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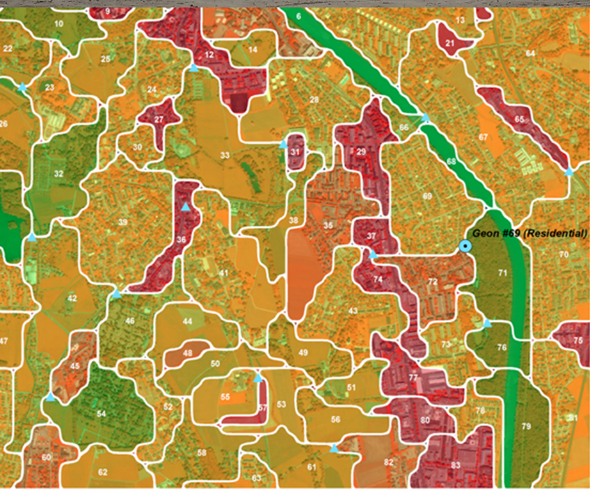
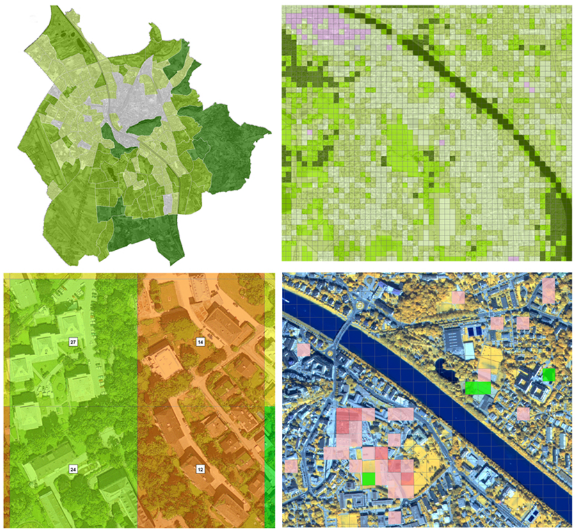
Urban Remote Sensing

Second Edition





Edited by

Qihao Weng

Dale Quattrochi

Paolo E. Gamba

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Urban Remote Sensing

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Remote Sensing Applications

Series Editor

Qihao Weng

Indiana State University
Terre Haute, Indiana, U.S.A.

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Qihao Weng, PhD
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7.1 INTRODUCTION

Urbanization is highly dynamic and now ubiquitous, with almost half the population of the world living in cities. This proportion is expected to reach approximately 72% by 2050 (United Nations 2012). Mega cities now represent the most powerful economic poles of growth and the hinterlands would represent a region with loss of biodiversity and degradation of environment (Czamanski et al. 2008) with increasing human environment and human bioproblems that may range from a micro-region to a local region and can affect global issues. This may include increased air and water pollution (Liu and Diamond 2005), local climate alteration, and increased energy demands (Gonzalez et al. 2005; Ramachandra et al. 2012a). It has been argued that the next phase of urban growth will be concentrated in the developing countries, which includes one of the fastest-growing economies—India (Ramachandra et al. 2012b; Taubenböck et al. 2009, 2012; Van Ginkel 2008).

India has been witnessing rapid urban growth, initially leading to concentrated growth with a steep increase in land prices and later to a fragmented outgrowth from the city boundaries toward the urban–rural side. This fragmented outgrowth often results in the phenomenon called urban sprawl (Bharath et al. 2012; Ramachandra et al. 2015a). Sprawl may be defined as regions and settlements that are located in the vicinity of a city and/or outskirts of the growing urban area with very low to low-density development that would evolve into high-density development in a few years depending on the economy and other major factors. These are connected to the urban core without proper recognition from the city development authorities or planners. These areas are mostly devoid of any basic amenities such as water, transport connectivity, sanitation, and electricity (Ramachandra et al. 2014d). Such urban expansions are normally and extensively associated with growth, which is uncoordinated and could result in a serious crisis in terms of sustainable city development and future planning of city growth (Bharath et al. 2013; Ramachandra et al. 2014a,b; Taubenböck et al. 2009).

There is a growing need for landscape monitoring since city managers of mega cities in India face unprecedented challenges with regard to urban planning and land use management owing to the high dynamic growth and change in spatial patterns over time and failures in identifying driving forces and pockets for landscape changes. This necessitates understanding the temporal changes in land use and growth rate, which would help provide vital insights into the decision-making process through understanding the impact of landscape changes, biodiversity, complexity, and fragmentation of the landscape (Bharath et al. 2014; Patino & Duque 2013; Ridd 1995; Zeng & Wu 2005). Therefore, the quantification of landscape changes must consider both modifications in spatial arrangements and their consequences. Simulation-based modeling can provide basic and valuable site-based insights into possible future developments; this includes understanding the paths or pockets of current growth, understanding development corridors attributed to various improving infrastructural facilities, and developmental activities as a result of policy decisions.

Modeling temporal land use dynamics would help in visualizing development scenarios with inputs to sustainable city development aimed at optimizing available resources and decision making (Burgess & Jenks 2002). Urban models based on the principles of cellular automata (CA) are developing rapidly. CA-based urban models usually pay more attention to simulating the dynamic process of urban development and defining the factors or rules driving the development (Batty 2005). Different CA models have been developed to simulate urban growth and urban land use/cover change over time. The differences among various models exist in modifying the five basic elements of CA, that is, the spatial tessellation of cells, states of cells, neighborhood, transition rules, and time (Liu 2009). CA models have been shown to be effective platforms for simulating dynamic spatial interactions among biophysical and socioeconomic factors associated with land use and land cover change (Ramachandra et al. 2012a). Various other approaches, such as regression modeling, neural networks, artificial intelligence, and so on, have been used effectively (Arsanjani et al. 2013; Mozumder & Tripathi 2014; Puertas et al. 2014).

While new urban models have provided insights into urban dynamics, a deeper understanding of the physical and socioeconomic patterns and processes associated with urbanization is still limited in India. Although emerging geospatial techniques have bridged the spatial data gap recently, there remain very few empirical case studies (Thapa & Murayama 2009). The urban population in India is growing at approximately 2.3% per annum, with the global urban population increasing from 13% (220 million in 1900) to 49% (3.2 billion in 2005) and is projected to escalate to 60% (4.9 billion) by 2030 (Ramachandra & Kumar 2008). The increase in urban population in response to the growth in urban areas is mainly attributed to migration. There are 48 urban agglomerations/cities having a population of more than 1 million in India (in 2011). However, unplanned urbanization coupled with the lack of holistic approaches leads to the lack of infrastructure and basic amenities. Hence, proper urban planning with operational, developmental, and restorative strategies is required to ensure the sustainable management of natural resources. Unplanned growth would involve radical land use conversion of forests, surface water bodies, and so on with the irretrievable loss of ground prospects (Basawaraja et al. 2011). The process of urbanization could be either in the form of townships or unplanned or organic. Many organic towns in India are now influencing large-scale infrastructure development and so on as a result of the impetus from the national government through development schemes such as JNNURM (Jawaharlal Nehru National Urban Renewal Mission). The focus is on the fast-track development through efficient infrastructure and delivery mechanisms, community participation, and so on. Large-scale land use and land cover changes, such as the loss of forests to meet the urban demands of fuel and land (Ramachandra & Kumar 2009), have led to changes in ecosystem structure, affecting its functioning and thereby threatening sustainable development. Cities are often attributed as the engines of economic growth. This compels cities to become smarter in handling large-scale urbanization and in finding new ways to manage complexity, increase efficiency, and improve quality of life. The design of smart cities requires an understanding of spatial patterns of urbanization to implement appropriate mitigation measures. This necessitates spatial information for the city administrators to visualize the patterns of urbanization and also predict the likely changes with the implementation of decisions (such as "what if" scenarios). Smart cities would be self-reliant and self-sufficient systems, providing basic necessities (such as water, sanitation, reliable utility services, and health care), transparent government transactions, and various citizen-centric services. This leads to the first objective of this chapter, that is, to understand the land use changes in five major cities in India.

7.2 CARBON FOOTPRINT ANALYSIS

India has been transitioning from a dependent economy to a more self-reliant manufacturing economy. This essentially involves the manufacturing process, which would entail more greenhouse gas (GHG) emissions, and a large workforce, which would increase the amount of carbon in the atmosphere. Such a transition to suit a very low carbon economy entails the adoption of modern technologies and adaptation strategies that involve improved regulatory mechanisms, better infrastructures, best business practices, low consumption rates, and improved green lifestyles. It should be noted that in the past two decades, an increased concern about global warming has been raised because of the increased emission of GHGs that form a blanket in the atmosphere, with all countries focusing on efforts to minimize these emissions. There has been a large-scale change in industrial output through the transformation of heavy industries in developed countries to a more knowledge-based and service-based economy that is comparatively cleaner (Shafik and Bandyopadhyay 1992). It must also be noted that there have been active citizen participation and awareness campaigns worldwide that have led to improved environmental regulations, which, in turn, decreased the rate of environmental degradation. Given these, international governing bodies should set targets to accomplish tasks and solve global environmental problems.

Also, organizations that govern environmental regulations are trying to establish strategies that would help mitigate GHGs of anthropogenic origin, thus reducing the threat of global warming (Kennedy et al. 2010; Wiedmann & Minx 2008). This resulted in many metropolitan cities across the globe showing interest in estimating GHG emissions and developing strategies to reduce emissions. Thus, carbon footprint is a measure of the impact of human activities on the environment in terms of the amount of GHGs produced (Finkbeiner 2009; Ramachandra et al. 2017). Carbon footprint, also called GHG footprint through estimation of GHG emission, is expressed in terms of carbon dioxide equivalent, indicating the amount of carbon in the atmosphere of a particular region. Carbon dioxide equivalent (CO_2e) is a unit for comparing the radiative forcing of a GHG (measure of influence of a climatic factor in changing the balance of energy radiation in the atmosphere) to that of carbon dioxide (ISO 2006a,b, Ramachandra et al. 2017). It is the amount of carbon dioxide by weight that is emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas (Wiedmann and Minx 2008).

7.3 NECESSITY OF UNDERSTANDING CARBON FOOTPRINT OF A REGION THROUGH QUANTIFICATION

Climate change is now one of most concerning areas for human existence in the next century. Decreasing our carbon footprint has the potential to reduce its impact on climate change by increasing human comfort. It would also add to the valuable information required as a component for sustainable urban planning for planners, policy makers, and local municipalities (Courchene and Allan 2008).

It has been widely reported that the last four decades have witnessed an abrupt increase in concentration of GHGs. All human activities such as industry, agriculture, deforestation, waste disposal, and specifically the burning of fossil fuels for various applications are considered the main factors that contribute to the increase in fossil fuel content in the atmosphere. The concentrations of atmospheric CO_2 increased from approximately 80 ppm considered by volume (ppmv) in the 1950s to 372 ppmv in 2001 and has been increasing approximately 20 ppmv every year as per the 2007 IPCC report. Similarly, CH_4 emissions have increased by 0.02 ppmv. This rapid increase in GHG concentrations in the atmosphere, mainly due to anthropogenic activities of humans, has affected the local and global climate and is said to have far-reaching consequences. The most significant contributors to global warming are the six Kyoto gases and, to a lesser extent, the chlorofluorocarbons (highlighted during the Montreal protocol; IPCC 2006, 2007). CO_2 is the primary GHG (contributing ~60%) followed by methane and nitrous oxide, with the largest GHG-producing sector being the energy supply sector (~26%) (IPCC 1996, 2007).

The effect of these gases is measured in terms of global warming potential (GWP) and depends on radiative forcing and time frame (usually 100 years). The GWP factor for CO_2 is 1 (considered as reference), that for CH_4 is 21, and that for N_2O is 298 (IPCC 2007). Today, it is important to understand and quantify the GHG emissions through a sectorial approach with specific methods. A sectorial approach would help in planning sectorial interventions in reducing carbon footprint in the atmosphere as well as necessary technological interventions based on sectorial needs.

Given these requirements, this chapter addresses three basic objectives based on understanding the steps in building and transforming sustainable urban systems. The first objective is to understand temporal land use change in the last two decades in five major cities in India and to model it based on agents of change. The second objective is to quantify GHG emissions. The third objective is to understand policy interventions required to overcome both land use change effects and effects of GHG emissions.

7.4 STUDY AREA AND DATA

This chapter aims to study five mega cities in India: Mumbai, Delhi, Kolkata, Chennai, and Bangalore, as shown in Figure 7.1. Table 7.1 shows latitude and longitude, population as per the year 2011 census, and metropolitan area spread of these mega cities.

Mumbai, named after the goddess Mumbadevi, has a rich history, and it has been referred to as Bombay province until 1955. The city is located along the west coastline of India. This region has undergone continuous land use change, mainly by reshaping under the Hornby Vellard project, in which the key objective was to merge several islands from the sea. Mumbai has a deep natural harbor, which serves as a significant access point to the Indian subcontinent through many European and Middle Eastern countries and hence getting the nickname "Gateway of India." Mumbai is the most populous city in India and is the ninth most populous urban agglomeration in the world. The Mumbai metropolitan region is composed of three complete districts, Mumbai city, Mumbai suburban, and Thane, and two partial districts, Palghar and Raigad. Because of its unique air, road, rail, and water transportation network,

FIGURE 7.1 Location details of mega cities.

TABLE 7.1
Location, Demographic, and Area Details of Mega Cities

Mega City	Latitude	Longitude	Population (Census 2011)	Area (km²)
Mumbai	18.97	72.82	18,414,288	4355
Delhi	28.61	77.23	16,314,838	1484
Kolkata	22.56	88.36	14,112,536	1886
Chennai	13.08	80.26	8,696,010	1189
Bangalore	12.96	77.56	8,499,399	741

Mumbai ranked first in commerce and industries by contributing 6.16% of India's gross domestic product. Mumbai enjoys a tropical dry and wet climate with an average annual precipitation of 2167 mm.

Delhi is the capital city and also a union territory of India, located at the northern part of the country, and stands on the west bank of river Yamuna. Delhi is surrounded by two states, namely, Haryana and Uttar Pradesh. With a population of 16,314,838 (Census 2011), Delhi is the second most populous urban agglomeration in India. Delhi and its adjoining urban region have been given the special status of National Capital Region under the Constitution of India's 69th Amendment Act of 1991. The Delhi metropolitan area consists of five municipal corporations: North Delhi Municipal Corporation, South Delhi Municipal Corporation, East Delhi Municipal Corporation, New Delhi Municipal Corporation, and Delhi Cantonment Board. Various historical monuments, such as Qutub Minar, Humayun's tomb, Iron

Pillar, and Red Fort, and political places of interest, such as Rashtrapati Bhavan, the Parliament House, the Supreme Court of India, the Cabinet Secretariat, and the Reserve Bank of India, are located in the central business district of New Delhi. The Delhi region has excellent railway, metro, and road connectivity such as the 28-km Delhi–Gurgaon Expressway, National Highway-1 connecting Delhi and Attari (near the Pakistan border), and National Highway-2 connecting Delhi and Kolkata (one of the busiest routes covering four states in between). Culture, history, and tourism, on one hand, and politics, economy, utility services, and transport, on the other hand, have made Delhi the second highest populated mega city next to Mumbai.

Kolkata is situated in the eastern part of India, and it is the capital city of West Bengal state. Much of Kolkata's development happened during the British rule during the late 1870s to 1910s. The region also served as the capital for British-held territories in India until 1911. With the increase in population from 9,194,000 in 1981 to 14,112,536 in 2011, Kolkata is the third most populous metropolitan city in India after Mumbai and Delhi. Kolkata is situated on the delta of River Ganga along the east bank of the Hoogly River, near Bay of Bengal. Majority of the landscape within the region was originally wetland, which has been consistently decreasing because of the unprecedented increase in population. The Kolkata Metropolitan Area (KMA) consists of four municipal corporations and 36 municipalities. The city has a rich culture and, unlike other cities in India, shows extreme passion for sports, especially football, which tends to attract a large number of tourists throughout the year. Kolkata is also known for its education sector, IT sector, banking sector, and heavy-scale industries. The city has completely taken advantage of the Port of Kolkata, which is one of the oldest operating ports in India, to export various consignments to other parts of the world.

Chennai is the capital city of the Tamil Nadu state. It is located at the eastern coast—Coromandel Coast, popularly known as the "Gateway to South India." It is one of the major metropolitan cities in India and has been one of the favorite destinations for tourism, industries, education, culture, and commerce. Chennai, which has a wide range of automobile industries, is famously called "Detroit of India" and is located in between two major rivers (i.e., Cooum and Adyar). Chennai has a tropical wet and dry climate with temperatures ranging from 15°C to 40°C. The jurisdiction of the Chennai (city) Corporation was expanded from 174 to 426 km^2 in 2011. The Chennai Metropolitan Area (CMA) has an area of 1189 km^2 comprising the Chennai city district and partially extending to two districts, Kancheepuram and Tiruvallur. Chennai is presently the fourth most populous city in India. The population of Chennai City has increased steeply from 4.34 million (2001) to 4.68 million (2011), whereas the CMA population shows an increase of 1.86 million based on the 2001 and 2011 census.

Bangalore is located in the southern part of India with an elevation of 900 m from the mean sea level. The city has been the capital of the Karnataka state since 1956. In 2006, the city administrative jurisdiction was expanded (known as Greater Bangalore) by merging existing city limits, eight urban local bodies, and 111 villages of the Bangalore urban district (Ramachandra and Kumar 2008). The city is located on a ridge and has numerous planned lakes (for storing water) that are interconnected and drain out to rivers from the three watersheds: Hebbal, Kormangala-Chellaghatta, and Vrishabhavathi (Ramachandra et al. 2015a). Bangalore was once called "Garden City" because of its lush green vegetation and large number of parks such as Lalbagh and Cubbon Park. After 2000, Bangalore experienced a huge population increase because of the establishment of a large number of information technology companies (the city has the nickname "Silicon Valley"). The city also houses public sector industries such as Bharat Electronics Limited, Hindustan Aeronautics Limited, National Aerospace Laboratories, Bharat Heavy Electricals Limited, and Bharat Earth Movers Limited. Because of the city's excellent transportation network and other infrastructure facilities, Bangalore is ranked third most productive metropolitan area of India.

Administrative boundaries of all mega cities were obtained from topographic maps or toposheets provided by Survey of India. The toposheets were geo-referenced and projected to respective Universal Transverse Mercator (UTM) zones. Bhuvan was used to supplement along with toposheets to ensure and delineate base layers such as administrative boundary, road and rail network, and drainage network. Each study area includes a 10-km buffer (from the administrative boundary centroid) to analyze and account for the land use changes in the future. Data collection involved obtaining ground control points (GCPs) using Global Positioning System (GPS). Bhuvan and Google Earth interfaces were used to collect data from remote areas and restricted areas where manual GPS data collection was not possible. They were also used to collect data in the form of points, lines, and polygons of industries, IT companies, educational institutes, healthcare units, road network, railway network, natural drainage network, restricted area, ecologically sensitive areas, coastal zones, and so on.

Satellite data starting from early 2000 to 2015 depending on availability were obtained from the US Geological Survey public domain website (https://earthexplorer.usgs.gov), which is available for free. Landsat 4, 5 (TM), 7 (ETM+), and 8 (OLI-TIRS) data were used for the analysis with a spatial resolution of 30 m. IRS LISS-III data were obtained from NRSC in case of missing Landsat data, with a spatial resolution of 23.5 m. GCPs were used to geo-register the satellite imageries to reduce any kind of discrepancy of temporal data.

7.5 METHOD

Figure 7.2 depicts the method adopted to assess urban growth patterns, which included three significant stages: data creation, land use and land cover analysis, and integrated model generation and validation.

7.5.1 Data Creation

Data were obtained from a survey of India topographic sheets. The sheets with scales of 1:50,000 and 1:250,000 were scanned with high resolution. City administrative maps were obtained from the respective metropolitan development authority database. Ground truth data of various locations within the study region were taken using handheld GPS. Places that were inaccessible and remote were visualized using Google Earth and Bhuvan.

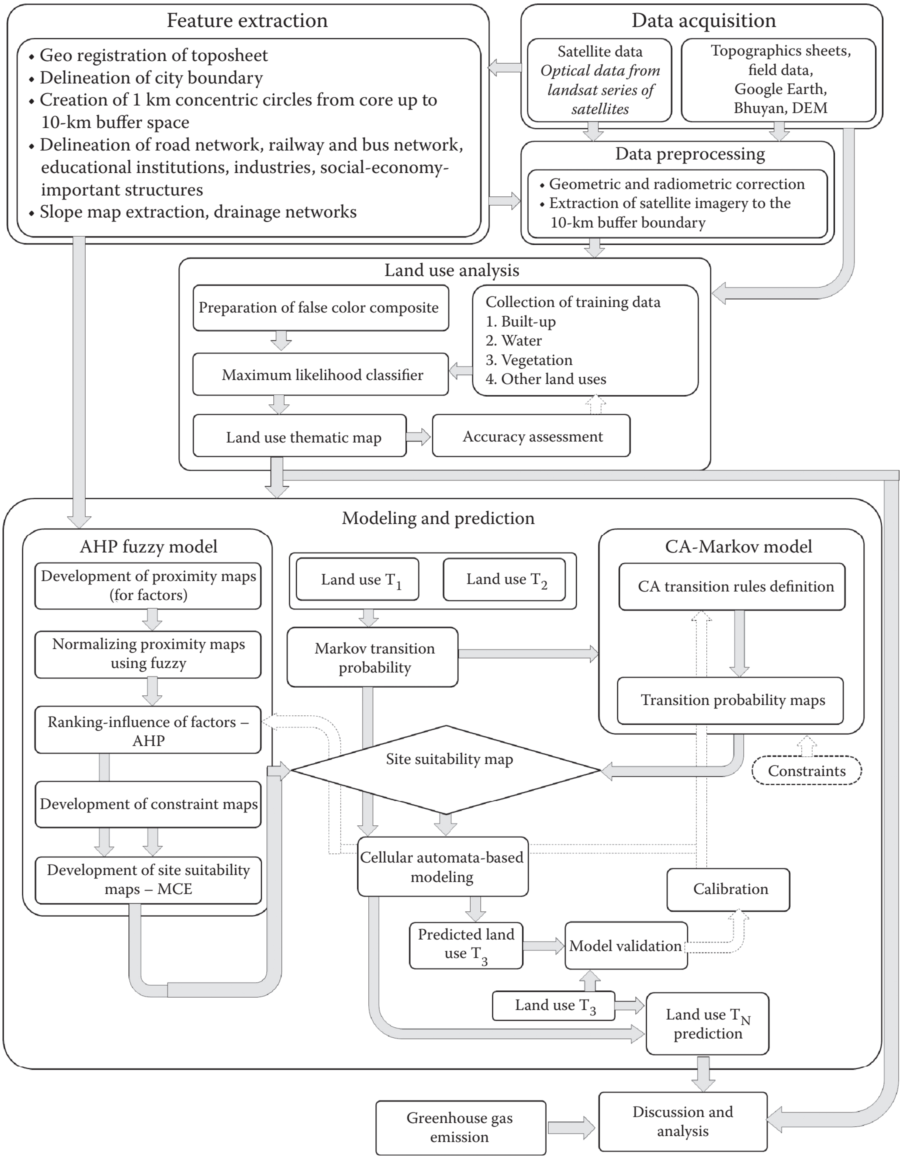

FIGURE 7.2 An integrated model approach.

All these data sets corresponding to different study regions were geo-referenced and re-projected to common datum world geodetic system 1984 (WGS84) and respective UTM zones to ensure uniformity in mapping. Hence, region-specific administrative boundary maps were obtained. Further, a 10-km buffer was drawn from the centroid of the central business district to better understand the urbanization process beyond city administrative boundaries. Concentric circles of 1-km radius were also delineated from the centroid along with four major directional grids (i.e., NE, NW, SE, and SW) to analyze minute changes within these fragments.

7.5.2 Land Use Analysis

Satellite data for various time periods were geo-referenced (to WGS84 and respective UTM zones), geo-corrected, rectified, and cropped, pertaining to different study regions. To maintain similar resolution and for better comparison, satellite data were resampled to 30 m using nearest-neighborhood function. Land use analysis was performed to understand change in landscape pattern throughout the study regions temporally. It involved the following process: (a) generation of a false color composite (FCC) image, (b) digitizing training polygons using FCC as base layer to distinguish heterogeneous features, (c) collection of training polygons via Google Earth (https://www.google.com/earth) (used as ancillary data for classification), (d) classification using Gaussian Maximum Likelihood (GML) classifier, and (e) validation and accuracy assessment. Land use analysis was performed using Geographical Analysis Support System open source software with four different categories as shown in Table 7.2.

A classification process is complete only when its accuracy is tested. Accuracy can be obtained by preparation of an error matrix or a confusion matrix (Congalton and Green 2008). User accuracy, producer accuracy, overall accuracy, and kappa statistics were calculated from the error matrix. Overall accuracy considers only diagonal elements of reference map and classified map, whereas kappa statistic takes into account off-diagonal elements as well (Lillesand et al. 2014).

7.5.3 Integrated Model Generation and Validation

Urbanizing agents and constraints were delineated in the form of points, lines, and polygons using Google Earth interface. Proximity maps were generated using minimum and maximum distance functions from each agent layer. Data values were normalized using fuzzy functions, and the entire range was between 0 and 255 (0 indicating no changes and 255 indicating maximum probability of change in land use types). The analytical hierarchical process was employed to estimate principal eigenvectors, and therefore, priority maps were created. Classified land use maps for initial stages, say, T_0, T_1, and T_2, were considered along with slope, and drainage layers analyzed using digital elevation model imageries were given as inputs to generate land use transitions

TABLE 7.2
List of Different Categories Used for Land Use Analysis and Corresponding Features

Category	Features Involved
Built-up	Houses, buildings, road features, paved surfaces, etc.
Vegetation	Trees, gardens, and forest
Water body	Seas, lakes, tanks, rivers, and estuaries
Others	Fallow/barren land, open fields, quarry site, dry river/lake basin, etc.

from T_0 to T_1 and from T_1 to T_2. Markov chain analysis was used to calculate the transition probability matrix based on two different time periods of classified images (Guan et al. 2008), where the probability of each land use type changing to the other remaining categories within the region considered is recorded after a specific number of iterations. Cellular automation with Markov chain was used to predict future land use for a specified year. Model validation was done by generating an error matrix for time period T_2 of both classified image versus simulated image.

7.5.4 Estimation of GHG Footprint

The method involved for calculating GHG can be divided into two significant steps. In the first step, a sector-wise approach was adopted to quantify GHG emissions. Various sectors and their description are given in Table 7.3. GHG

TABLE 7.3
Sector-Wise GHG Emission and Description

Sl. no.	Sector	Description
1	Energy sector: electricity consumption and fugitive emissions	Combustion of fossil fuels in thermal power plants; gases occurring during extraction, production, processing, and transportation of fossil fuels. Gas emissions include CO_2, SO_x, NO_x, SPM, and CH_4.
2	Domestic sector	Major contribution from activities like cooking (using LPG, firewood, and kerosene), lighting, and heating and from household appliances. CO_2, SO_x, NO_x and SPM.
3	Transportation sector	Emissions calculated by considering fuel consumed or distance traveled by various types of vehicles. Emissions from number of vehicles using compressed natural gas (CNG) were also accounted for. CO_2, SO_x, N_2O and CH_4.
4	Industrial sector	Major industries considered to emit CO_2 are iron and steel, ammonia manufacturing units, chemical products from fossil fuels, cement industry, petrochemical plants, fertilizer plants, power plants, glass industry, etc.
5	Agriculture sector	Includes paddy cultivation—the main phenomenon of CH_4 emissions from rice fields to atmosphere, agricultural soils, and burning of crop residues. Gases quantified under this sector are CH_4, N_2O (direct and indirect emissions), NO_x, and CO_2.
6	Livestock sector	Chief activities listed under animal husbandry include enteric fermentation and manure management. CH_4 and N_2O gases are calculated in this sector.
7	Waste sector	Methane is the major GHG emitted under the waste sector. The broad classes under waste can be listed as municipal solid waste disposal, domestic wastewater and industrial wastewater. Nitrous oxide (N_2O) emissions can occur both directly (from wastewater treatment plants) or indirectly (from wastewater after disposal of effluent to water bodies).

footprint was calculated using equation factors and various attributes as per Ramachandra et al. 2015b.

The major GHGs that were taken into consideration were carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The second step included the conversion of non-CO_2 gases into units of CO_2 equivalent (CO_2e), and the aggregation of CO_2e was conducted as a region-specific analysis covering all the five study regions.

7.6 RESULT AND OUTCOMES

7.6.1 Land Use Analysis

Land use for different time periods was assessed using GML classifier. Dramatic changes in the landscape of various parts of India for over three decades are shown in Figure 7.3. Mumbai has shown a significant increase in built-up areas from 3.32% in 1973 to 14.26% in 2009. An extensive decrease of 74% can be seen in vegetation

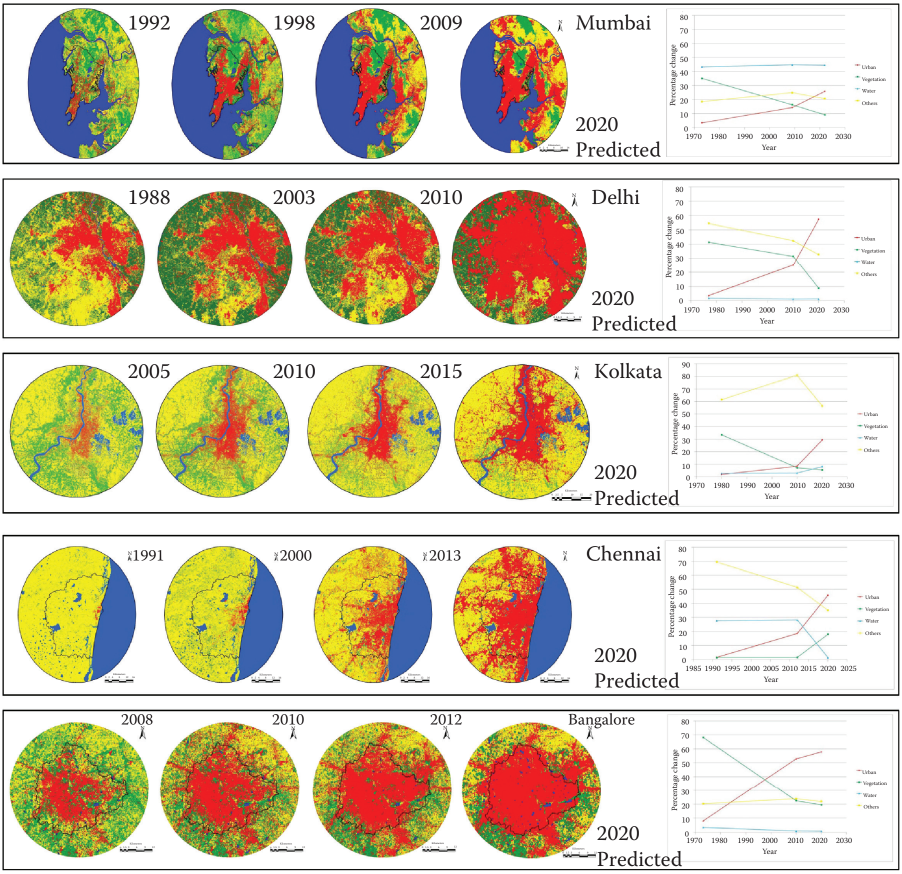

FIGURE 7.3 Temporal landscape dynamics of study regions.

category from 1973 to 2009. In terms of urbanization and urban sprawl, Delhi is no different from Mumbai, since it also shows an increase in impervious urban areas from 3.6% to 25.06% over a period of 33 years. This tremendous change in landscape makes surrounding places more vulnerable to various hazards and issues such as ecological imbalance (Riley et al. 2005; Xian et al. 2007), change in rainfall pattern leading to urban floods (Bronstert et al. 2002; McCuen and Beighley 2003), formation of urban heat island, traffic density congestion and therefore increases in air pollution, stress on surface as well as subsurface water resource, and so on. Further, density gradient analysis showed agents that fueled rapid urban growth in and around the Indira Gandhi International Airport (IGI) and the Indian Air Force base (Hindon). Classification results for Kolkata indicate a steep increase in urban category, which occurred at the cost of wetland and agriculture land degradation in various places (Ramachandra et al. 2014c).

Results for the Chennai region revealed a surge in built-up areas of 72% (1991–2000) and 646% (2000–2013). It is necessary to note that the growth that occurred especially in 2000 and 2010 is attributed to industrial and information technology policy measures. Industries play a key role in the urban growth process by attracting a huge number of populations from core city areas to urban fringe or transition zones; these zones later become part of a greater city region. Land use results for the Bangalore region shows a twofold increase in urban area from 24.86% to 48.39% within a span of 4 years (2008–2012). During this period, Bangalore lost a huge amount of trees especially due to pressure from construction of buildings, expansion of roadways, introduction of the metro-rail system, and so on. The vegetation cover decreased from 38.34% to 26.40%, showing unplanned urban growth.

7.6.2 Validation

Accuracy assessment for land use classification was performed based on kappa statistics and overall accuracy as shown in Table 7.4. The results of overall accuracy indicate that classified maps along with ground truth have a lot of resemblance and are therefore accurate.

7.6.3 Modeling and Prediction

Land use transitions were calculated to determine land use change for the year 2020 for Mumbai, Delhi, Kolkata, Chennai, and Bangalore. Markov chain was used to derive probability of change between two time periods. Knowing the land use of T_0 and T_1, the land use of time period T_2 was predicted. Prediction was made considering important urbanizing agents such as industries, educational institutes, road network, rail network, hospitals, and other service facilities. Constraints such as water bodies, wetland areas, protected areas, and so on were assumed to remain constant over all periods of time. Predicted results for time T_2 were compared with classified maps for time period T_2 to validate the data sets. Predicted maps were observed to be in good agreement, obtaining high accuracy and kappa values. Therefore, the process was repeated to predict land use for the period T_n. Cities like Delhi and Kolkata have shown a twofold increase in paved areas from time period T_2 to T_n.

TABLE 7.4
Overall Accuracy and Kappa Statistics

City	Mumbai			Delhi			Chennai			Kolkata			Bangalore		
Year	1992	1998	2009	1988	2003	2010	1991	2010	2013	2005	2010	2015	2008	2010	2012
Overall accuracy (%)	73	99	97	99	88	91	92	91	97	88	93	91	94	98	97
Kappa	0.81	0.82	0.81	0.99	0.84	0.96	0.92	0.9	0.9	0.9	0.99	0.96	0.98	0.96	0.95

Density and gradient analysis for the predicted areas confirmed that core urban areas are clumped as one large built-up patch, thereby not giving any other category the chance to develop.

7.6.4 Transition Probability

Based on land use during T_1 and T_2, Markov transition potentials were computed, and the probability matrices of each land use type are given in Table 7.5. Diagonal elements indicative of land use classes being the same and other elements indicate the probability of land use to transition into land use classes. The results for most of the cities and built-up areas remain almost constant; non-urban land use classes have a higher

TABLE 7.5
Markov Transitional Probability for Study Regions

		Built-Up Areas	Water Bodies	Vegetation	Others
	Markov Transition Probabilities for Mumbai for the Period 1998–2009				
1998–2009	**Built-up areas**	0.990	0.000	0.000	0.010
	Water bodies	0.332	0.634	0.030	0.004
	Vegetation	0.486	0.003	0.475	0.036
	Others	0.623	0.001	0.002	0.374
	Markov Transition Probabilities for Delhi for the Period 2003–2010				
2003–2010	**Built-up areas**	0.970	0.000	0.002	0.028
	Water bodies	0.38	0.604	0.008	0.008
	Vegetation	0.528	0.001	0.431	0.04
	Others	0.613	0.001	0.018	0.368
	Markov Transition Probabilities for Kolkata for the Period 2010–2015				
2010–2015	**Built-up areas**	0.992	0.000	0.000	0.008
	Water bodies	0.18	0.754	0.005	0.061
	Vegetation	0.612	0.001	0.386	0.001
	Others	0.693	0.000	0.006	0.301
	Markov Transition Probabilities for Bangalore for the Period 2010–2015				
2008–2012	**Built-up areas**	0.998	0.000	0.000	0.002
	Water bodies	0.604	0.386	0.004	0.006
	Vegetation	0.793	0.001	0.177	0.029
	Others	0.486	0.002	0.006	0.506
	Markov Transition Probabilities for Chennai for the Period 2010–2015				
2008–2012	**Built-up areas**	0.948	0.000	0.030	0.022
	Water bodies	0.326	0.645	0.008	0.021
	Vegetation	0.516	0.000	0.467	0.017
	Others	0.294	0.004	0.013	0.689

probability of transitioning into an urban land use class. Bangalore showed substantial loss of water bodies and vegetation (as also reported by Ramachandra et al. 2017; Ramachandra and Bharath 2016). Kolkata and Chennai also follow the same trend.

7.6.5 GHG Footprint

Results from the energy sector revealed that Delhi has the highest commercial CO_2e emission. The Delhi region consumed 5339.63 MU of electricity during 2009–2010, releasing 5428.55 Gg of CO_2. The Kolkata region, which released approximately 1746.34 Gg of CO_2, contributed the least among the five cities. Delhi also showed maximum CO_2e for the domestic sector, with 11,690.43 Gg, followed by Chennai (8617.29 Gg), Greater Mumbai (8474.32 Gg), Kolkata (6337.11 Gg), and Bangalore (4273.81 Gg). Transportation sector emissions were recorded for vehicles using fuel CNG and non-CNG separately. The lowest value under this sector was for the Kolkata region, with 1886.60 Gg of emission from the non-CNG category only, whereas the peak values were observed for the Delhi region with 10,867.51 Gg under the non-CNG category and 1527.03 under CNG vehicles. The industry sector emission results revealed that ammonia production and fertilizer industries in Greater Mumbai and Chennai yielded 654.5 and 223.28 Gg of CO_2e, respectively. The Delhi region had a large amount of CO_2e emission from the agriculture sector (17.05 Gg from paddy cultivation, 248.26 Gg from soils, and 2.68 Gg from crop residue burning), followed by Bangalore (5.10 Gg from paddy cultivation and 113.86 Gg from soils). The livestock management and waste sector also had similar results, where Delhi was at the peak in terms of CO_2e emission followed by other regions. The combination of all these sectors clearly indicates that the range varies from 38,633.20 Gg/year (Delhi region) to 14,812.10 Gg/year (Kolkata region). Furthermore, sector-wise analysis shows that, of all the considered sectors, the transportation sector (Delhi, 32.08%; Bangalore, 43.48%) and the domestic sector (Mumbai, 37.20%; Chennai, 39.01%; Kolkata, 42.78%) have the highest emissions. The huge emissions from the transportation sector can be attributed to unplanned urbanization as well as to a lack of public transportation system, as a result of which people tend to use private vehicles. The results sector-wise are presented in Figure 7.4.

7.7 DISCUSSION AND CONCLUSION

Land use assessment that showcased urban growth has been phenomenal and would prosper with the help of initiatives that a growing economy like India would be providing. Accuracy assessment provided insights into accurate land use maps and their usability. Further GHG emission quantification would help toward the development of an indicator that would govern all aspects of sustainable development goals (SDGs) as described by the United Nations. In June 2015, the government of India has envisioned the development of smart cities through physical, institutional, and social infrastructures under its smart cities mission. That would help in understanding city growth and in improving quality of life. More possibly to improve socioeconomic cultural visibility of these smart cities to attract foreign investments. However, with this mission, there would be rapid urbanization as predicted, which means inadequacy of resources to match the rate of urbanization. The smart cities

FIGURE 7.4 GHG emissions of study regions.

mission should develop an urban observatory to fill in the gaps in current land use and to monitor the sustainable goals of the urbanization process and all its dimensions and then create plans using these digital observations to improve strategies.

Strategies here are in the form of major components such as the following: (i) Green field development through smart townships. A holistic land management approach should be used here. (ii) Adoption of smart applications like transport, reuse, and recycle of wastewater; smart metering; recovering energy from solid waste; and so on. This would reduce pressure on nonrenewable sources of energy. (iii) Retrofitting current cities to match the comfort and security offered by existing climate-resilient infrastructures by reducing GHG footprint. (iv) Development of existing built-up areas through the creation of new combinations of land uses and improving infrastructure and amenities considering the location and needs of the citizens. (v) Maintaining the carrying capacity of the city, considering the available resources for citizens' use; otherwise, there would be increased GHG emissions.

This necessitates very efficient and citizen-friendly decision making through (i) understanding integrated land use planning based on the carrying capacity of a city, (ii) improving public transit system and making it more citizen friendly (especially because of the large amount of GHG emissions from the transport sector), (iii) improving and developing mass rapid-transport systems, and (iv) improving the application of ICTs and forming an urban data observatory as enabling technologies.

As shown in analyses, most cities are facing a crisis in terms of senseless unplanned rapid urbanization. Environmentally friendly urban centers with basic amenities and advanced infrastructure (such as sensors, electronic devices, and networks) would stimulate sustainable economic growth and improvements in citizen-centric services. This improvement in citizen-centric services can be realized if the data collected by the government and other stakeholders can be accessed and used by citizens. This could be possible by building different tiers of data repositories. Each tier would represent a specific need and a specific objective. This also includes developing a spatial database infrastructure that is connected and more accessible, forming an interconnected database network system or Internet of things, which, in turn, leads to huge databases that can be adopted for decision making with data security aspects in mind. This will eventually develop into an urban observatory. This would allow piling up of sufficient useful data in databases that would contribute to effective and coordinated governance, which would then support urban growth through improved economy and active participation of citizens. Although these cities are undergoing smart technological innovations through connectedness of data, this is limited to a certain network of users and should be used to focus on increased living comfort through providing adequate infrastructure, green spaces, and basic amenities to every citizen.

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