< 10
10-20
20-30
30-40
>40
10 0 10 20
KILOMETRE
Delhi
Suspended Particulate Matter (SPM)
< 150
150-300
300-450
> 450
10 0 10 20
KILOMETRE

litres into the Yamuna. Of this amount, approximately 300 million litres per day are from the industrial sector. Delhi also contributes 200 million litres of untreated sewage, which is why the Yamuna is one of the most polluted rivers in the world (Mallik, 2000). The Najafgarh drain alone contributed more than 80% of the waste water entering into the river. All this is mainly due to industrialization and the increasing population that leads to high discharge of waste water from houses.

Figure 11



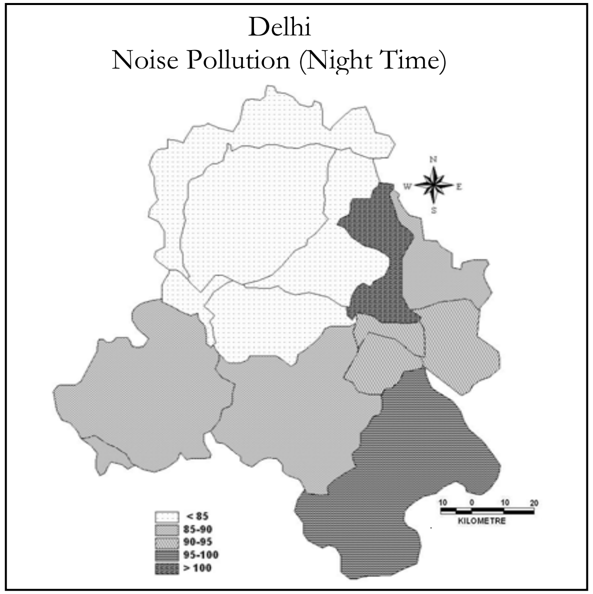
3.7. Noise pollution

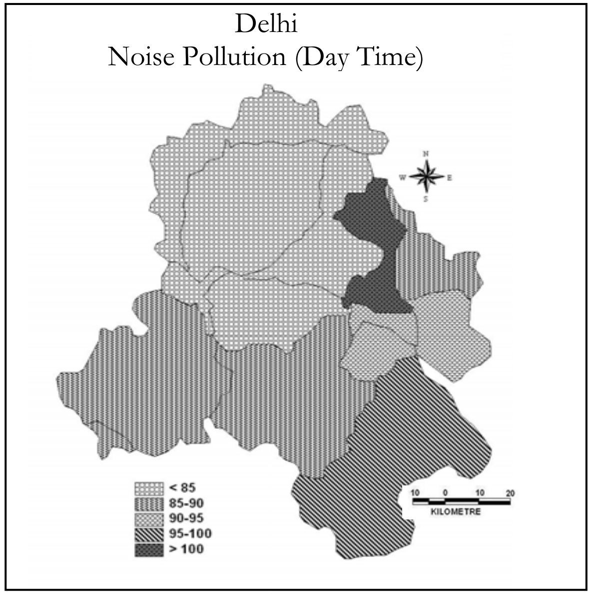
Noise pollution in urban areas is another major cause of concern, especially when there is fast increase in number of automobiles. There are many sources of noise pollution in Delhi and most of them are associated with development of roads, air and rail transport, and the increasing number of industries. Some activities associated with urban living also lead to increased noise levels. Three-wheelers, trucks, and motorcycles remain the chief source of noise pollution on Delhi roads followed by generators in the residential, commercial and industrial locations that is due to short supply of electricity in the summer season. The main industrial areas of Delhi are Wazirpur, Mayapuri, Nariana, and some others add lots of noise pollution to the city environment. A study of the population affected by air and noise pollution in Jaipur used predictive and dispersion models in a GIS environment using IRS-1C, LISS-III FCC, and PAN data of 1998 (Maithani *et al.*, 2002). This paper also addresses the noise pollution variation in Delhi using GIS software with the help of data collected from CPCB. Figure 12 shows noise pollution levels during day and night time. It is seen that most of the Eastern and Southern districts are recording more than 90 db noise levels, but during night time the level of noise goes below 90 db in almost all the districts except in one. The situation is more serious when we examine the noise level during peak hours. Almost all the districts of Delhi recorded noise levels of more than 93 db, which is beyond the permissible limit of 80 db during day time. This high level of noise pollution has many adverse health effects on human such as hearing loss and strokes. So there is an urgent need to put strict regulation to reduce the level of noise in Delhi.

4. Conclusions and policy recommendations

The critical issues and challenges of development and management for growing urban centres like Delhi, Mumbai, and Kolkata have been the subject of extensive discussions and debates in recent years. The major problems associated with urban centres in India is that of unplanned expansion, changing land use/land cover, loss of productive agricultural land, increasing rainfall runoff, and depletion of the water table. It is evident from the foregoing study that major urban environmental problems occur due to high population growth (the 46.31% increase during 1991-2001) and the uncontrolled and mismanaged urban expansion which has led to the doubling of the densely built-up area during last decade in Delhi. There is a reduction (16.8%) in agricultural land because of urban expansion in the fringe areas. Pollution loads affecting the air, water and land in Delhi have also increased considerably, and average night-time temperatures (so-called "heat pollution") have increased significantly. Management of huge volumes of garbage and solid waste, including medical waste, is very difficult, and

Figure 12


Delhi
Noise Pollution (Night Time)
N
W
E
S
< 85
85-90
90-95
95-100
> 100
10
0
10
20
KILOMETRE


Delhi
Noise Pollution (Day Time)
N
W
E
S
< 85
85-90
90-95
95-100
> 100
10
0
10
20
KILOMETRE

has led to increasing environmental health burdens. Increasing surface temperatures and noise pollution also lead to health impacts. Remote sensing imagery, with its repetitive and synoptic viewing capabilities, together with GIS, are important tools to map, assess, and monitor the changes in the urban environment. High-resolution satellite imagery (IKONOS, Quick Bird) can also be used to monitor urban expansion and illegal housing construction over a period of time and to find out the potential waste disposal sites for solid waste management. Thermal infrared (TIR) satellite data can be used to assess the so-called 'urban heat island' surface temperatures, and areas with high atmospheric pollution.[1] The thermal satellite data confirms a suspected increase in the surface temperature in just four years, coincident with the growth in built-up areas and the loss of farm land. The paper suggests that the database generated from remote sensing imageries in digital image processing DIP software and thematic maps prepared using socio-economic data in GIS environment could be helpful for sustainable development, planning and good governance of Delhi and some other cities as well.

To fight with the problems of environmental degradation and to meet the challenges of sustainable development, it is suggested that the use of remote sensing and GIS in conjunction with geospatial data is of vital importance. There is need for the use of an urban information database that can be generated using remote sensing data and GIS techniques. Top priority should be given to the issues related to the planned development of the city, reduction in atmospheric pollution, and traffic congestion. The administrative, technical, and managerial staff of the urban local bodies need to be strengthened. The officials of various government departments should be given thorough exposure and training of remote sensing and GIS for its application and implementation in the urban environmental management plans. The problems and challenges faced by mankind are of national importance, but it has to be dealt at the local level. Left unchecked, growing environmental burdens will not only affect human health, but also affect the investment decisions of private firms looking to site new facilities. So, it can be seen from the foregoing study that the deterioration of urban environmental quality is due to a combination of a growing population

1. Although this was not done in this study, satellite imagery has been used for surface temperature mapping.

and rising consumption levels, the consequences of which can be effectively monitored and assessed by using geo-spatial tools.

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