Visualization of Land-Use/Land-Cover Changes in Major Asian and African Cities

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1. Introduction

Due to various socioeconomic activities and natural phenomena, many parts of the globe are undergoing rapid land-use/land-cover (LULC) changes. These changes are occurring across spatial scales from local to global and at temporal frequencies of days to millennia (Townshend et al. 1991). Understanding the process and pattern of LULC changes over space and time remains one of the important key topics in various fields such as sustainability, global environmental change, and land-change and geospatial sciences.

Remote sensing technology has a long history of supporting LULC map development, even before the launch of the first Landsat platform in 1972 (Sohl & Sleeter 2011). Prior to the availability of satellite imagery, aerial photography served as a primary source of information for LULC mapping and still remains an important source today (Akbari et al. 2003). In recent years, low to medium spatial resolution (multispectral: 5~250 m; e.g. MODIS, ASTER, ALOS, SPOT, LANDSAT) and high spatial resolution (multispectral: 0.6~5 m; e.g. IKONOS, QuickBird, GeoEye) satellite images have been used in LULC change-related studies. Remote sensing satellite data, combined with geographical information system (GIS) tools and techniques, provide more efficiency in LULC mapping and change detection and modeling. Satellite remote sensing is a relatively inexpensive and efficient method of acquiring up-to-date information about the LULC of a large geographical area, compared to the traditional aerial photogrammetry and land surveys. It is also one of the practical methods used for obtaining data for inaccessible regions.

The terms “land use” and “land cover” are often used interchangeably in the literature and daily practice. Forest cover, glacier cover, lakes, wetlands, agriculture, and water can be considered as land cover. Land cover is defined as the immediate surface, including biota, soil, topography, surface and ground water, and human structure (mainly built-up) (Lambin et al. 2006), while the term "land use" indicates how human beings utilize or associate the landscape of any area. In other words, a parcel of land (land cover) can be utilized for or associated with activities such as forestry, animal husbandry and farmland, etc. In this context, land use is defined as the purpose for which humans exploit the land cover. It involves both the manner in which biophysical attributes of the land are manipulated and the intent underlying that manipulation (Lambin et al. 2006). Natural and physical scientists are more interested in land-cover changes, while geographers, anthropologists and planners focus more on land-use changes (Turner & Meyer 1994). The less deviation between land use and land cover has created a common platform for the discussion of LULC change.

The knowledge of LULC is important in the management of the earth's resources in general, and in landscape and urban planning in particular. LULC changes are so pervasive that, when aggregated globally, they significantly affect key aspects of earth system functioning (Lambin et al. 2001). LULC changes are usually examined from various perspectives in order to identify the drivers of such changes and their processes and consequences at different spatial and temporal scales. The new era of LULC mapping started after NASA's launch of the Earth Resource Technology Satellite (later renamed Landsat) in July 1972. Landsat still remains as a primary satellite data provider globally. In the context of LULC classification, the 1976 publication "A Land Use and Land Cover Classification System for Use with Remote Sensor Data" provides a classification system that defines LULC categories that can be derived from remote sensing satellite images (Anderson 1976). Over the years, many satellite data sources and classification systems have emerged, parallel to the advancement of satellite remote sensing technology. Indeed, "the ever-expanding constellation of satellite platforms has acquired thousands of trillions of bytes of data invaluable for planning and land management applications" (Rogan & Chen 2004, p. 304). The early applications of remote sensing technology were largely experimental, but soon expanded in the field of land-change science (Gutman et al. 2004; Turner et al. 2007), also known as land-use science (Aspinall 2006; Müller & Munroe 2014) and land-system science (Reenberg 2009; Verburg et al. 2013).

The recent advances in remote sensing technology has, in one way or another, helped researchers investigate the pattern and process of LULC change in various contexts, such as in the contexts of vegetation analysis (e.g. Goodchild 1994; Stow et al. 2004; Anderson et al. 2010; Hüttich et al. 2011; Yang et al. 2012; Smith et al. 2014), urban/suburban studies (e.g. Chan et al. 2001; Seto et al. 2011; Benediktsson et al. 2003; Chen et al. 2006; Mundia, Aniya & Murayama 2011; Thapa & Murayama 2008; Estoque & Murayama 2013a, 2014, 2015, 2016; Bagan & Yamagata 2014), wetland monitoring (e.g. Chopra et al. 2001; Phinn et al. 2000; Tong et al. 2014), crop mapping and monitoring (e.g. Moran et al. 1997; Fang 1998; Ferencz et al. 2004; Bellvert et al. 2013) and ecosystem services (e.g. Nelson et al. 2009; Polasky et al. 2011; Estoque & Murayama 2012, 2013b, 2016). Using satellite remote sensing and other ancillary data, future LULC changes can also be projected (e.g. Estoque & Murayama 2012, 2014, 2016; Thapa & Murayama 2012a, 2012b; Vimal et al. 2012; Arsanjani et al. 2013; Moghadam & Helbich 2013).

In recent years, efforts have been made by various organizations and institutions around the world to establish global LULC databases. For example, in 2010, the National Geomatics Center of China launched the GlobeLand30 mapping project and produced a 30 m global land-cover data product with 10 categories for the years 2000 and 2010 (http://www.globallandcover.com). The Lincoln Institute of Land Policy (http://www.lincolninst.edu) (Angel et al. 2012) has produced the Atlas of Urban Expansion, providing some important information about the spatiotemporal dimension of LULC changes in some major cities around the world. Recently, the Food and Agriculture Organization (FAO) of the United Nations (UN) has also developed a LULC database, called the Global Land Cover-SHARE, for the year 2014 under the Global Land Cover Network (GLCN) (http://www.glcn.org). About 14 years ago (2000), the Joint Research Centre of the European Commission developed the Global Land Cover 2000 database (http://bioval.jrc.ec.europa.eu). The European Space Agency (ESA) has also developed global LULC maps for the 2000, 2005 and 2010 epochs (http://www.esa-landcover-cci.org/?q=node/158). The Socioeconomic Data and Applications Center (SEDAC) of NASA (http://sedac.ciesin.columbia.edu) is another database that provides verification of LULC data at the regional level.

The rapid expansion of urban areas is affecting the earth's LULC pattern. According to the UN statistics for the year 2014, 54% of the world's total population live in urban areas (UN 2014). If the current trends continue, the world's urban population is expected to increase up to 66% by 2050 (UN 2014). In 1950, the world's urban population was 30% (UN 2014). These statistics show that the growth of urban population has been very rapid in the past six decades. According to the UN, "several decades ago most of the world's largest urban agglomerations were found in the more developed regions, but today's large cities are concentrated in the global south. The fastest growing urban agglomerations are medium-sized cities and cities with less than one million inhabitants located in Asia and Africa" (UN 2014, p. 1). Furthermore, LULC changes in the unplanned urban areas of the developing countries are also faster than in the developed countries (Haregeweyn et al. 2012).

Some studies have focused on the urbanization patterns in the developing countries, especially in the Asian and African regions (Estoque & Murayama 2011, 2015; Mundia et al. 2011; Yamashita 2011; Thapa & Murayama 2012a, 2012b; Dadras et al. 2014; Estoque et al. 2014). Analyses and projections of urbanization patterns can help with the assessment of ecosystem changes and their environmental implications at various temporal and spatial scales (Lambin & Ehrlich 1997). Additionally, the time-space relationship is also important for understanding the dynamic process of urban growth and LULC changes (Thapa & Murayama 2012a). We recognize that these types of analyses are important for landscape and urban planning toward sustainable urban development. However, these analyses can only be done if LULC data are available.

In most Asian and African cities, however, the availability of multi-temporal and spatially consistent LULC maps is still limited. Remote sensing technology supports LULC mapping and spatiotemporal change detection across different landscapes, including urban areas. The Landsat series is one of the most important source of satellite data for spatiotemporal LULC change analysis. The start of the Landsat series, i.e. 1972, is also parallel to the rapid urban expansion in the Asian and African regions, i.e. approximately after the year 1970. Thus, Landsat images are important sources of data for the study of urbanization-related LULC changes in the Asian and African regions.

The primary objective of this project is to establish a database of LULC maps derived from remote sensing satellite images (Landsat images) for a number of major Asian and African cities. It aims to detect the changes in the landscape of these cities and examine how the spatial structure of each city has changed over the years (2000–2014). The remainder of this report is structured as follows: Chapter 2 describes some of the available satellite data and their characteristics; Chapter 3 provides an overview of LULC classification methods and describes the data processing methodologies employed in this project; Chapter 4 presents the classification and change detection results for each city; and Chapter 5 summarizes the findings.

2. Data availability

Remote sensing satellite images are important sources of data for LULC mapping and change detection. Remote sensing can be categorized into two types: active remote sensing and passive remote sensing.

An active sensor is a radar instrument used for measuring signals transmitted by the sensor that were reflected, refracted or scattered by the earth's surface or its atmosphere (http://www.nasa.gov). RADAR and LiDAR are examples of active remote sensing in which the time delay between emission and return is measured, establishing the location, speed and direction of an object (http://www.nasa.gov). Active remote sensing depends on airborne remote sensing systems, which acquire data for specific needs and fly when the weather conditions are optimal. Users can choose the wavelength bands, area, season and other parameters based on their needs. However, active remote sensors do not offer continuous datasets because they only acquire data 'by order'. If and when active remote sensing data are needed, the users need to consider the costs and time delay in the ordering process.

On the other hand, a passive sensor is a microwave instrument designed to receive and measure natural emissions produced by the earth's surface features and its atmosphere (http://www.nasa.gov). Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, infrared and radiometers. Nowadays, most passive remote sensing systems are based on satellites, designed for monitoring earth's surface conditions and providing long-term, continuous data for the whole globe. In this project, we used passive remote sensing data (satellite data) for several reasons: (1) the project needs remote sensing data for a number of cities in Asia and Africa; (2) remote sensing satellites provide data for the required time period (2000-2014); (3) the cost of remote sensing satellite data is less than that of airborne remote sensing; and (4) some remote sensing satellite data are free (e.g. Landsat data).

Remote sensing systems differ in the level of detail or resolution they can capture. There are four different aspects of resolution important in remote sensing: spatial, spectral, radiometric and temporal. Spatial resolution refers to the smallest feature discernible in an image. Spectral resolution refers to the number and width of spectral bands recorded for an image. The number of values available to record the brightness levels in an image is a measure of radiometric resolution, while temporal resolution refers to the frequency of image acquisition. These four sensor characteristics need to be considered in the selection of remote sensing data best suited for a specific application (Aronoff 2005). Based on spatial resolution, satellite images can be categorized into three: low, medium and high spatial resolution.

2.1. Low spatial resolution satellite images

Low spatial resolution satellites produce coarser images (e.g. Fig. 2.1) than the other two types. In some cases, however, low spatial resolution satellite images have their own advantages. For example, when a LULC classification needs to be done over a large area, low spatial resolution satellite images can reduce the cost and time since they cover a wider area (e.g. MODIS vs. QuickBird). The Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) are two examples of low spatial resolution satellite sensors.

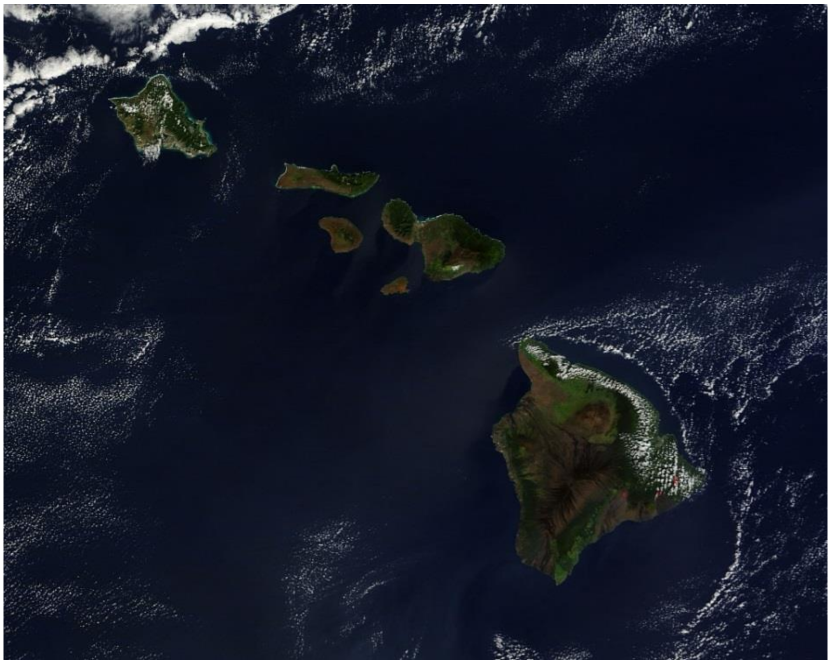

Fig. 2.1. Low spatial resolution image (500 m): MODIS image of Hawaii
Data source: http://modis.gsfc.nasa.gov
RGB Combination: True color (Red-band 1; Green-band 4; Blue-band 3)
Date: 2014.12.20

MODIS

MODIS is a payload scientific instrument launched into earth orbit by NASA in 1999 on board the Terra (EOS AM) satellite, and in 2002 on board the Aqua (EOS PM) satellite. The MODIS instrument is the primary sensor for acquiring data of global coverage. It has a wide swath of 2330 km and can cover the earth in 1 to 2 days. The instrument provides 36 spectral bands ranging from 0.4 µm to 14.4 µm wavelength at spatial resolutions of 250 m (2 bands), 500 m (5 bands) and 1 km (29 bands) (http://modis.gsfc.nasa.gov). They are designed to provide measurements in large-scale global dynamics, including changes in the earth's cloud cover, radiation budget, and processes occurring in the oceans, on land, and in the lower atmosphere (Abtew & Melesse 2012).

NOAA AVHRR

The AVHRR is a broadband, four or five-channel scanner (depending on the model), sensing in the visible, near-infrared and thermal infrared portions of the electromagnetic spectrum. The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and surface temperature (http://noaasis.noaa.gov). The AVHRR sensors produce imagery data with a spatial resolution of 1.1 km GSD in five or six wavelength bands, depending on the satellite. The image is received as a continuous image covering a 2400-km wide area. The data are supplied in two formats: 1.1 km spatial resolution local area coverage (LAC) imagery and 4 km spatial resolution global area coverage (GAC) imagery. AVHRR data are used in a variety of time-critical and large-area applications (Aronoff 2005). Examples include weather forecasting, assessment of snow coverage and depth, monitoring of crop conditions, and forest fire detection.

2.2. Medium spatial resolution satellite images

Medium spatial resolution satellites (multispectral: 5 m to 250 m) such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Advanced Land Observing Satellite (ALOS), SPOT (Satellite Pour l'Observation de la Terre, French for “earth observation”) and Landsat TM/ETM+/OLI are used in the generation of quantitative LULC maps for regional scale land-change studies (Powell et al. 2007). Medium spatial resolution satellite images (e.g. Fig. 2.2) enable applications in various fields such as agriculture, forestry, geology, archaeology, and urban and regional land-use planning. Using ASTER images, Pareta & Pareta (2011) were able to study forest carbon management. In Sabah, Malaysian Borneo, Morel et al. (2011) were able to estimate the above-ground biomass of a forest and an oil palm plantation using ALOS PALSAR data. And in Madrid, Hewitt & Escobar (2011) were able to examine the territorial dynamics and detect the changes in fast-growing regions with Landsat images. Many researchers in the field of remote sensing and geospatial sciences select images in this category because of spatial resolution (medium) and cost (Landsat data are free).

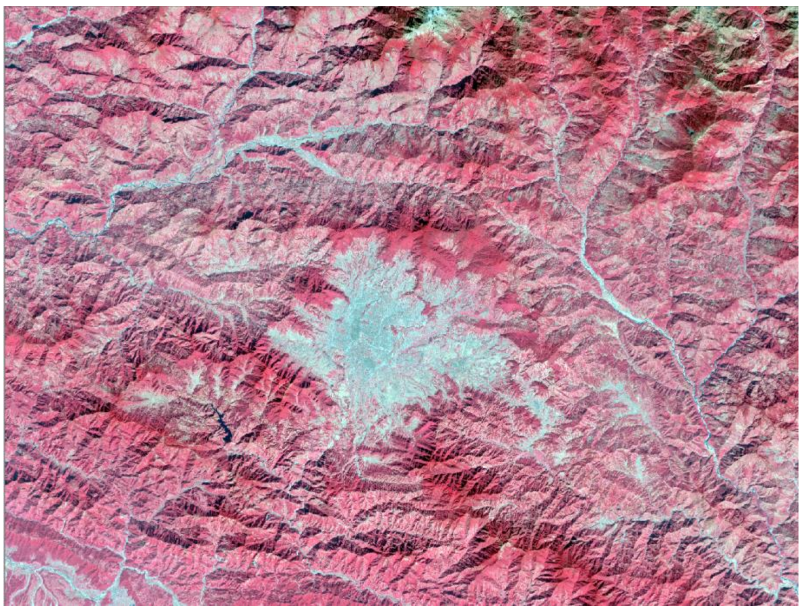

Fig. 2.2. Medium spatial resolution image (30 m): Landsat-8 image of Kathmandu
Data source: http://earthexplorer.usgs.gov
RGB Combination: Color Infrared (Red-band 5; Green-band 4; Blue-band 3)
Date: 2013.11.18

Landsat

The Earth Resources Technology Satellite (ERTS-1), known as Landsat-1, was the first satellite designed to provide systematic global coverage of earth resources (Aronoff 2005). Later, the Landsat program launched a series of satellites named as Landsat-2 – Landsat-8. The Landsat sensors collect data every 16-day revisit, producing a large amount of archived data (Dalsted et al. 2003). Of the suite of medium spatial resolution satellites, Landsat is the most widely used for earth observation applications. A survey by the American Society for Photogrammetry and Remote Sensing found that the majority of respondents (71%) use Landsat as their primary source of medium spatial resolution satellite data (Powell et al. 2007). The popularity of Landsat data can be attributed to some of the Landsat program's key characteristics, including a systematic data acquisition plan and archiving procedure that ensures global coverage and data availability. Further, the program's free data distribution policy has resulted in a widespread use. The keys to Landsat's popularity also include the features of the Landsat data: its large footprint and a spatial resolution fine enough to characterize typical land cover dynamics related to land management.

ASTER

ASTER, a Japanese sensor, is one of the five remote sensory devices on board the Terra satellite launched into earth orbit by NASA in 1999 (http://asterweb.jpl.nasa.gov). The instrument has been collecting superficial data since February 2000. ASTER provides images of the planet earth in 14 different bands of the electromagnetic spectrum, ranging from visible to thermal infrared light. The spatial resolution of ASTER images ranges from 15 to 90 m. ASTER consists of three instruments: the visible and near-infrared (VNIR), the shortwave infrared (SWIR) and the thermal infrared (TIR). VNIR produces images in four bands with a spatial resolution of 15 m, SWIR offers 30 m spatial resolution images with six bands, and TIR has five bands with a spatial resolution of 90 m. ASTER data are used to measure snow and ice distribution, vegetation types, rock and soil properties, surface temperature, and cloud properties (Aronoff 2005).

ALOS

ALOS was launched by the Japan Aerospace Exploration Agency (JAXA) in January 2006. The dimensions of ALOS are 3.5 m wide × 4.5 m long × 6.5 m high, and its gross weight is approximately 4 tons; one of the largest among land observing satellites. ALOS has three remote sensing instruments, namely the PRISM, AVNIR-2 and PALSAR (Remote Sensing Technology Center of Japan). The Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) is a panchromatic radiometer for collecting high spatial resolution terrain data including elevation. The Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near-infrared radiometer for observing land and coastal zones. Lastly, the Phased Array type L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor for cloud-free and day and night land observation. The major missions of ALOS include cartography, regional observation, disaster monitoring, and resource surveying (JAXA 2008).

SPOT

SPOT is a commercial earth observation satellite system operating from space, run by Spot Image, based in Toulouse, France. It was designed for exploring the earth's resources, detecting and forecasting phenomena involving climatology and oceanography, and monitoring human activities and natural phenomena (http://www.cnes.fr). The SPOT system has already launched seven satellites (named SPOT 1 to SPOT 7). With a 60-km wide swath, the SPOT satellites provide a coverage of the earth within 26 days. SPOT 1, 2, 3 and 4 provide panchromatic and multispectral imagery with a spatial resolution of 10 m and 20 m, respectively. SPOT 5, launched in 2002, has a spatial resolution of 2.5 to 5 m in panchromatic mode and 10 m in multispectral mode. SPOT 6 and SPOT 7, launched in 2012 and 2014, have a higher spatial resolution of 1.5 m in panchromatic mode and 6 m in multispectral mode.

2.3. High spatial resolution satellite images

High spatial resolution satellite sensors require higher capacity in computer storage and processing. So they appeared later than low and medium spatial resolution satellite sensors. High spatial resolution satellites are operated as commercial ventures. Image acquisition programs are tailored to produce commercial products of selected geographic regions to meet the needs of government and private-sector clients (Aronoff 2005). High spatial resolution satellite images (e.g. Fig. 2.3) are the basis for the generation of qualitative land-use maps (i.e. land-use zoning maps) and the delineation of transportation networks (Lwin et al. 2012). High spatial resolution satellites have the highest-quality images, but also have the most expensive ones among the three types of satellites. QuickBird and IKONOS are examples of high spatial resolution satellite sensors.

Fig. 2.3. High spatial resolution image (0.61 m): Pansharpened QuickBird image of AZADI Tower in Tehran
Data source: http://www.satimagingcorp.com
RGB Combination: Natural Color (Red-band 3; Green-band 2; Blue-band 1)
Date: 2009.6.26

IKONOS

IKONOS is a commercial earth observation satellite, and was the first to collect publicly available high spatial resolution imagery at 1 and 4 m spatial resolution. It offers multispectral and panchromatic images. The sensor is point-based, allowing viewing at angles of up to ±45° in the across-track or along-track directions (Aronoff 2005). This provides more frequent imaging of a given area. The IKONOS launch was called "one of the most significant developments in the history of the space age" (Bergquist 2011).

QuickBird

QuickBird is a high spatial resolution commercial earth observation satellite owned by DigitalGlobe. It was launched in 2001 as the first satellite in a constellation of three scheduled to be in orbit by 2008. QuickBird uses the Ball Aerospace's Global Imaging System 2000, known as BGIS 2000. The satellite collects panchromatic (black and white) imagery at 61 cm spatial resolution and multispectral imagery at 1.63 m to 2.44 m spatial resolution, as orbit altitude is lowered during the end of mission life (https://www.digitalglobe.com). At these spatial resolutions, buildings and other infrastructure are clearly visible. The imagery can be imported into remote sensing image processing software, as well as into GIS packages for analysis. The imagery can also be used as a backdrop for mapping applications, such as Google Earth and Google Maps.

In general, higher spatial resolution images supply more information. However, it should be mentioned that high spatial resolution images are not always the best choice. Cost and purpose need to be considered. If the goal of remote sensing is to identify large 'abnormal' areas, then the pixel size can be increased with the size of the 'abnormality'. If the users intend to use remote sensing data for direct ground scouting, then sufficient resolution to identify land features may be needed (Dalsted et al. 2003).

Table 2.1 summarizes the characteristics of satellite sensors widely used for earth resource remote sensing. In this project, we used Landsat satellite images based on the following considerations: resolution requirements, turnaround and revisit period, spectral bands measured by the sensor, and data processing requirements. As mentioned earlier, the popularity of Landsat data can be attributed to some of the Landsat program's key characteristics, including its systematic data acquisition plan and archiving procedure that ensures global coverage and data availability. For this project, we needed Landsat data for over 30 major cities in Asia and Africa at two time points: ca. 2000 and 2014.

Table. 2.1. Characteristics of satellite sensors widely used for earth resource remote sensing.

Platform	Sensor	Band number	Channel	Wavelength (µm)	Spatial resolution (m)	Revisit or cycle period	Swath width
NASA Terra and Aqua satellites[1]	MODIS[1]	1 2 3 4 5–7 8–10 11–12 13–14 15–19 20–25 26 27–36	Red NIR Blue Green SWIR Blue Green Red NIR TIR SWIR TIR	620–670 841–876 459–479 545–565 (see footnote) 1.36–1.39 	250 250 500 500 500 1000 1000 1000 1000 1000 1000 1000	1–2 days	2330 km
NOAA 11,12, 14,15, 16,17[2]	AVHRR	1 2 3A 3B 4 5	Green, Red NIR SWIR SWIR TIR TIR	0.58–0.68 0.73–1.00 1.58–1.64 3.55–3.93 10.30–11.30 11.50–12.50	1100	12 hours	2400 km
Landsat-5[3]	TM	1 2 3 4 5 6 7	Blue Green Red NIR SWIR 1 TIR SWIR 2	0.45–0.52 0.52–0.60 0.63–0.69 0.76–0.90 1.55–1.75 10.4–12.5 2.08–2.35	30 30 30 30 30 120 30	16 days	185 km
Landsat-7[4]	ETM+	1 2 3 4 5 6 7 8	Blue Green Red NIR SWIR 1 TIR SWIR 2 Pan	0.45–0.52 0.52–0.60 0.63–0.69 0.77–0.90 1.55–1.75 10.4–12.5 2.09–2.35 0.52–0.90	30 30 30 30 30 60 30 15	16 days	185 km

[1] http://modis.gsfc.nasa.gov/about/specifications.php

[2] http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html

[3] http://landsat.usgs.gov/about_landsat5.php

[4] http://landsat.usgs.gov/about_landsat7.php

Landsat-8[5]	OLI/TIRS	1	Coastal	0.43–0.45	30	16 days	185 km
		2	Blue	0.45–0.51	30		
		3	Green	0.53–0.59	30		
		4	Red	0.64–0.67	30		
		5	NIR	0.85–0.88	30		
		6	SWIR 1	1.57–1.65	30		
		7	SWIR 2	2.11–2.29	30		
		8	Pan	0.50–0.68	15		
		9	Cirrus	1.36–1.38	30		
		10	TIRS 1	10.60–11.19	100		
		11	TIRS 2	11.50–12.51	100		
Terra[6]	ASTER[6]	1	Green	0.52–0.60	15	By request	60 km
		2	Red	0.63–0.69	15		
		3	NIR	0.78–0.86	15		
		4–9	SWIR	(see footnote)	30		
		10–14	TIR		90		
SPOT 1, 2 & 3[7]	HRV	P	Pan	0.51–0.73	10	26 days	60 km
		1	Green	0.50–0.59	20		
		2	Red	0.61–0.68	20		
		3	NIR	0.78–0.89	20		
SPOT 4[7]	HRVIR	M	Mono	0.61–0.68	10	26 days	60 km
		1	Green	0.50–0.59	20		
		2	Red	0.61–0.68	20		
		3	NIR	0.78–0.89	20		
		4	SWIR	1.58–1.75	20		
SPOT 5[7]	HRG	P	Pan	0.48–0.71	2.5 or 5	26 days	60 km
		1	Green	0.50–0.59	10		
		2	Red	0.61–0.68	10		
		3	NIR	0.78–0.89	10		
		4	SWIR	1.58–1.75	20		
SPOT 6 &7[8]	NAOMI	P	Pan	0.45–0.75	1.5	26 days	60 km
		1	Blue	0.45–0.52	6		
		2	Green	0.53–0.59	6		
		3	Red	0.62–0.69	6		
		4	NIR	0.76–0.89	6		

[5] http://landsat.usgs.gov/landsat8.php

[6] http://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/aster/; http://www.science.aster.ersdac.jspacesystems.or.jp/jp/documnts/users_guide/part2/01.html

[7] http://www.blackbridge.com/geomatics/upload/airbus/SPOT1-5%20Resolutions%20and%20Spectral%20Modes.pdf

[8] http://www.satimagingcorp.com/satellite-sensors/spot-6/; http://www.satimagingcorp.com/satellite-sensors/spot-7/

ALOS[9]	PRISM AVNIR-2 PALSAR	P 1 2 3 4	Pan Blue Green Red NIR	0.52–0.77 0.42–0.50 0.52–0.60 0.61–0.69 0.76–0.89	2.5 10 10 10 10 10 and 100	46 days	70 km
IKONOS[10]	Panchro- matic Multi- spectral	P 1 2 3 4	Pan Blue Green Red NIR	0.45–0.90 0.45–0.52 0.51–0.60 0.63–0.70 0.76–0.85	1 4 4 4 4	1.5–3 days	11 km
QuickBird[11]	Panchro- matic Multi- spectral	P 1 2 3 4	Pan Blue Green Red NIR	0.45–0.90 0.45–0.52 0.52–0.60 0.63–0.69 0.76–0.90	0.61 2.44 2.44 2.44 2.44	1–3.5 days	16.5 km

[9] http://www.eorc.jaxa.jp/ALOS/en/about/about_index.htm

[10] http://www.satimagingcorp.com/satellite-sensors/ikonos/

[11] http://glcf.umd.edu/library/guide/QuickBird_Product_Guide.pdf

3. Overview of classification methods, study areas and data processing

3.1. Overview of remote sensing image classification methods

There are two types of remote sensing image classification methods: supervised and unsupervised. Supervised classification requires *a priori* knowledge of the data and study area. It is a widely used technique for classifying and extracting quantitative information from remotely sensed image data, where samples or training data are used in the classification process. On the other hand, unsupervised classification does not require *a priori* knowledge. It is done mainly by using some clustering algorithms to classify an image (Richards 1993). Aside from these two groups (supervised and unsupervised), classification methods can also be grouped into two, i.e. pixel-based and object-based (Note: sub-pixel classification methods are also available). Machine learning algorithms are also emerging, including random forests and support vector machines.

Pixel-based classification and object-based classification

The development and advancement of geographic object-based image analysis (GEOBIA) (Hay & Castilla 2008; Blaschke et al. 2014) techniques provides an alternative to the traditional pixel-based classification approach. In a pixel-based classification, an entire digital image is processed pixel-by-pixel using spectral information. On the other hand, in a GEOBIA technique, pixels are group into objects based on spectral, shape, texture and contextual information through image segmentation (Platt & Rapoza 2008; Blaschke 2010). Image segmentation is the process of partitioning an image into isolated objects so that each object shares a homogeneous spectral similarity (Blaschke et al. 2004). However, amidst the advancement of GEOBIA techniques, pixel-based classification still remains the basis for thousands of remote sensing applications (Blaschke 2010). The limited access of researchers to software packages that support GEOBIA might be one of the reasons behind this trend. Needless to say, pixel-based classification techniques can also provide accurate and satisfactory results.

Random Forests classification

"Random Forests" (RF) is a machine learning method that uses a collection of tree-structured classifiers for classification (Breiman 2001). It is an ensemble classification method and a learning algorithm that assembles a set of classifiers instead of one classifier, and then classifies new data points by taking a vote of their predictions (Breiman 2001; Liaw & Wiener 2002; Akar & Gungor 2012). RF is an advanced version of bagging (Breiman 2001), in which randomness is added (Akar & Gungor 2012). The key advantages of RF algorithms are their nonparametric nature, high classification accuracy, and ability to determine variable importance (Rodriguez-Galiano et al. 2012).

Support Vector Machine classification

Support Vector Machines (SVMs) are based on statistical learning theory (Vapnik 1995). The primary objective of SVMs is to generate a hyperplane that represents the optimal separation of linearly separable categories. Most SVM applications involve the separation of only two categories by a decision boundary, called the "optimal separating hyperplane" (OSH) (Brian et al. 2011). In general, SVMs select the decision boundary from an infinite number of potential ones, leaving the greatest margin between the closest data points to the hyperplane, which are referred to as "support vectors" (Griffiths et al. 2010).

For the purpose of this project, we used the supervised classification method, employing the maximum likelihood algorithm. We used our knowledge of the study areas and skills in remote sensing image interpretation to prepare the needed training data and eventually classify all the images. The maximum likelihood algorithm is one of the most widely used algorithms in remote sensing image classification. It is derived from the Bayes' theorem (Richards 1993; Ahmad & Quegan 2012).

3.2. Study areas

Over the past few decades, urbanization in various countries, including Asian and African countries, has been rapid. The primary objective of this project is to establish a database of LULC maps derived from remote sensing satellite images during this time period for various major Asian and African cities. It aims to detect the changes in the landscape of these cities and examine how the spatial structure of each city has changed over the years.

In this project, the study areas include 24 major Asian cities (Baghdad, Iraq; Bangkok, Thailand; Beijing, China; Chongqing, China; Delhi, India; Dhaka, Bangladesh; Dubai, UAE; Hangzhou, China; Hanoi, Vietnam; Istanbul, Turkey; Jakarta, Indonesia; Karachi, Pakistan; Kathmandu, Nepal; Kuala Lumpur, Malaysia; Manila, Philippines; Nanjing, China; Pyongyang, North Korea; Riyadh, KSA; Seoul, South Korea; Shanghai, China; Suzhou, China; Taipei, Taiwan; Tehran, Iran; Yangon, Myanmar) and 11 major African cities (Addis Ababa, Ethiopia; Bamako, Mali; Cairo, Egypt; Casablanca, Morocco; Dakar, Senegal; Johannesburg, South Africa; Khartoum, Sudan; Lagos, Nigeria; Lusaka, Zambia; Maputo, Mozambique; Nairobi, Kenya). For the purpose of comparison, we used a common unit of analysis, i.e. a 100 km × 100 km subset of each city.

3.3. Data processing

For the purpose of this project, eight LULC categories were considered: urban dense, urban sparse, forest, cropland, grassland, bareland, water, and other land. The other land category includes clouds, shadow and snow. The same LULC categories have been used in previous studies (e.g. Lwin & Murayama 2013).

We first searched for the best remote sensing satellite images (Landsat data) for each city for 2000 and 2014, i.e. cloud-free or with minimal cloud cover. The selected images, which are all Level 1T products, were downloaded from http://earthexplorer.usgs.gov. In the Level 1T product type, the images have been geometrically corrected. Subsequently, the study area (100 km × 100 km) for each city was clipped, processed and classified using the maximum likelihood supervised classification method explained above.

4. LULC classification results

This chapter provides a brief description of the 35 major cities included in this project (24 Asian cities and 11 African cities). The results of the LULC classification and change detection analysis are also presented in this chapter. It should be noted that the total land area of each city is based on the spatial extents of the classified LULC maps (100 km × 100 km; except Yangon) and does not necessarily correspond to the cities' respective administrative land area. In Table 4.0, the cities with no shading were processed in 2014-2015 (Murayama et al. 2015), while those shaded in grey were processed in 2015-2016. Time 1 and Time 2 correspond to the acquisition years of the Landsat images used.

Table 4.0. List of the 35 major cities examined.

City	Country	Continent	Time 1	Time 2
Addis Ababa	Ethiopia	Africa	2000	2014
Baghdad	Iraq	Asia	2000	2014
Bamako	Mali	Africa	1999	2014
Bangkok	Thailand	Asia	1999	2014
Beijing	China	Asia	2002	2014
Cairo	Egypt	Africa	1999	2015
Casablanca	Morocco	Africa	2000	2014
Chongqing	China	Asia	2000	2014
Dakar	Senegal	Africa	2000	2014
Delhi	India	Asia	1999	2014
Dhaka	Bangladesh	Asia	2000	2014
Dubai	United Arab Emirates (UAE)	Asia	2000	2014
Hangzhou	China	Asia	2000	2015
Hanoi	Vietnam	Asia	2001	2014
Istanbul	Turkey	Asia	2000	2014
Jakarta	Indonesia	Asia	2001	2014
Johannesburg	South Africa	Africa	2000	2014
Karachi	Pakistan	Asia	2000	2014
Kathmandu	Nepal	Asia	2001	2013
Khartoum	Sudan	Africa	2000	2014
Kuala Lumpur	Malaysia	Asia	2001	2014
Lagos	Nigeria	Africa	2002	2014
Lusaka	Zambia	Africa	2001	2014
Manila	Philippines	Asia	2001	2014
Maputo	Mozambique	Africa	2000	2014
Nairobi	Kenya	Africa	2000	2014
Nanjing	China	Asia	2000	2014
Pyongyang	North Korea	Asia	2001	2014
Riyadh	Kingdom of Saudi Arabia (KSA)	Asia	2000	2014
Seoul	South Korea	Asia	2000	2014
Shanghai	China	Asia	2000	2015
Suzhou	China	Asia	2000	2014
Taipei	Taiwan	Asia	2001	2014
Tehran	Iran	Asia	2000	2014
Yangon	Myanmar	Asia	1989	2014

4.1. Addis Ababa Metropolitan Area, Ethiopia

Geographical and socioeconomic characteristics

Addis Ababa is the capital and largest city of Ethiopia. It is located in the central part of the country at 9° 0' N latitude and 38° 45' E longitude. It is also the country's commercial and political center. Addis Ababa is one of the fastest growing cities in Sub Saharan Africa. According to the World Bank (2014), the population of Addis Ababa has nearly doubled every decade since the 1980s. The 2013 population of the city was estimated at 3.1 million and projected to reach 12 million by 2024.

The geographic location of Addis Ababa and with its political and socio-economic status have made this city a melting pot to hundreds of thousands of people coming from all corners of the country in search of employment opportunities and services (UN-Habitat 2008). Today, due to poor landscape and urban planning (World Bank 2014), the city is faced with various urban problems, including poverty, unemployment, congestion, transport and infrastructure problems, environmental degradation, housing shortage, and squatter settlements, among others (Kamete et al. 2001; Wubshet 2002; UN-Habitat 2007; Megento 2013).

LULC changes in Addis Ababa Metropolitan Area

Figs. 4.1(a) and 4.1(b) show the LULC classification results for Addis Ababa, while Fig. 4.1(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that the urban area of Addis Ababa has been expanding in all directions (north, south, east and west). The whole landscape has a sizable cropland which is also expanding. Grasslands and barelands also cover a large area, while forest and water bodies cover only a small portion of the area.

The statistics (Table 4.1) reveal a substantial increase in the area of urban dense. In 2000, urban dense had an area of 6.33 thousand ha (0.63%). In 2014, its area increased to 29.45 thousand ha (2.94%), resulting in a net gain of 23.12 thousand ha. The area of urban sparse also increased from 10.64 thousand ha (1.06%) in 2000 to 11.69 thousand ha (1.17%), with a net gain of 1.05 thousand ha. As mentioned above, Cropland is also one of the major LULC types in Addis Ababa. In 2000, cropland accounted for 27.98% (279.82 thousand ha) and in 2014 it accounted for 33.86% (338.66 thousand ha), resulting in a net gain of 58.84 thousand ha. The area of grassland also increased from 32.37% (323.72 thousand ha) to 33.60% (336.05 thousand ha), with a net gain of 12.33 thousand ha. By contrast, bareland covered 354.13 thousand ha (35.41%) in 2000 and 234.62 thousand ha (23.46 %) in 2014, resulting in a net loss of 119.51 thousand ha (Table 4.1). Overall, the LULC changes in Addis Ababa metropolitan area from 2000 to 2014 show that there has been a substantial built-up expansion (especially urban dense). Interestingly, the area of all the other LULC categories, except for bareland, has also been increasing.

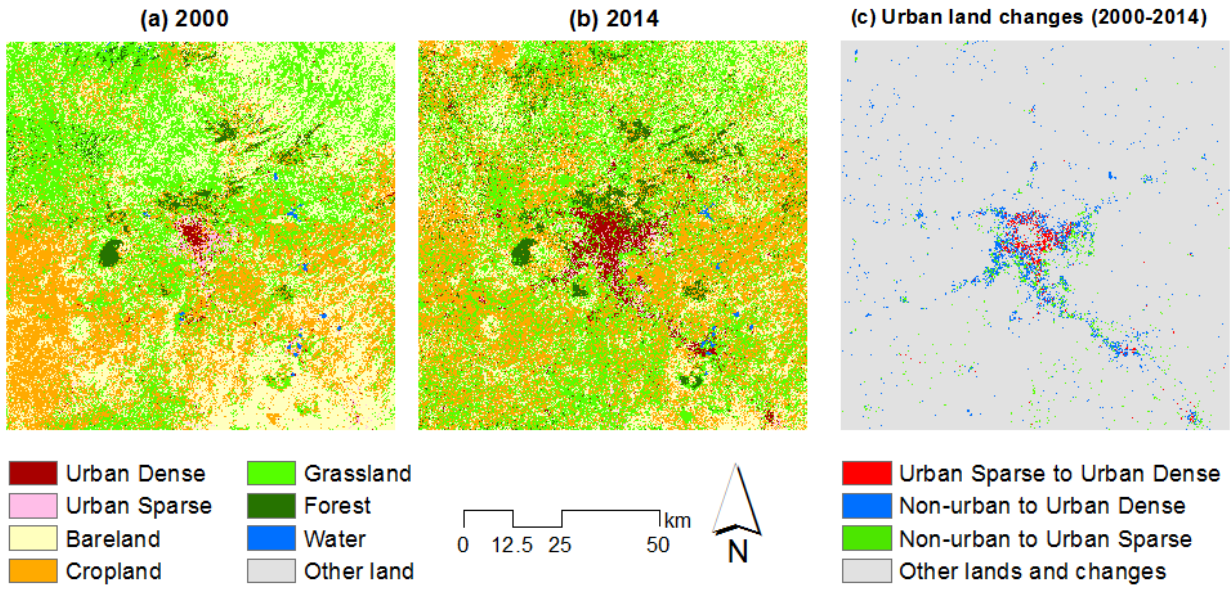

Fig. 4.1. LULC maps and spatial distribution of urban land changes in Addis Ababa Metropolitan Area.

Table 4.1. LULC changes in Addis Ababa Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	6.33	0.63	29.45	2.94	23.12	365.13
Urban Sparse	10.64	1.06	11.69	1.17	1.05	9.91
Forest	23.42	2.34	48.24	4.82	24.82	105.96
Cropland	279.82	27.98	338.66	33.86	58.84	21.03
Grassland	323.72	32.37	336.05	33.60	12.33	3.81
Bareland	354.13	35.41	234.62	23.46	-119.51	-33.75
Water	2.04	0.20	1.39	0.14	-0.65	-31.71
Total	1000.10	100.00	1000.10	100.00		

4.2. Baghdad Metropolitan Area, Iraq

Geographical and socioeconomic characteristics

Baghdad, the capital city of Iraq, is located in the east-central part of the country. In 2011, Baghdad had a population of approximately 7.2 million (UN-Habitat 2012). It is the second largest city in the Arab world, after Cairo, Egypt. Geographically, Baghdad is situated on the Tigris River, on the Mesopotamian Plain. The city accounts for 24% of Iraq's population (https://citiesintransition.net/fct-cities/baghdad/). The city contains the majority of country's industries, such as oil refineries, and textile, cement, tobacco, liquor, and military (arms) industries (NRC 2014).

The Iran-Iraq war in 1980 and the Iraqi attack of Kuwait and Gulf War in 1990 largely stagnated the economic development of the country (NRC 2014). During these wars, the city's infrastructures and industries were damaged. Baghdad suffered 45% of all casualties, with an estimated 10,463 conflict-related deaths in 2007. Nevertheless, since 2010 there has been a concerted effort by the government of Iraq to rebuild Baghdad. The increase in oil production in the country enabled the government to replace the old buildings with new ones and to develop plans for Baghdad (UN-Habitat 2012). Nearly half of Baghdad's total population reside in the poor-quality environment.

LULC changes in Baghdad Metropolitan Area

Figs. 4.2(a) and 4.2(b) show the LULC classification results for Baghdad using the maximum likelihood supervised classification method. Fig. 4.2(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that both urban dense and urban sparse have been expanding on both sides of the Tigris River. Cropland is mixed with urban land use as the city is located on a floodplain. The LULC maps also show indications that urban sparse has been expanding outward of the city center, while the urban sparse at the city core has been converted into urban dense.

In 2000, urban dense had an area of 16.51 thousand ha, covering 1.65% of the whole landscape (Table 4.2). In 2014, its area increased to 77.16 thousand ha, resulting in a net gain of 60.65 thousand ha. In 2000, urban sparse had an area of 104.16 thousand ha (10.41%) only, but in 2014, its area increased to 221.44 thousand ha (22.14%), with a net gain of 117.28 ha. Among the eight LULC categories, bareland was the most dominant. It accounted for 52.42% (524.38 thousand ha) in 2000 and 41.83% (418.46 thousand ha) in 2014. The second major LULC type is grassland, covering 208.34 thousand ha (20.83%) in 2000 and 130.67 thousand ha (13.06%) in 2014. The results also show that the decline in the area of bareland was also substantial (20.20%) (Table 4.2).

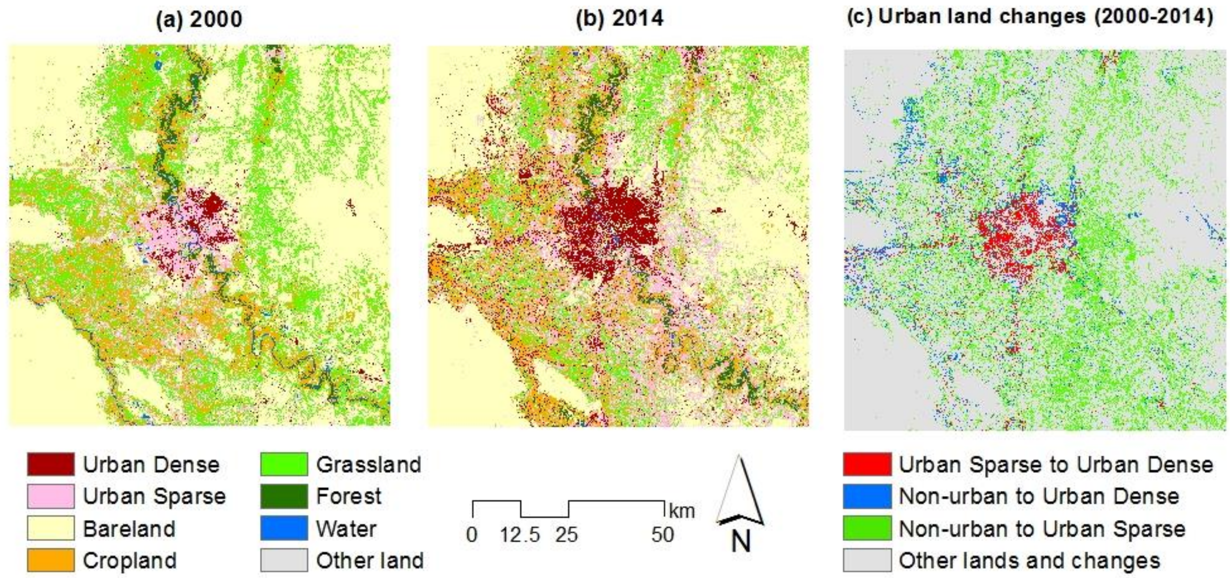

Fig. 4.2. LULC maps and spatial distribution of urban land changes in Baghdad Metropolitan Area.

Table 4.2. LULC changes in Baghdad Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	16.51	1.65	77.16	7.71	60.65	367.35
Urban Sparse	104.16	10.41	221.44	22.14	117.28	112.60
Forest	18.84	1.88	19.53	1.95	0.69	3.66
Cropland	119.98	11.99	129.10	12.90	9.12	7.60
Grassland	208.34	20.83	130.67	13.06	-77.67	-37.28
Bareland	524.38	52.42	418.46	41.83	-105.92	-20.20
Water	8.20	0.82	4.03	0.40	-4.17	-50.85
Total	1000.40	100.00	1000.40	100.00		

4.3. Bamako Metropolitan Area, Mali

Geographical and socioeconomic characteristics

Bamako is the capital and largest city of the Republic of Mali. Geographically, Bamako is located at 12° 37' N latitude and 8° 1' W longitude. It is situated on both sides of the Niger River. The topography of Bamako is relatively flat except to the immediate north. The average elevation of the area is 350 m above sea level. A large area around Bamako City is covered by desert or semi-desert lands. The development of Bamako City started in the northern part of the river, and later moved to the southern part, following the construction of bridges.

Bamako is the seventh largest West African urban center after Lagos, Abidjan, Kano, Ibadan, Dakar and Accra. The area of the city is about 252 km^2. In 2011, it had a population of 2.04 million, with an annual population growth rate of 5.4%. In 2009, the population density of Bamako was 7184 people/km^2 (http://www.citypopulation.de). The rapid population growth of Bamako has had a negative impact on the growing inadequacy of basic services, expansion of informal settlements, congestion in the city center, and overall livability of the city. Bamako is the major administrative center of Mali where major financial and trade activities are concentrated. Other economic activities and industries in the city include agriculture and fishery.

LULC changes in Bamako Metropolitan Area

Figs. 4.3(a) and 4.3(b) show the LULC classification results for Bamako using the maximum likelihood supervised classification method. Fig. 4.3(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 1999 and 2014. The LULC maps show that in 1999, urban dense was mainly concentrated in the northern side of the river. However, in 2014, both the northern and southern sides of the river have been urbanized. While barelands surround the major urban area, croplands are found in areas much closer to the urban area.

In 1999, urban dense had an area of 0.65 thousand ha, covering 0.06% of the whole landscape (Table 4.3). In 2014, its area increased to 6.33 thousand ha, i.e. 0.63% of the landscape, resulting in a net gain of 874.83%. In 1999, urban sparse had an area of 23.59 thousand ha (2.36%) only, but in 2014, its area increased to 53.30 thousand ha (5.33%). Cropland had an area of 11.24 thousand ha (1.12%) in 1999, but in 2014, its area also increased to 15.36 thousand ha (1.54%). The area of forest also increased from 106.54 thousand ha (10.65%) in 1999 to 202.47 thousand ha (20.24%) in 2014 (Table 4.3). Overall, the LULC changes in Bamako metropolitan area show a substantial built-up expansion between 1999 and 2014, as indicated by the increase in the area of urban dense and urban sparse.

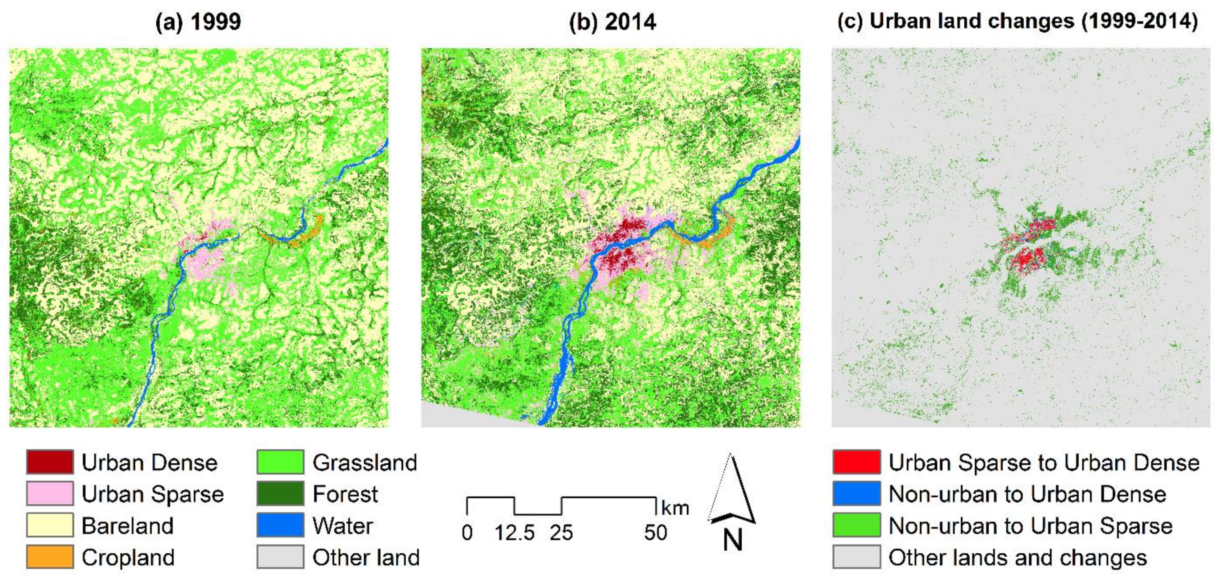

Fig. 4.3. LULC maps and spatial distribution of urban land changes in Bamako Metropolitan Area.

Table 4.3. LULC changes in Bamako Metropolitan Area (1999–2014).

	1999		2014		Net Changes (1999–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 1999
Urban Dense	0.65	0.06	6.33	0.63	5.68	874.83
Urban Sparse	23.59	2.36	53.30	5.33	29.71	125.91
Forest	106.54	10.65	202.47	20.24	95.93	90.04
Cropland	11.24	1.12	15.36	1.54	4.12	36.64
Grassland	401.44	40.13	285.83	28.57	-115.60	-28.80
Bareland	449.86	44.97	403.95	40.38	-45.92	-10.21
Water	7.07	0.71	20.97	2.10	13.90	196.56
Other land	0.00	0.00	12.18	1.22	12.18	---
Total	1000.40	100.00	1000.40	100.00		

4.4. Bangkok Metropolitan Area, Thailand

Geographical and socioeconomic characteristics

The Bangkok Metropolitan Region (BMR) houses Thailand's capital city, Bangkok. BMR has a total land area of 7762 km^2, and is managed by the Bangkok Metropolitan Administration. Geographically, Bangkok is situated at 13° 45' N latitude and 100° 28' E longitude, along the banks of the Chao Phraya River, which extends to the Gulf of Thailand.

While Bangkok serves as the BMR's headquarters for numerous multinational companies and the country's center for major financial institutions, it is also one of Asia's commercial and transport hubs and one of the world's most popular tourist destinations (Siemens 2011; ADB 2014). Due to its dominance and influence, any adverse effect on its socioeconomic status will certainly have a negative impact on the country's economy (World Bank 2009).

In 2000, BMR had a population of 10.2 million and a density of 1309 people/km^2. In 2010, these figures increased to 14.6 million and 1884 people/km^2, respectively (http://www.citypopulation.de). In 2000, BMR's population represented 16.68% of the total population of Thailand, while in 2010, it accounted for 22.17%. According to ADB (2014), the increase in BMR's population from 2000 to 2010 contributed to the decrease in the quality of infrastructure and service provision in the region, as it also increased the city's poverty index because most immigrants from the rural areas had low levels of education and income, and poor housing conditions. In addition, due to the flatness of the area and its proximity to the seashore, the region annually faces the problems of flooding (World Bank 2009).

LULC changes in Bangkok Metropolitan Region

In general, the landscape of BMR is dominated by cropland, with some patches of forest and grassland. Figs. 4.4(a) and 4.4(b) show the classified LULC maps of BMR, while Fig. 4.4(c) highlights the detected urban land changes between 1999 and 2014, including the changes from urban sparse to urban dense (red), non-urban to urban dense (blue), and non-urban to urban sparse (green). The LULC maps show that the built-up lands of BMR (urban dense and urban sparse) have been expanding outward of the city core and along the major roads (Fig. 4.4(c)). The maps also show that some smaller cores are developing, especially in the western, northern and southeastern parts of BMR (Fig. 4.4). In 1999, urban dense had an area of 32.78 thousand ha, i.e. 3.28% of the whole landscape (Table 4.4). In 2014, its area increased to 117.59 thousand ha (11.76%), resulting in a remarkable net gain of 84.81 thousand ha over the 15-year period. The increase in the area of urban dense was due to its gains from non-urban areas, but more especially from urban sparse. By contrast, the area of urban sparse decreased from 102.94 thousand ha (10.29%) in 1999 to 100.83 thousand ha in 2014 (10.08%) (Table 4.4), with a net loss of 2.11 thousand ha. The decrease in the area of urban sparse was mainly due to its loss to urban dense, which was greater than the area it gained from the non-urban areas. This shows that while there are indications for an urban sprawl in BMR, there are also signs for an infilling pattern.

The other important LULC types in BMR, i.e. forest and cropland, also had substantial changes in their respective areas between 1999 and 2014 (Table 4.4.). The results reveal that, during the 15-year period, more than a half of BMR's forest cover were converted into other land uses. During the same period, BMR's cropland also decreased by more than 6%. Overall, the results show that BMR has been experiencing remarkable landscape changes, posing many challenges in the context of sustainable landscape and urban development planning.

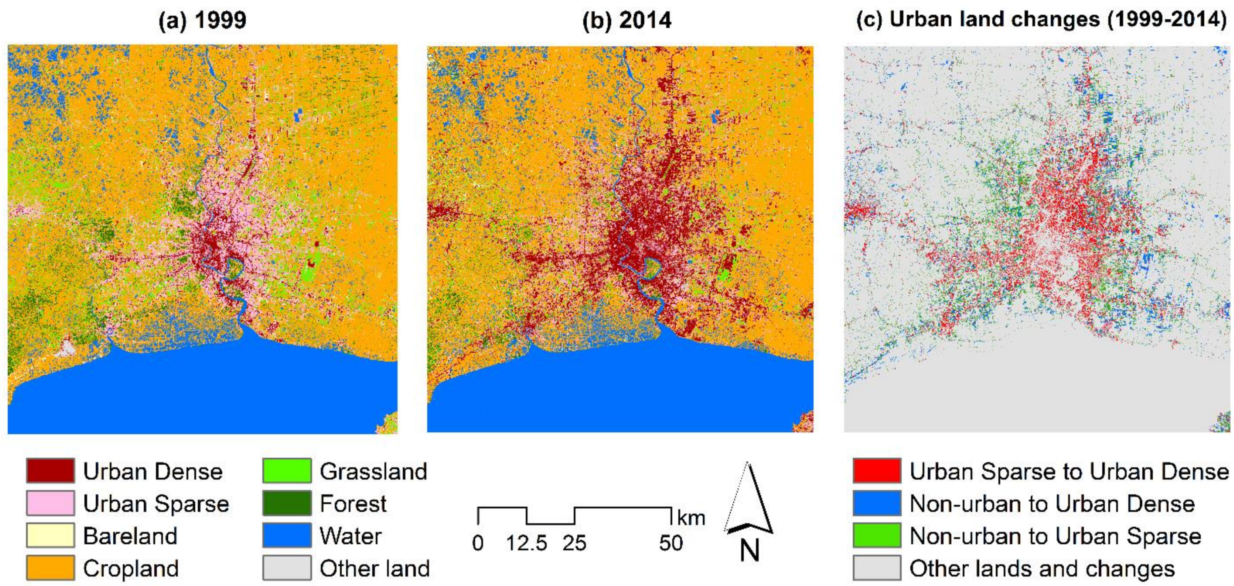

Fig. 4.4. LULC maps and spatial distribution of urban land changes in BMR.

Table 4.4. LULC changes in BMR (1999–2014).

	1999		2014		Net Changes (1999–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 1999
Urban Dense	32.78	3.28	117.59	11.76	84.81	258.72
Urban Sparse	102.94	10.29	100.83	10.08	-2.11	-2.05
Forest	35.93	3.59	15.44	1.54	-20.49	-57.04
Cropland	497.87	49.78	466.71	46.67	-31.16	-6.26
Grassland	61.69	6.17	38.34	3.83	-23.36	-37.86
Bareland	13.45	1.34	11.21	1.12	-2.24	-16.66
Water	253.66	25.36	249.92	24.99	-3.74	-1.47
Other land	1.77	0.18	0.07	0.01	-1.71	-96.17
Total	1000.10	100.00	1000.10	100.00		

4.5. Beijing Metropolitan Area, China

Geographical and socioeconomic characteristics

Beijing is the capital city of China and the country's political, cultural and educational center. Beijing is also one of the most populous cities in the world. Its population in 2013 was 21.15 million. The city proper is the third largest in the world (http://www.globaltimes.cn). The land area of Beijing is about 16,410 km^2 (http://english.mofcom.gov.cn). In the 1980s, the metropolitan area of Beijing was about 1500 km^2 only, but soon expanded due to the Chinese economic reform.

In recent years, the population of Beijing has also been growing rapidly. Between 2000 and 2010, the number of people living in the city grew by 44% – from 13,569,194 in 2000 to 19,612,368 in 2010. The average growth rate of cities since the 1960s has been around 20% per decade (http://worldpopulationreview.com). Although Beijing is a historical city, its urbanization process has been incredible. This has been due to the Chinese economic reform and economic globalization.

LULC changes in Beijing Metropolitan Area

Figs. 4.5(a) and 4.5(b) show the LULC classification results for Beijing using the maximum likelihood supervised classification method. Fig. 4.5(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue) and urban sparse to urban dense (red) between 2002 and 2014. The gray areas are other lands and changes. Table 4.5 shows the statistics of the eight LULC categories and the detected changes from 2002 to 2014.

There are some differences between Beijing and the other cities. Firstly, unlike the capital cities of other Asian or African countries, Beijing is a big city, which has been almost fully developed. Spatially, Beijing's urban area radiates from the center (the Forbidden City). Secondly, Beijing is situated in the northern tip of the roughly triangular North China Plain. Despite this, however, Beijing still has a major water security problem. Beijing has a rather dry, monsoon-influenced, humid continental climate. Thirdly, because of the unique culture of China, people prefer to live together rather than separately. Even in small villages, the residential houses are built next to each other, and are surrounded by agricultural lands. This pattern resulted to 'urban dense'.

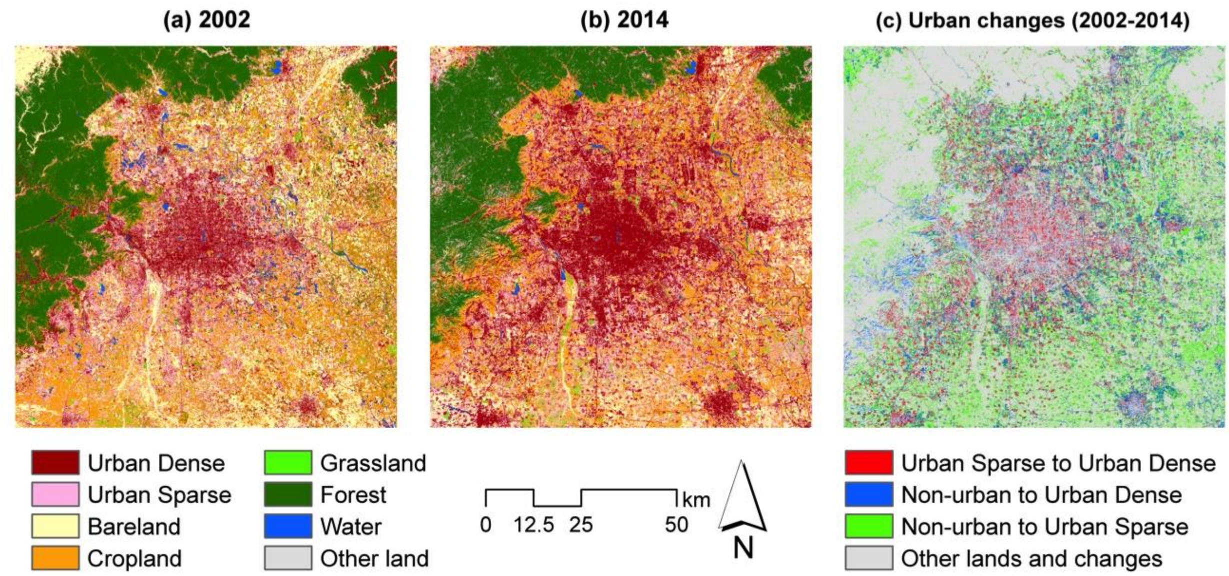

Fig. 4.5. LULC maps and spatial distribution of urban land changes in Beijing Metropolitan Area.

Table 4.5. LULC changes in Beijing Metropolitan Area (2002–2014).

	2002		2014		Net Changes (2002–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2002
Urban Dense	149.40	14.93	241.35	24.13	91.95	61.55
Urban Sparse	176.30	17.62	253.52	25.34	77.23	43.80
Forest	206.46	20.64	168.66	16.86	-37.80	-18.31
Cropland	219.78	21.97	213.43	21.33	-6.35	-2.89
Grassland	8.73	0.87	15.28	1.53	6.55	75.03
Bareland	225.93	22.58	98.29	9.83	-127.64	-56.49
Water	13.80	1.38	4.64	0.46	-9.16	-66.36
Other Land	0.00	0.00	5.22	0.52	5.22	---
Total	1000.40	100.00	1000.40	100.00		

4.6. Cairo Metropolitan Area, Egypt

Geographical and socioeconomic characteristics

Cairo, the capital city of Egypt, is the oldest city in the African continent. Its total area is approximately 528 km^2. The eastern and western parts of Cairo are surrounded by non-arable, desert lands. Consequently, Cairo’s spatial pattern of urban growth has been mainly towards the northern part, in the Nile Delta or to a lesser extent, to the south along the Nile River where agricultural land is dominant (Yin et al. 2005). The climate here is desert, with an average annual rainfall of only 18 mm (Effat & Hassan 2014). The annual temperature averages 21.3 °C, with a range of 14.5 °C between the hottest and coolest months.

As one of the largest markets in both Africa and the Middle East, Cairo accounts for two-thirds of the country's gross national product. The tourism industry is a major source of revenue for Cairo. In 2013, Cairo had a population of approximately 9.12 million, which ranked second in Africa after Lagos (http://www.worldpopulationstatistics.com/cairo-population-2013/). However, the annual population growth rate of Cairo from 1996 to 2006 was 1.52% only (http://www.citypopulation.de/), which is a low figure in Africa.

LULC changes in Cairo Metropolitan Area

Figs. 4.6(a) and 4.6(b) show the LULC classification results for Cairo using the maximum likelihood supervised classification method. Fig. 4.6(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 1999 and 2015. The gray areas are other lands and changes. The LULC maps show that the urban core of Cairo is crossed by the Neil River and most of the lands close to the river have been developed for urban and agricultural uses. The maps also show large areas located in the southeast and southwest of Cairo City which have been classified as bareland in 1999 and 2015. Most of these barelands are dessert because of Cairo’s climate and these areas hindered the city’s urban development. However, the LULC change detection results also show that built-up lands, especially urban sparse, have started expanding towards the edge of the desert (Fig. 4.6(c)).

Table 4.6 shows the statistics of LULC changes between 1999 and 2015 in Cairo. The data show that the area of urban dense and urban sparse has increased by 16.92 thousand ha and 31.17 thousand ha, respectively, in the past 16 years. As a result, the proportion of built-up lands (urban dense and urban sparse) relative to the whole landscape increased from 6.02% to 10.83%. Cropland also had a substantial net gain of 30.76 thousand ha. The gains of built-up and cropland mostly came from the loss of bareland, whose total area has decreased from 607.55 thousand ha to 531.49 thousand ha during the same period. These detected changes from bareland to urban and agricultural uses seem to indicate that in recent years there has been an effort to develop some desert areas.

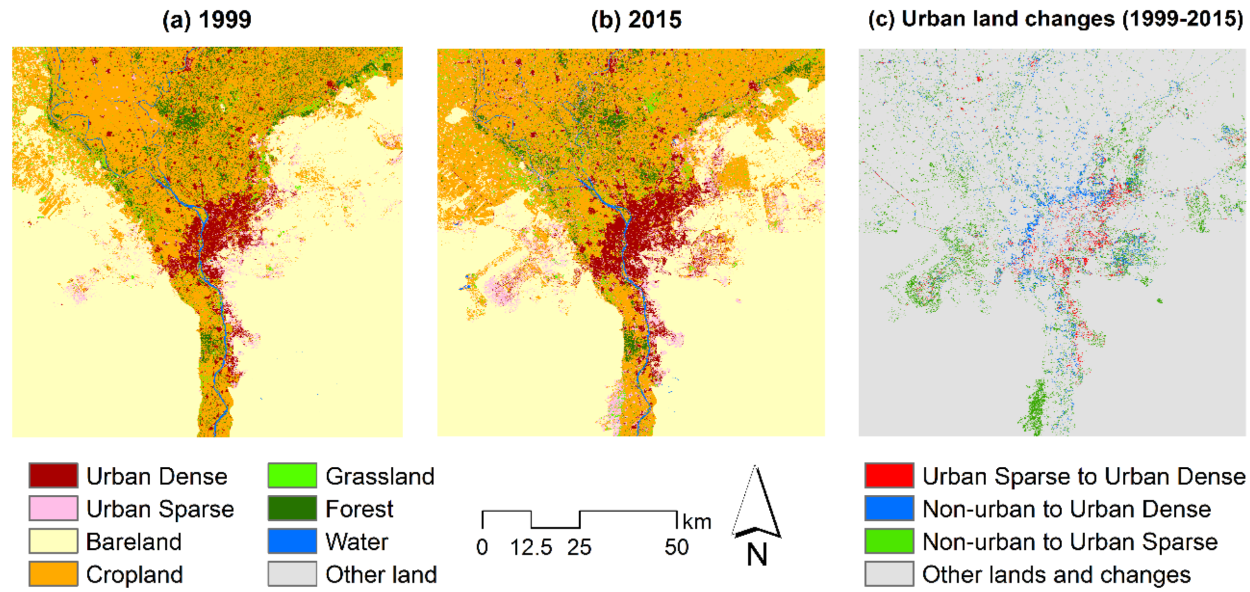

Fig. 4.6. LULC maps and spatial distribution of urban land changes in Cairo Metropolitan Area.

Table 4.6. LULC changes in Cairo Metropolitan Area (1999–2015).

	1999		2015		Net Changes (1999-2015)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 1999
Urban Dense	39.63	3.96	56.55	5.65	16.92	42.71
Urban Sparse	20.65	2.06	51.82	5.18	31.17	150.96
Forest	39.72	3.97	33.24	3.32	-6.48	-16.32
Cropland	269.74	26.96	300.50	30.04	30.76	11.40
Grassland	16.84	1.68	21.11	2.11	4.27	25.38
Bareland	607.55	60.73	531.49	53.13	-76.06	-12.52
Water	6.27	0.63	5.69	0.57	-0.58	-9.26
Total	1000.4	100	1000.4	100		

4.7. Casablanca Metropolitan Area, Morocco

Geographical and socioeconomic characteristics

Casablanca, Morocco’s economic capital, is the most populous city in North Africa and one of the largest cities in the continent. Geographically, the city is located in northwestern Morocco on the shores of the Atlantic Ocean at 33° 32' N latitude and 7° 35' W longitude. Casablanca is also Morocco’s main port. It also houses the leading local companies and international corporations doing business in the country.

In 2011, Casablanca had a population of three million and a density of 9132 people/km^2. Its population accounts for 11% of Morocco’s total population (CIA World Factbook 2015). The Grand Casablanca region accounts for 32% and 56% of the country's production units and industrial labor, respectively. Phosphate and its related products, as well as fish, glass, textiles, and electronics are among the region’s foremost products for export. However, due to poor landscape and urban planning and the concentration of major socioeconomic activities, Casablanca has been facing various problems, including pollution and congestion.

LULC changes in Casablanca Metropolitan Area

Figs. 4.7(a) and 4.7(b) show the LULC classification results for Casablanca using the maximum likelihood supervised classification method. Fig. 4.7(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that Casablanca’s built-up land (especially urban sparse) has been expanding to the eastern and western parts, but more especially to the southern part of the city. Cropland is mixed with urban land use. The LULC maps also show that urban sparse has been expanding outward of the city center, while the urban sparse at the city core has been converted into urban dense.

In 2000, urban dense had an area of 5.55 thousand ha, covering 0.55% of the whole landscape (Table 4.7). In 2014, its area increased to 8.96 thousand ha, resulting in a net gain of 3.41 thousand ha. In 2000, urban sparse had an area of 18.52 thousand ha (1.85%) only, but in 2014, its area also increased to 25.83 thousand ha (2.58%), with a net gain of 7.31 thousand ha. Among the eight LULC categories, bareland was the most dominant. It accounted for 46.21% (462.39 thousand ha) in 2000 and 42.71% (427.43 thousand ha) in 2014. The results also show a substantial decline in the area of forest (50.66%) (Table 4.7).

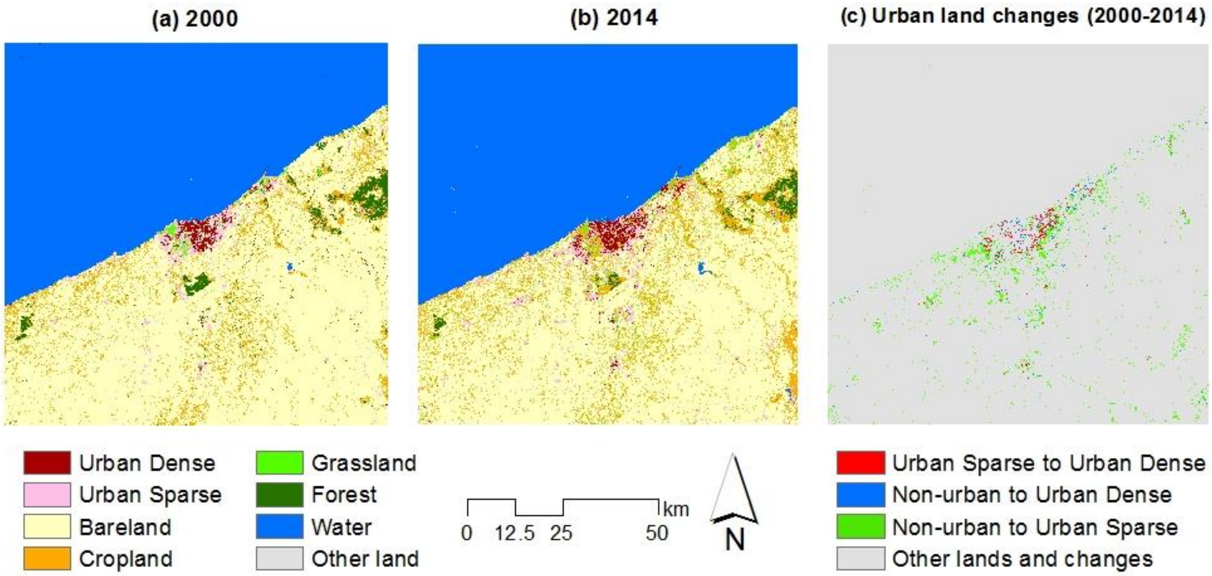

Fig. 4.7. LULC maps and spatial distribution of urban land changes in Casablanca Metropolitan Area.

Table 4.7. LULC changes in Casablanca Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	5.55	0.55	8.96	0.90	3.41	61.44
Urban Sparse	18.52	1.85	25.83	2.58	7.31	39.47
Forest	15.26	1.52	7.53	0.75	-7.73	-50.66
Cropland	53.21	5.32	75.24	7.52	22.03	41.40
Grassland	4.16	0.42	14.08	1.41	9.92	238.46
Bareland	462.39	46.21	427.43	42.71	-34.96	-7.56
Water	441.61	44.13	441.63	44.13	0.02	0.00
Total	1000.70	100.00	1000.70	100.00		

4.8. Chongqing Metropolitan Area, China

Geographical and socioeconomic characteristics

Chongqing is one of the four ‘direct-controlled’ municipalities in China. It is the biggest inland city of the country. The whole municipality has a total area of 82,403 km^2, while the city core covers 5473 km^2 (http://english.mofcom.gov.cn/). Chongqing City is also called ‘mountain city' and ‘city on rivers’ as its boundary covers a large area crisscrossed by rivers and mountains. The surrounding area of Chongqing includes the Daba Mountains in the north, the Wu Mountains in the east, the Wuling Mountains in the southeast, and the Dalou Mountains in the south. The whole area slopes down from north and south towards the Yangtze River valley, with sharp rises and falls.

In 2000, Chongqing had a population of 4.91 million only (http://www.citypopulation.de), but in 2014 this figure increased to 12.92 million (United Nations 2014). This shows that over the past 14 years, Chongqing’s population has increased by almost threefold, growing at a rate of 11.65% per year (simple rate). Today, Chongqing is considered as the largest city in south-west China. The rapid urbanization of Chongqing has been the result of the ‘Great Western Development Strategy’ policy established by the central government in 2000. In 2011, Chongqing's nominal GDP reached 1001.1 billion yuan (US$158.9 billion) while registering an annual growth of 16.4%. This number has quadrupled since 1998. The city has also invested heavily in infrastructure to attract investment. Today, the road network and railways connecting Chongqing to the rest of China have been completed, and the Chongqing Jiangbei International Airport now serves around 30 million people per year. The city now houses major international companies like Microsoft and Ford.

LULC changes in Chongqing Metropolitan Area

Figs. 4.8(a) and 4.8(b) show the LULC classification results for Chongqing using the maximum likelihood supervised classification method. Fig. 4.8(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2000 and 2014. The gray areas are other lands and changes. The LULC maps show that in 2000, Chongqing’s built-up lands (urban dense and urban sparse) are found mainly in areas where the two main rivers intersect. The maps also show that from 2000 to 2014, while Chongqing’s built-up land has expanded in all directions, the expansion to the southern part, but more especially to the northeastern part was substantial. We can also see from the maps that although Chongqing’s contiguous urban expansion to the eastern and western parts has been obstructed by the mountains, large patches of croplands have been converted into built-up lands. Cropland was, and still is, the dominant LULC category in the area. The availability of irrigation water makes the area suitable for cultivation. By contrast, most of the forested lands are found in the mountain regions and no substantial deforestation has been detected. Although the area of bareland has decreased, bigger patches have emerged in 2014. Based on the spatial pattern of built-up expansion, these patches of bareland are likely to be converted into built-up in the future.

Table 4.8 shows the statistics of LULC changes between 2000 and 2014 in Chongqing. The most apparent changes are the remarkable expansions of urban dense and urban sparse. From 2000 to 2014, the area of urban dense increased from 16.88 thousand ha to 87.37 thousand ha, resulting in an increase rate of 417.77%, while the area of urban sparse increased from 8.09 thousand ha to 40.39 thousand ha, with an increase rate of 399.06%. In 2000, built-up lands (urban dense and urban sparse) occupied only 2.50% of the whole landscape. However, after 14 years, the extent of built-up has increased to 12.77%. The rapid expansion of built-up land was at the expense of grassland, but more especially cropland. Cropland, the most dominant LULC type in the area, decreased by 99.99 thousand ha from 2000 to 2014. Interestingly, the area of forest was stable amidst rapid urbanization of the area. One possible explanation is that most of the forested lands were located in the mountain regions to which built-up could not easily expand. Overall, the LULC changes in Chongqing show a substantial gain of built-up and a substantial loss of cropland.

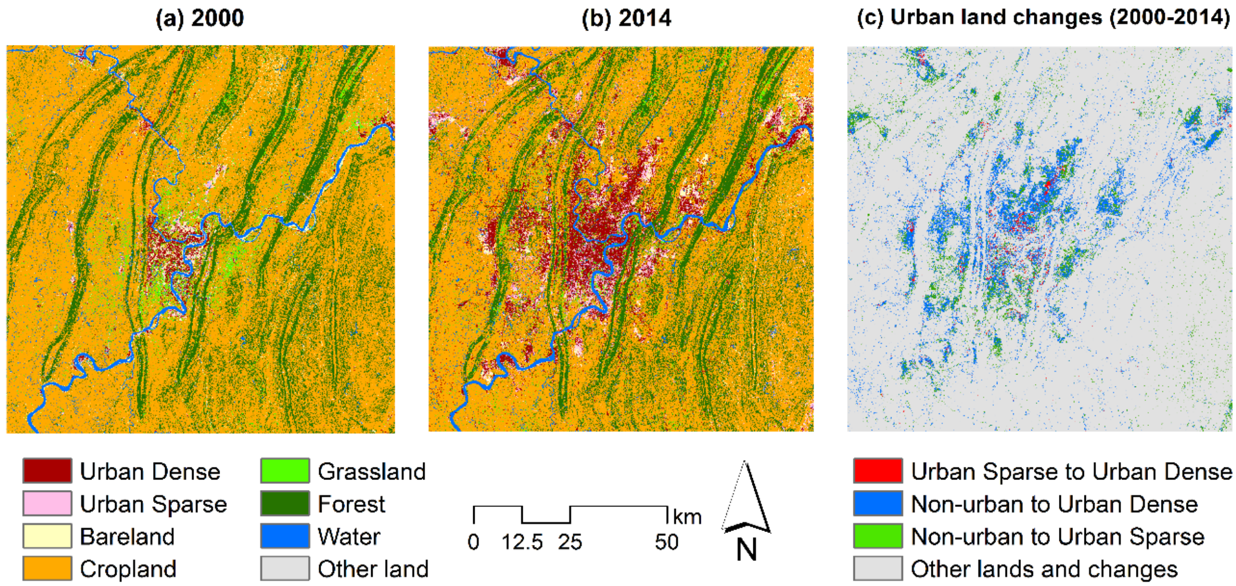

Fig. 4.8. LULC maps and spatial distribution of urban land changes in Chongqing Metropolitan Area.

Table 4.8. LULC changes in Chongqing Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	16.88	1.69	87.37	8.73	70.50	417.77
Urban Sparse	8.09	0.81	40.39	4.04	32.30	399.06
Forest	196.65	19.66	198.76	19.87	2.11	1.07
Cropland	688.16	68.79	588.18	58.79	-99.99	-14.53
Grassland	33.97	3.40	27.08	2.71	-6.90	-20.30
Bareland	23.97	2.40	22.01	2.20	-1.96	-8.18
Water	32.67	3.27	36.61	3.66	3.94	12.06
Total	1000.40	100.00	1000.40	100.00		

4.9. Dakar Metropolitan Area, Senegal

Geographical and socioeconomic characteristics

Dakar is the capital city of Senegal and the industrial commercial and government center of the country. It has an area of 550 km^2, located on the Cap Verde Peninsula (WEC 2012). Dakar also houses the whole of the institutional structures of the country (Ngagne 2007).

In recent years, Dakar has experienced rapid urban growth, which is generally linked to rural-urban migration of people seeking better economic opportunities in the city (Ngagne 2007). The population of the Dakar metropolitan area grew from some 374,700 in 1961 (right after independence in 1960) to 2.77 million in 2005 (Koenig 2009) and to over 3 million in 2011 (http://www.indexmundi.com). The population of Dakar alone is nearly a quarter of the country's population.

Consequently, the city has been faced with the challenges of uncontrolled and unplanned urban growth like many other African capital cities. The city of Dakar faces important challenges in being able to provide housing and adequate urban services for its growing population (Koenig 2009). This situation has brought various urban management problems, with needs now growing with respect to employment, education, health, hygiene, and infrastructure, among others (Ngagne 2007).

LULC changes in Dakar Metropolitan Area

Figs. 4.9(a) and 4.9(b) show the LULC classification results for Dakar using the maximum likelihood supervised classification method. Fig. 4.9(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. Dakar urban area is dominated by urban dense. Almost all the built-up lands (urban dense and urban sparse) are located west of the area towards the sea port and are observed to grow towards the east.

In 2000, urban dense had an area of 11.28 thousand ha (1.13 %). In 2014, its area increased to 15.82 thousand ha (1.58 %), with a net gain of 4.5 thousand ha (Table 4.9). The area of urban sparse was only 0.39 thousand ha (0.04 %) in 2000, but in 2014 it also increased to 1.59 thousand ha (0.16 %), resulting in a net gain of 1.99 thousand ha. Cropland, although very small in relation to the study area, had a substantial increase in its area between 2000 and 2014. Its area increased from 0.09% (0.88 thousand ha) in 2000 to 0.51% (5.14 thousand ha) in 2014, with a net gain of 4.26 thousand ha. On the other hand, forests and grasslands both experienced losses. From 2000 to 2014, the area of forest decreased from 0.62% (6.17 thousand ha) to 0.27% (2.74 thousand ha) while grassland decreased from 9.04% (90.47 thousand ha) to 4.67% (46.67 thousand ha). The net losses in forest and grassland areas were 3.42 thousand ha and 43.80 thousand ha, respectively. However, it is important to note that a large portion of the grassland losses was due to its loss to bareland (Fig 4.9(a) and 4.9(b)). This can be due to 'seasonal differences' resulting from the large gap (8 months) between the two images used in the LULC classifications. The area of bareland increased from 5.30% (50.03 thousand ha) in 2000 to 9.02% (90.22 thousand ha) in 2014 (Table 4.9).

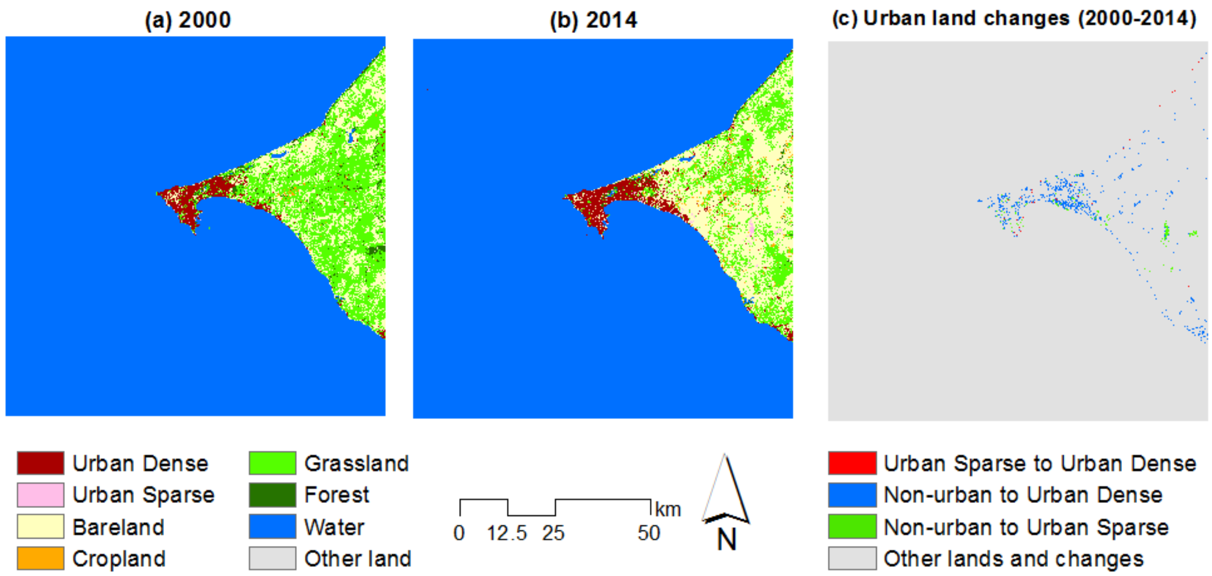

Fig. 4.9. LULC maps and spatial distribution of urban land changes in Dakar Metropolitan Area.

Table 4.9. LULC changes in Dakar Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	11.28	1.13	15.82	1.58	4.54	40.22
Urban Sparse	0.39	0.04	1.59	0.16	1.20	306.74
Forest	6.17	0.62	2.74	0.27	-3.42	-55.55
Cropland	0.88	0.09	5.14	0.51	4.26	485.64
Grassland	90.47	9.04	46.67	4.67	-43.80	-48.41
Bareland	53.03	5.30	90.22	9.02	37.19	70.13
Water	838.19	83.79	838.22	83.79	0.04	0.00
Total	1000.40	100.00	1000.40	100.00		

4.10. Delhi Metropolitan Area, India

Geographical and socioeconomic characteristics

Delhi, officially called the National Capital Territory of Delhi (NCTD), is the capital territory of India. The city is located on the Ganges plain, which also include two prominent geographical features – the Yamuna flood plains and the Delhi ridge (Ahmad et al. 2013). The boundary of Delhi covers a region of 1484 km^2, making it the largest city in India in terms of land area. Delhi has an atypical humid subtropical climate, with temperature ranging from 5 to 40 °C during the whole year. The warm season lasts from April to July, while the cold season lasts from December to February (https://weatherspark.com/).

The NCTD is composed of five governing bodies: the New Delhi Municipal Council (NDMC), the Delhi Cantonment Board (DCB), the North Delhi Municipal Corporation, the South Delhi Municipal Corporation, and the East Delhi Municipal Corporation. The metropolitan area had a total population of 13.85 million in 2001 and 16.78 million in 2011, with an annual growth rate of 1.94% (http://www.citypopulation.de). Delhi is the largest commercial center in northern India. Its economy is primarily based on the tertiary (service) sector, which generated over 82% of the Gross State Domestic Product (GSDP) in 2011 (Ahmad et al. 2013).

LULC changes in Delhi Metropolitan Area

Figs. 4.10(a) and 4.10(b) show the LULC classification results for Delhi using the maximum likelihood supervised classification method. Fig. 4.10(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 1999 and 2014. The gray areas are other lands and changes. The LULC maps show that cropland dominates the area. Delhi's urban area is concentrated mainly on the eastern and western sides of the Yamuna River. In the northeastern part, another town has been built and connected to the Delhi Metropolitan Area with a road. The maps also show that built-up lands (urban dense and urban sparse) have been expanding in all directions.

Table 4.10 shows the statistics of LULC changes between 1999 and 2014 in Delhi. The most important change detected was the rapid expansion of urban dense, whose area has increased from 32.81 thousand ha to 92.35 thousand ha in the past 15 years. Interestingly, the total area of cropland was stable during the period amidst rapid built-up expansion. The gains in built-up lands came mostly from the loss of bareland (66.44 thousand ha) and forest (9.02 thousand ha). Due to the large population of the area, there is a great demand for crops. This might help explain why agricultural lands are kept and given less priority for built-up expansion.

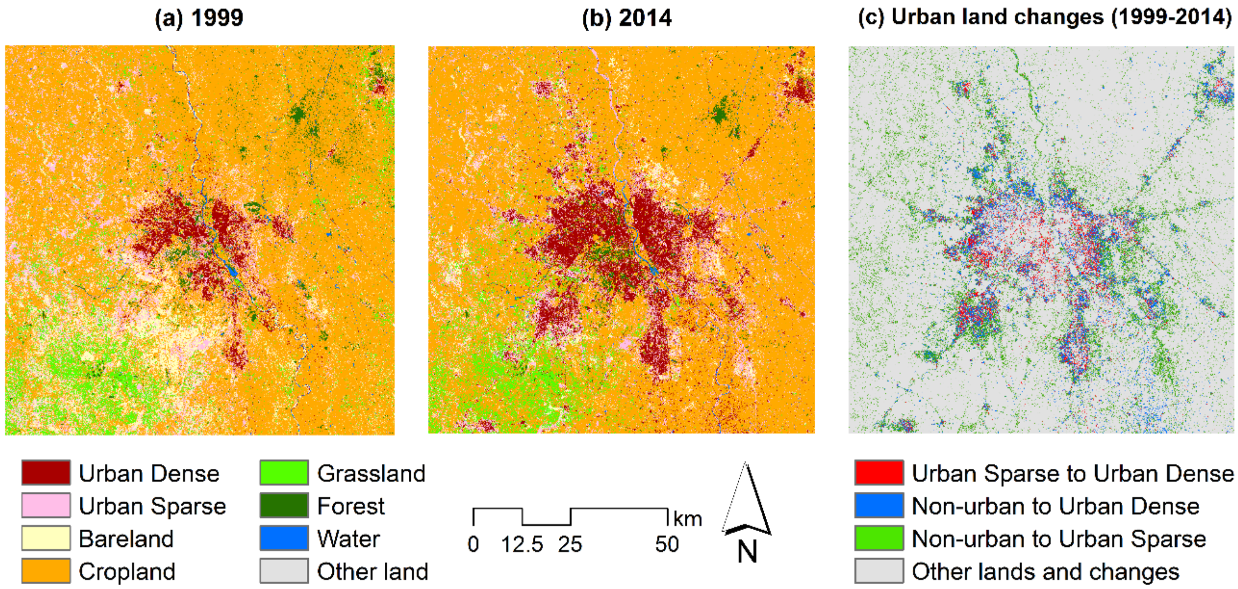

Fig. 4.10. LULC maps and spatial distribution of urban land changes in Delhi Metropolitan Area.

Table 4.10. LULC changes in Delhi Metropolitan Area (1999–2014).

	1999		2014		Net Changes (1999-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 1999
Urban Dense	32.81	3.28	92.35	9.23	59.54	181.47
Urban Sparse	109.14	10.91	122.08	12.20	12.93	11.85
Forest	25.47	2.55	16.45	1.64	-9.02	-35.41
Cropland	663.76	66.35	669.63	66.94	5.87	0.88
Grassland	59.82	5.98	56.81	5.68	-3.01	-5.03
Bareland	104.57	10.45	38.13	3.81	-66.44	-63.54
Water	4.82	0.48	4.95	0.49	0.13	2.67
Total	1000.4	100	1000.4	100		

4.11. Dhaka Metropolitan Area, Bangladesh

Geographical and socioeconomic characteristics

Dhaka metropolitan area is commonly known as the Greater Dhaka Area (GDA). Administratively, the metropolitan area is called the Dhaka Statistical Metropolitan Area (SMA), and comprises the Dhaka City Corporation (DCC), Keraniganj Demra, Narayangoni, Dhaka Contonmenet, Tongi and adjoining rural area (Chowdhury 2007). Dhaka City, the capital of Bangladesh, is located in the Dhaka metropolitan region. Geographically, Dhaka is located at 23° 43' N latitude and 90° 25' E longitude and is situated in the great delta region of the Ganges and Brahmaputra rivers. A large area of Dhaka is covered by a flat wetland. Its elevation ranges from 0.5 m to 12 m above sea level.

Dhaka is one of the major cities in South Asia. Being a member of the "megacity" family of the world, it is also one of the world's most densely populated cities. According to the 2001 census, the Dhaka Statistical Metropolitan Area (SMA) accommodates 10.7 million people, which is 37.45% of the total urban population of Bangladesh (http://www.bbs.gov.bd). The UN ranked Dhaka City as the 11th biggest population agglomeration in the world; it had a 3.6% annual growth rate from 2010 to 2015 (UN 2014).

The GDA is one of the major business hubs of South Asia and it is one of the fast-growing economic regions in Asia. The largest industrial sectors of Dhaka are textiles, jute, cement, ceramics, construction materials, newsprint, accessories, leather goods, electronics and appliances. Various estimates indicate that up to one quarter of Dhaka's population lives in informal settlements (shantytowns, slums or favelas). Additionally, the geographical location of Dhaka poses some social and environmental problems like flooding.

LULC changes in Dhaka Metropolitan Area

Figs. 4.11(a) and 4.11(b) show the LULC classification results for Dhaka using the maximum likelihood supervised classification method. Fig. 4.11(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that the spatial urban expansion of Dhaka is greatly limited by the two rivers surrounding the city. Urban dense is spatially arranged along the riverbanks. Cropland is mixed with urban land use as the city is located on a floodplain. Urban sparse has been expanding outward of the city center, while the urban sparse at the city core has been converted into urban dense. The major river (water category) that flows through the Dhaka metropolitan area was dynamic.

In 2000, urban dense had an area of 4.39 thousand ha, covering 0.44% of the whole landscape (Table 4.11). In 2014, its area increased to 10.88 thousand ha, i.e. 1.09% of the landscape. From 2000 to 2014, urban dense had a net gain of 6.49 thousand ha. The area of urban sparse in 2000 was 16.33 thousand ha (1.63%) only, but in 2014, it also increased to 61.78 thousand ha (6.18%), resulting in a net gain of 45.45 thousand ha. Among the eight LULC categories, cropland was the most dominant. It accounted for 43.64% (436.620 thousand ha) in 2000 and 53.59% (536.16 thousand ha) in 2014. The second major LULC type is forest, covering 403.83 thousand ha (40.37%) in 2000 and 298.39 thousand ha (29.83%) in 2014. Overall, the LULC changes in the Dhaka metropolitan area show a sizable urban expansion, with a declining forest cover.

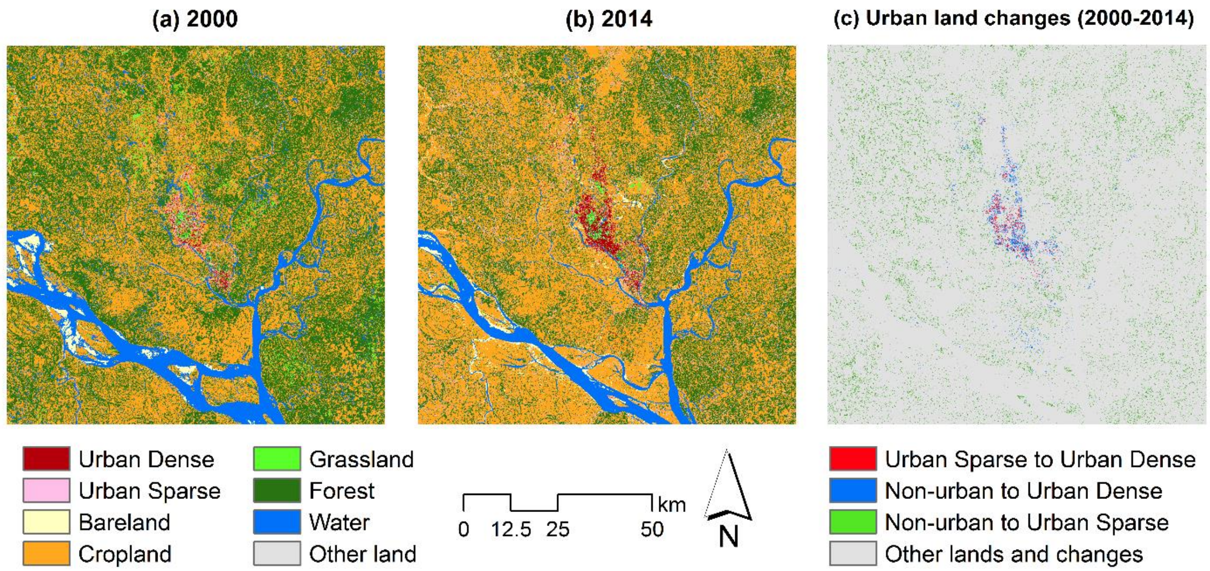

Fig. 4.11. LULC maps and spatial distribution of urban land changes in Dhaka Metropolitan Area.

Table 4.11. LULC changes in Dhaka Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	4.39	0.44	10.88	1.09	6.49	147.75
Urban Sparse	16.33	1.63	61.78	6.18	45.45	278.32
Forest	403.83	40.37	298.39	29.83	-105.44	-26.11
Cropland	436.62	43.64	536.16	53.59	99.54	22.80
Grassland	18.31	1.83	5.80	0.58	-12.51	-68.32
Bareland	11.60	1.16	18.68	1.87	7.09	61.12
Water	109.32	10.93	68.71	6.87	-40.61	-37.15
Total	1000.40	100.00	1000.40	100.00		

4.12. Dubai Metropolitan Area, UAE

Geographical and socioeconomic characteristics

Dubai is one of the seven emirates that comprise the whole United Arab Emirates (UAE). It is the most populous city in the country. It is located on the southeast coast of the Persian Gulf. Over the years, this city has emerged as a global and business hub of the Middle East. It serves as the bridge to connect the mystery Islam and traditional Arab culture to the world. Dubai is located at 25° 16' N latitude, 55° 19' E and covers an area of 4110 km^2, with the addition of The Burjal Arab Island. The city has a hot desert climate, with an approximately average temperature of 41 °C during summer.

Dubai is considered as one of the world's fastest growing economies. In recent years, its population had increased rapidly, with 1.31 million in 2005 and 2.28 million in 2014 (http://www.citypopulation.de). Its gross domestic product was projected to reach USD 107.1 billion in 2014 at a growth rate of 6.1%, according to Citibank (Thomson Reuters 2014). The Citibank also believes that hosting Expo 2020 will stimulate economic growth during the preparation phase (2015-2020) (Thomson Reuters 2014).

LULC changes in Dubai Metropolitan Area

Figs. 4.12(a) and 4.12(b) show the classified LULC maps of Dubai metropolitan area, while Fig. 4.12(c) highlights the detected urban land changes between 2000 and 2014, including the changes from urban sparse to urban dense (red), non-urban to urban dense (blue) and non-urban to urban sparse (green). As a result of the famous land reclamation project on the southeast coast of the Persian Gulf, Dubai's natural fringe boundary has expanded. In Table 4.12, the area covered by water has decreased by 4.37 thousand ha in the past 15 years.

In 2000, urban dense had an area of 13.49 thousand ha, accounting for 1.35% of the whole landscape (Table 4.12). In 2014, its area increased to 46.68 thousand ha, i.e. 4.66% of the landscape, resulting in a net gain of 33.19 thousand ha. The increase in the area of urban dense was due to its gains from urban sparse and non-urban areas, including waterbodies (Fig. 4.12(c)). Urban sparse also had a high net gain of 14.96 thousand ha from 2000 to 2014. In 2000, it had an area of 24.73 thousand ha (2.47%), which increased to 39.69 thousand ha (3.97%) in 2014. Combining urban dense and urban sparse together, the total built-up land of Dubai in 2000 was just about 4% of the whole landscape, but in 2014 it increased to about 9%. By contrast, the area of bareland decreased by 75.30 thousand ha during the same period. Interestingly, the area of cropland and grassland increased by 26.75 thousand ha and 4.79 thousand ha, respectively. The increase might have been due to the introduction and use of modern agricultural farming techniques in this arid or dry region (desert). Overall, the data show that Dubai metropolitan area has experienced a remarkable landscape changes (especially built-up expansion) over the 14-year period. And because such change will likely to continue in the future, a continuous urban growth monitoring and landscape planning is needed for its sustainable urban development.

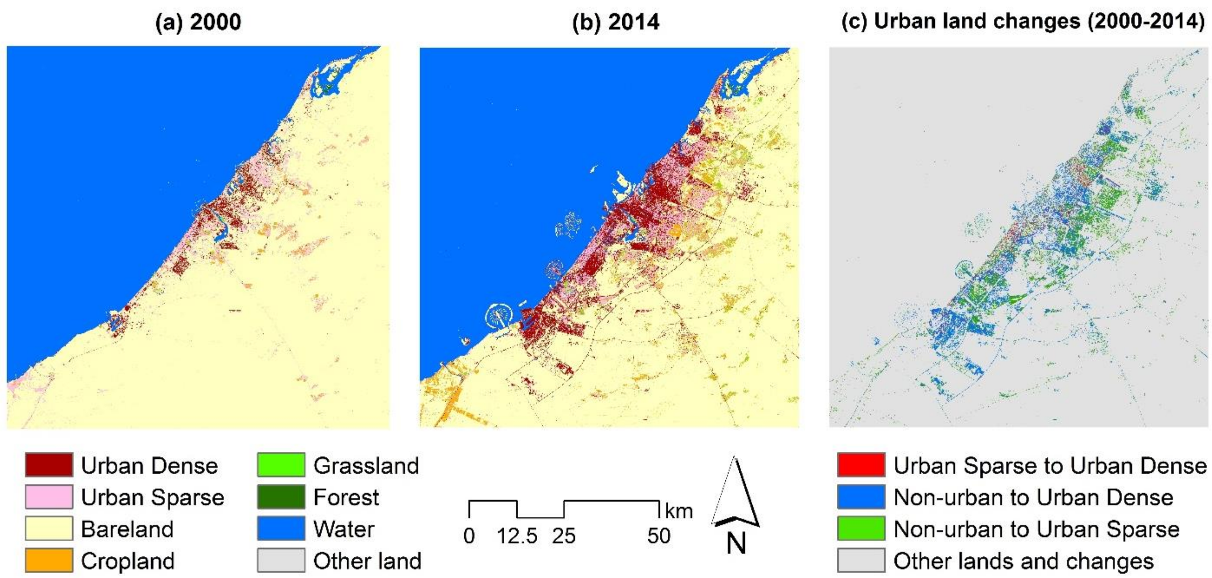

Fig. 4.12. LULC maps and spatial distribution of urban land changes in Dubai Metropolitan Area.

Table 4.12. LULC changes in Dubai (2000-2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	13.49	1.35	46.68	4.66	33.19	246.13
Urban Sparse	24.73	2.47	39.69	3.97	14.96	60.49
Forest	0.49	0.05	0.47	0.05	-0.02	-4.10
Cropland	5.07	0.51	31.82	3.18	26.75	527.98
Grassland	0.50	0.05	5.29	0.53	4.79	952.24
Bareland	513.65	51.31	438.35	43.79	-75.30	-14.66
Water	443.07	44.26	438.71	43.83	-4.37	-0.99
Total	1001.00	100.00	1001.00	100.00		

4.13. Hangzhou Metropolitan Area, China

Geographical and socioeconomic characteristics

Hangzhou is the provincial capital and largest city of Zhejiang Province, China. It is located at the southern wing of the Yangtze River Delta, 180 km away from Shanghai. The Hangzhou Metropolitan Area (HMA) covers an area of 16,596 km^2, while the main city occupies an area of 4876 km^2 (Qian 2015). Known as 'the Paradise on the Earth', the city owns picturesque natural landscape and environment. The whole HMA is composed of 65.6% hilly land, 26.4% plain, and 8% bodies of water (http://www.hangzhoutravel.org/). The city has a northern subtropical monsoon climate with four distinct seasons. The mean annual temperature is 17.0 °C, with monthly daily averages ranging from 4.6 °C in January to 28.9 °C in July.

Hangzhou had a population of 3.24 million in 2000 and 5.16 million in 2010, with an annual growth rate of 4.77% (http://www.citypopulation.de). In 2014, the population has gone up to 6.12 million (United Nations 2014). Serving as the second largest metropolis in the Yangtze River Delta Region (after Shanghai), Hangzhou's economy has developed rapidly in the past 15 years, especially in cultural and creative industry, tourism and leisure, financial services, e-commerce, and information technology. The rapid economic improvement of Hangzhou has brought many benefits to local residents. In 2014, the average annual per capita income in the city was 68,398 yuan (US$10,103) (Hangzhou Statistical Bureau 2014). In the same year, the urban resident annual per capita disposable income reached 39,310 yuan (US$5806), while the rural resident annual per capita net income was 18,923 yuan (US$2795) (Hangzhou Statistical Bureau 2014).

LULC changes in Hangzhou Metropolitan Area

Figs. 4.13(a) and 4.13(b) show the LULC classification results for Hangzhou using the maximum likelihood supervised classification method. Fig. 4.13(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2000 and 2015. The gray areas are other lands and changes. In 2000, Hangzhou's urban area was concentrated mainly on the northern side of Yangtze River. Some small patches of built-up lands (mostly urban dense) were also observed southeast and northeast of the urban core. In 2015, the extent of built-up lands (urban dense and urban sparse) expanded to the southern side of the river (Fig. 4.13(a)). The change map shows an unbalanced built-up expansion along the east-west direction, i.e. there were more gains of built-up on the eastern side (Fig. 4.13(c)). The presence of mountains on the western side is a major factor for this observed built-up expansion pattern in the area. In both years (2000 and 2015), forest and cropland were the two most dominant LULC categories. The Yangtze River and the scattered lakes and ponds are important water sources that support vegetation growth and agricultural farming.

Table 4.13 shows the statistics of LULC changes between 2000 and 2015 in Hangzhou. The results clearly show that Hangzhou has been experiencing rapid urbanization. In the past 15 years (2000-2015), the area of urban dense has increased from 58.42 thousand ha to 172.75 thousand ha, while the area of urban sparse has increased from 17.11 thousand ha to 49.27 thousand ha. These two categories had an individual net change rate of nearly 200%. The observed expansion of built-up lands was at the expense of the other LULC categories, especially cropland and forest. Cropland had a net loss of 86.86 thousand ha, while forest had a net loss of 21.96 thousand ha. In 2015, forest and cropland were still the most dominant LULC types in the area, with a combine proportion of 64.82% despite their substantial losses. However, the rapid expansion of urban dense and urban sparse has made the proportion of built-up land to increase from 7.55% to 22.20%.

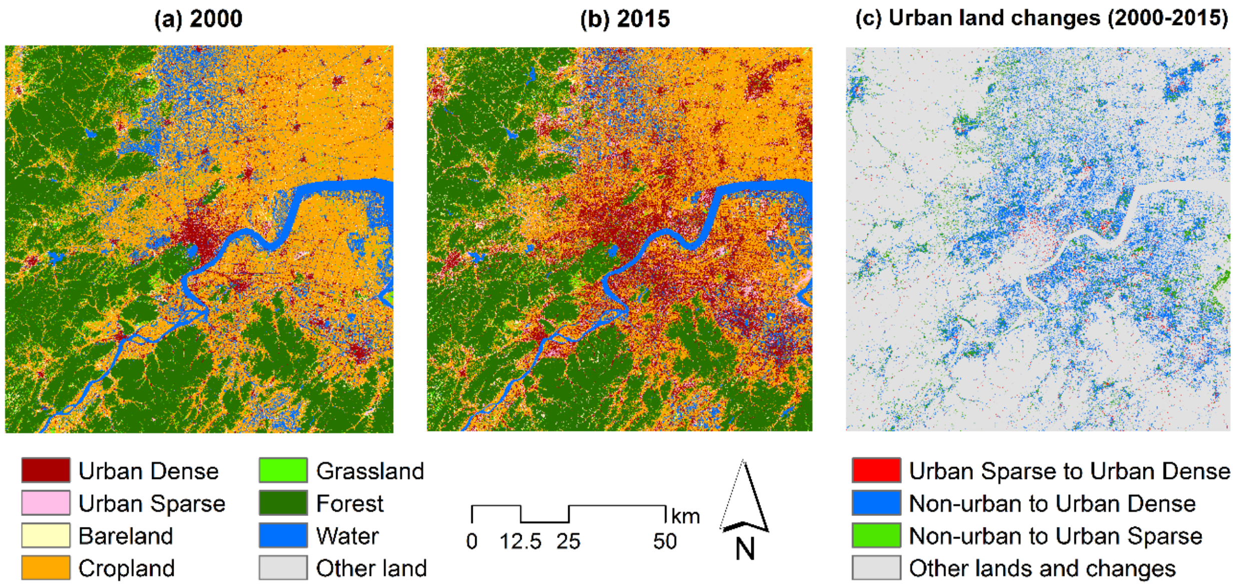

Fig. 4.13. LULC maps and spatial distribution of urban land changes in Hangzhou Metropolitan Area.

Table 4.13. LULC changes in Hangzhou Metropolitan Area (2000–2015)

	2000		2015		Net Changes (2000-2015)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	58.42	5.84	172.75	17.27	114.33	195.71
Urban Sparse	17.11	1.71	49.27	4.93	32.17	188.02
Forest	349.96	34.98	328.00	32.79	-21.96	-6.28
Cropland	407.24	40.71	320.39	32.03	-86.86	-21.33
Grassland	22.44	2.24	22.37	2.24	-0.07	-0.30
Bareland	34.47	3.45	33.37	3.34	-1.11	-3.21
Water	110.76	11.07	74.25	7.42	-36.51	-32.96
Total	1000.40	100.00	1000.40	100.00		

4.14. Hanoi Metropolitan Area, Vietnam

Geographical and socioeconomic characteristics

Hanoi is the capital of Vietnam and the country's second largest city. In 2009, the urban districts of Hanoi had a population of 2.6 million (http://www.gso.gov.vn), while the metropolitan area had 6.5 million (http://balita.ph). Hanoi is located in the northern region of Vietnam, situated in Vietnam's Red River delta, nearly 90 km away from the coastal area. Hanoi is 1760 km north of Ho Chi Minh City and 120 km west of Haiphong City. The landscape of Hanoi expands from the delta to the midland and mountainous regions. In general, the terrain becomes gradually lower from north to south and from west to east, with an average height ranging from 5 to 20 m above sea level. The hilly and mountainous regions are located in the northern and western parts of the city.

In recent years, the sharp growth of local population, together with the unequal living standards between rural and urban areas, has created many challenges. Because Hanoi expanded its administrative boundary in 2008, merging Hanoi and Ha Tay province, the capital city's population has reached 7.1 million. During the past four years, Hanoi's population has been increasing at the rate of 0.43 million people per year (http://tuoitrenews.vn). On the average, the population has been growing at the rate of 50 thousand per year due to migration, with working age people in the majority. In order to respond to this rapid population growth, the expansion of Hanoi's administrative boundary was an important process.

LULC changes in Hanoi Metropolitan Area

Figs. 4.14(a) and 4.14(b) show the LULC classification results for Hanoi using the maximum likelihood supervised classification method. Fig. 4.14(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue) and urban sparse to urban dense (red) between 2001 and 2014. The gray areas are other lands and changes. Table 4.14 shows the statistics of LULC changes between 2001 and 2014 in Hanoi.

Compared with other capital cities, Hanoi is small. As a city located in a tropical region, Hanoi also has a typical tropical city characteristic: the land use and land cover are influenced by the season. Some of the detected changes were due 'seasonal differences' because the images used in the LULC classification were captured in different seasons. As the capital city of a developing country, Hanoi also underwent huge changes brought about by economic globalization. From 2001 to 2014, the area of urban dense increased by 175%, while the area of urban sparse increased by 11%.

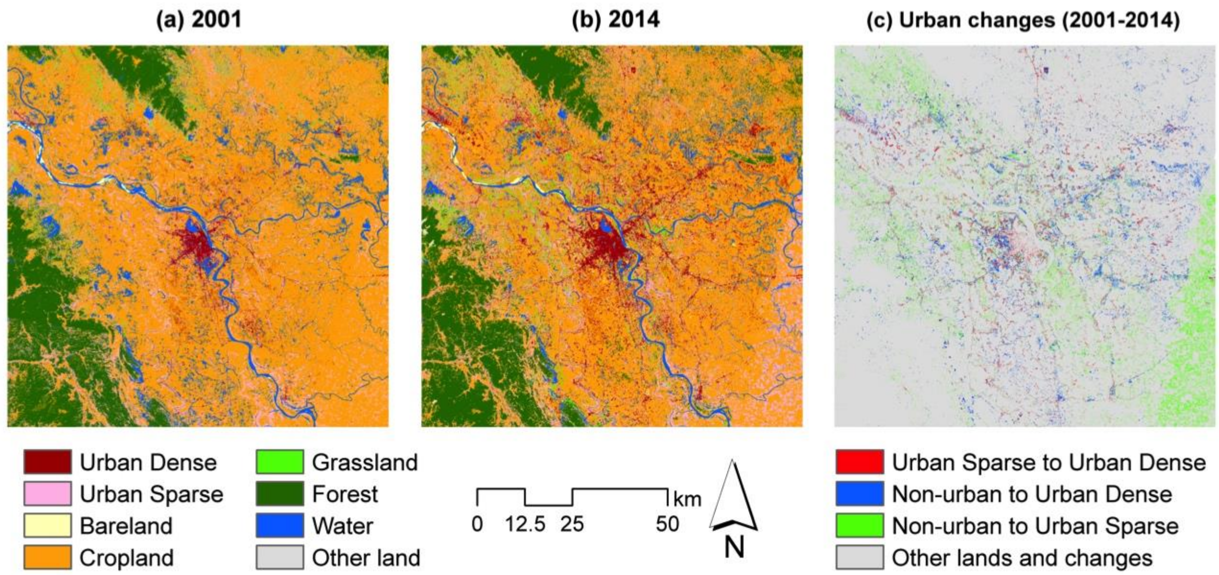

Fig. 4.14. LULC maps and spatial distribution of urban land changes in Hanoi Metropolitan Area.

Table 4.14. LULC changes in Hanoi Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	26.83	2.68	73.79	7.37	46.96	175.02
Urban Sparse	125.17	12.51	139.81	13.97	14.64	11.70
Forest	132.57	13.25	144.47	14.44	11.90	8.98
Cropland	623.39	62.30	545.53	54.52	-77.87	-12.49
Grassland	11.28	1.13	21.29	2.13	10.01	88.78
Bareland	7.49	0.75	20.12	2.01	12.63	168.69
Water	73.91	7.39	54.90	5.49	-19.00	-25.71
Other Land	0.05	0.00	0.77	0.08	0.72	1516.79
Total	1000.68	100.00	1000.68	100.00		

4.15. Istanbul Metropolitan Area, Turkey

Geographical and socioeconomic characteristics

Istanbul is the largest city in Turkey and one of the biggest metropolitan areas in the world with a population of approximately 12.5 million (Dubovyk 2011). Istanbul is historically known as Constantinople and Byzantium. Although it has been continuously inhabited since 3000 BCE, it did not become a city until the Greeks arrived in the area in the 7th century BCE. Geographically, the city is a transcontinental city as it is located on the Bosphorus waterway in northwest Turkey, between the Black Sea and the Sea of Marmara. Istanbul has been ranked as the fifth largest city in the world in terms of population within city limit (UN 2014). Since the middle of the 20th century, the increase of population in the city and its neighborhoods has resulted in high rates of urban expansion (Kucukmehmetoglu 2008).

Istanbul's economy is considered as a one of the fastest growing economies in the world. The city has always been the main economic hub of the country because of its location at an international junction of land and sea trade routes. Istanbul accounts for 27% of Turkey’s GDP and 20% of country’s industrial labor force (UGE 2001). Its economy is diverse, producing different types of commodities such as olive oil, tobacco, transport vehicles, and electronics. The city is also a famous tourist destination.

LULC changes in Istanbul Metropolitan Area

Figs. 4.15(a) and 4.15(b) show the LULC classification results for Istanbul using the maximum likelihood supervised classification method. Fig. 4.15(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that the urban area of Istanbul is concentrated mostly on the southern side of the landmass bisected by water (see Fig. 4.15(a) and 4.15(b)). Urban dense is found mostly around the city center located near the lower (south) end of the body of water that connects the Black Sea (north) and the Sea of Marmara (south). The location of Istanbul port near the city center is also an important factor for the development of the region.

In 2000, urban dense had an area of 27.69 thousand ha, covering 2.77% of the whole landscape (Table 4.15). In 2014, its area increased to 46.41 thousand ha, resulting in a net gain of 67.58 thousand ha. In 2000, urban sparse had an area of 96.93 thousand ha (9.69%), but in 2014, its area also increased to 172.15 thousand ha (17.21%). Forest also had a substantial gain over the same period (24.42 thousand ha). By contrast, cropland had a substantial loss (66.79 thousand ha). Overall, the LULC changes in Istanbul metropolitan area from 2000 to 2014 show that the expansion of built-up lands (urban dense and urban sparse) has been remarkable. By contrast, the area of all the other LULC categories, except for forest, has decreased.

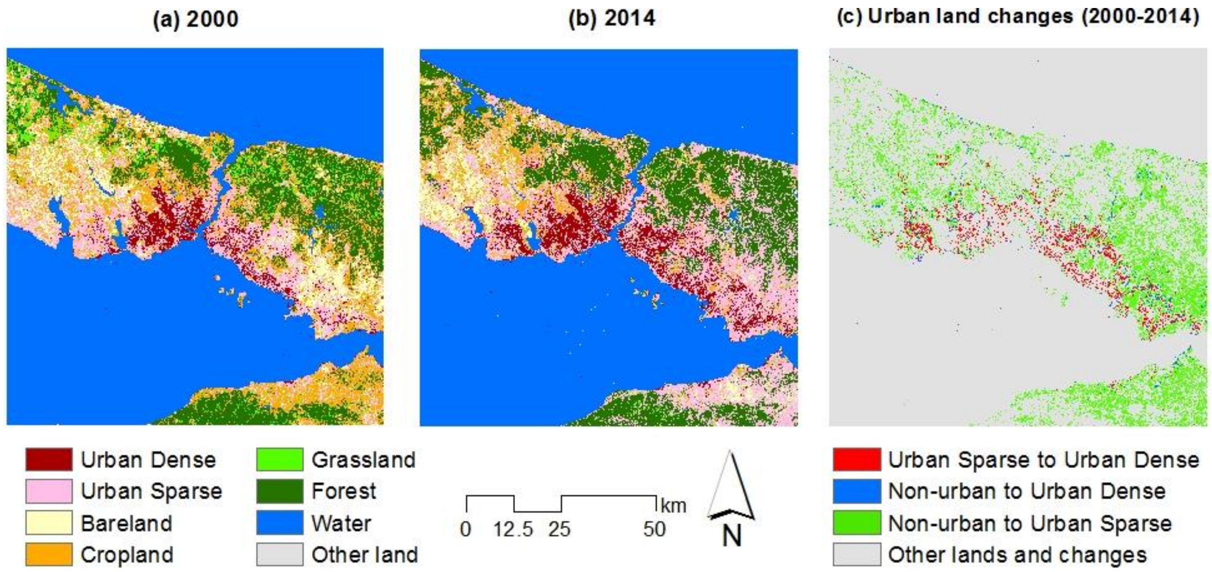

Fig. 4.15. LULC maps and spatial distribution of urban land changes in Istanbul Metropolitan Area.

Table 4.15. LULC changes in Istanbul Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	27.69	2.77	46.41	4.64	18.72	67.61
Urban Sparse	96.93	9.69	172.15	17.21	75.22	77.60
Forest	112.65	11.26	137.07	13.71	24.42	21.68
Cropland	122.67	12.27	55.88	5.59	-66.79	-54.45
Grassland	29.22	2.92	5.58	0.56	-23.64	-80.90
Bareland	64.51	6.45	40.71	4.07	-23.80	-36.89
Water	546.42	54.64	542.29	54.22	-4.13	-0.76
Total	1000.10	100.00	1000.10	100.00		

4.16. Jakarta Metropolitan Area, Indonesia

Geographical and socioeconomic characteristics of Jakarta

The Jakarta metropolitan area includes the cities of Jakarta, Bogor, Depok, Tangerang and Bekasi. It is commonly known as "Jabodetabek", an acronym derived from the first few letters of each city. Jakarta is the capital city of the Republic of Indonesia. Geographically, Jakarta City is located at 6° 08' S latitude and 106° 45' E longitude, on the northwest coast of the Java Island. The landscape of Jakarta is a low, flat basin, averaging 7 m above sea level. The southern part of the city is comparatively hilly, while some flat areas in the northern part are below sea level. The total land area of the Jakarta metropolitan area is about 7700 km^2, while Jakarta City has an area of about 660 km^2.

Jakarta is one of the most popular urban agglomerations in the world. The population of Jakarta City was 9.12 million in 2013 (https://www.cia.gov) and the metropolitan area of Jakarta has a population of 27 million, with an annual growth rate of 3.2% (http://www.citypopulation.de). The UN ranked Jakarta City as the 28th largest population agglomeration in the world (UN 2014). Jakarta is also listed as a global city in the 2008 Globalization and World Cities Study Group and Network (GaWC) research (http://www.lboro.ac.uk).

The Jakarta metropolitan area is the main economic and administrative center of Indonesia. Financial services, trade and manufacturing are the main economic activities in the city. Major industries in Jakarta include electronics, automotive, chemicals, mechanical engineering, and biomedical sciences manufacturing. However, the Jakarta metropolitan area has also been facing a wide range of urban problems since the last few decades, including flooding and traffic congestion.

LULC changes in Jakarta Metropolitan Area

Figs. 4.16(a) and 4.16(b) show the LULC classification results for Jakarta using the maximum likelihood supervised classification method. Fig. 4.16(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2001 and 2014. The LULC maps show that the city's urbanized area is located mostly in the northern part, while the southern part is covered with forest. It can be observed that urban dense is highly agglomerated around the port of Jakarta City, located close to the city center. It seems that the location of the port in the northern part of the city is an important factor in the development of the area. In addition, the administrative center, international airport and many industries are also concentrated in the northern part of the city. The maps also show that Jakarta's urban area has been expanding towards the south, following a triangular spatial pattern.

In 2001, urban dense had an area of 37.89 thousand ha, covering 3.79% of the whole landscape (Table 4.16). In 2014, its area increased to 81.63 thousand ha, i.e. 8.16% of the landscape, resulting in a net gain of 43.74 thousand ha over the 13-year period. In 2001, urban sparse only had an area of 51.78 thousand ha (5.18%), but in 2014, its area increased to 80.38 thousand ha (8.03%). By contrast, the other LULC categories, including forest, cropland and grassland all had substantial losses over the same period (Table 4.16). Overall, the LULC changes in Jakarta metropolitan area show a substantial built-up expansion between 2001 and 2014, as indicated by the increase in the area of urban dense and urban sparse, at the expense of the other major LULC categories, including forest and cropland.

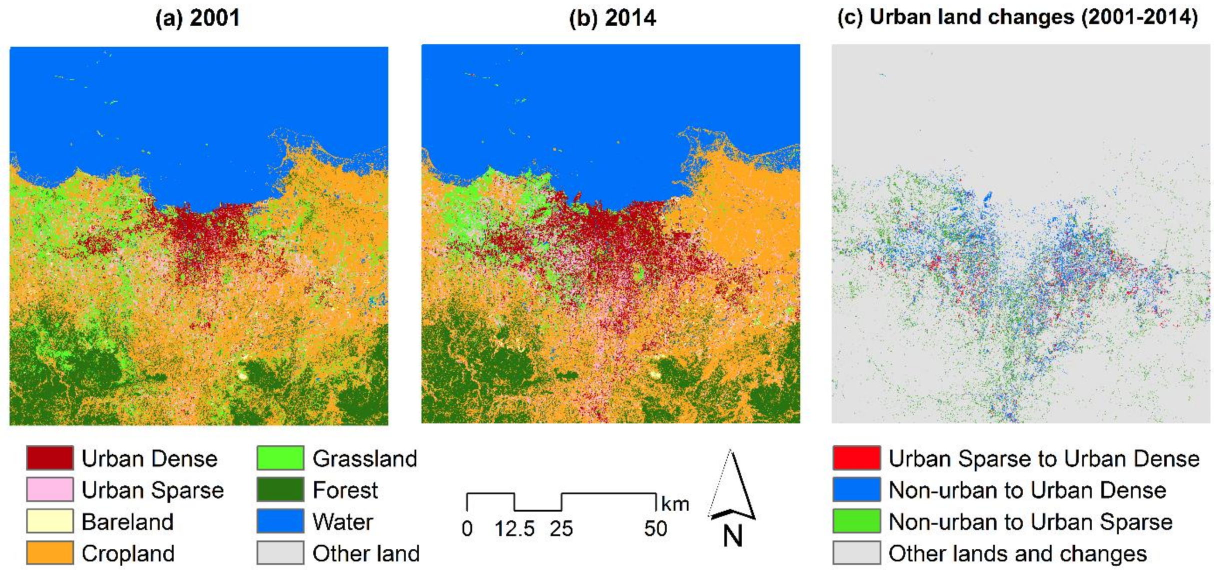

Fig. 4.16. LULC maps and spatial distribution of urban land changes in Jakarta Metropolitan Area.

Table 4.16. LULC changes in Jakarta Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	37.89	3.79	81.63	8.16	43.74	115.44
Urban Sparse	51.78	5.18	80.38	8.03	28.60	55.24
Forest	130.91	13.09	118.28	11.82	-12.62	-9.64
Cropland	313.71	31.36	294.80	29.47	-18.91	-6.03
Grassland	92.83	9.28	54.08	5.41	-38.75	-41.75
Bareland	7.20	0.72	8.85	0.88	1.65	22.98
Water	366.07	36.59	362.37	36.22	-3.71	-1.01
Total	1000.39	100.00	1000.39	100.00		

4.17. Johannesburg Metropolitan Area, South Africa

Geographical and socioeconomic characteristics

Johannesburg is the largest city in South Africa. The city is also one of the 50 largest urban agglomerations in the world (http://www.citypopulation.de/). Geographically, Johannesburg is located on the eastern plateau of South Africa at approximately 26° 12' S latitude and 28° 2' E longitude.

In 2011, Johannesburg had a population of 4.4 million and a density of 2900 people/km^2. Johannesburg is one of the world's leading financial center, while it being the South Africa's center of finance, business and corporate headquarter, with strong global and African links (Todes 2012). It is South Africa's largest local economy, accounting for 13.7% of national output and 11.2% of employment (Quantec 2009). Headquarters for gold mining companies, steel and cement productions are mostly located within the city limits of Johannesburg. However, higher level of unemployment (approximately 46%) and higher level of poverty (approximately 20%) are major urban problems in the city (Smith 2013).

LULC changes in Johannesburg Metropolitan Area

Figs. 4.17(a) and 4.17(b) show the LULC classification results for Johannesburg using the maximum likelihood supervised classification method. Fig. 4.17(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that Johannesburg's built-up lands (urban dense and urban sparse) are found mostly around the city center. However, the maps also show that built-up lands have been expanding outward of the city center. A large proportion of urban sparse has also been converted into urban dense.

In 2000, urban dense had area of 39.45 thousand ha, covering 3.94% of the whole landscape (Table 4.17). In 2014, its area increased to 85.31 thousand ha, resulting in a net gain of 45.86 thousand ha. By contrast, the area of urban sparse decreased from 245.62 thousand ha (24.54%) in 2000 to 244.16 thousand ha (24.40%) in 2014. Among the eight LULC categories, bareland was the most dominant. It accounted for 60.05% (600.91 thousand ha) in 2000 and 61.75% (617.95 thousand ha) in 2014. The other major LULC type after urban dense and urban sparse was grassland, covering 76.11 thousand ha (7.61%) in 2000 and 33.65 thousand ha (3.36%) in 2014. The decline of forest over the period was also substantial (69.71%).

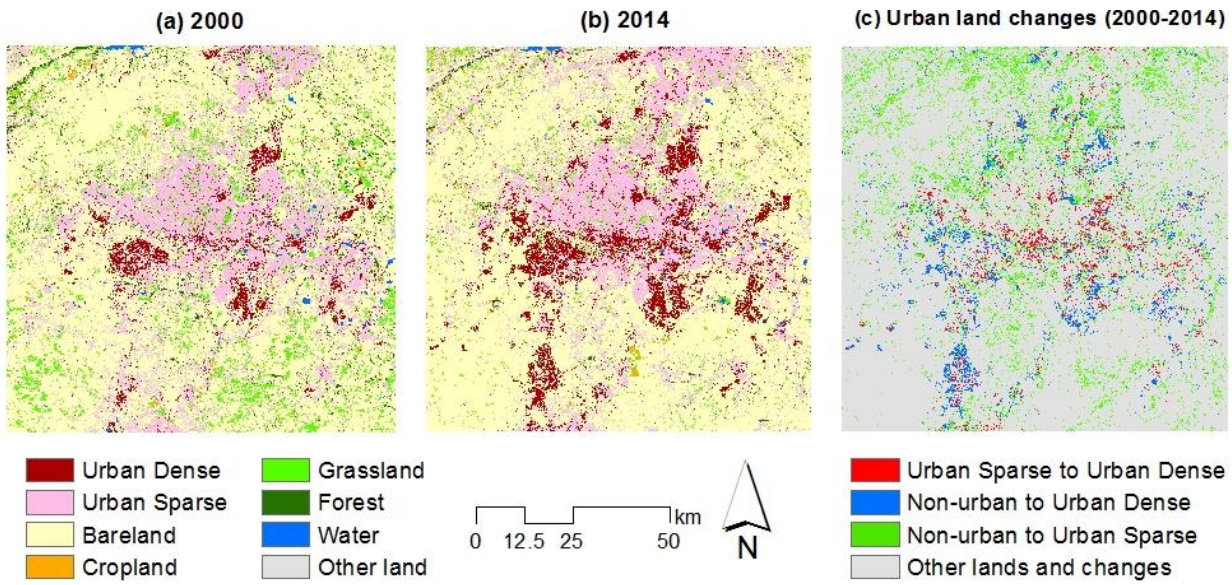

Fig. 4.17. LULC maps and spatial distribution of urban land changes in Johannesburg Metropolitan Area.

Table 4.17. LULC changes in Johannesburg Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	39.45	3.94	85.31	8.53	45.86	116.25
Urban Sparse	245.62	24.54	244.16	24.40	-1.46	-0.59
Forest	27.93	2.79	8.46	0.85	-19.47	-69.71
Cropland	5.98	0.60	7.48	0.75	1.50	25.08
Grassland	76.11	7.61	33.65	3.36	-42.46	-55.79
Bareland	600.91	60.05	617.95	61.75	17.04	2.84
Water	4.71	0.47	3.69	0.37	-1.02	-21.66
Total	1000.70	100.00	1000.70	100.00		

4.18. Karachi Metropolitan Area, Pakistan

Geographical and socioeconomic characteristics

Karachi, the capital of Pakistan, is one of the most populous metropolitan cities in the world. Geographically, the city is located in the southeastern part of the country at 24° 51' N latitude and 67° 0' E longitude. River Malir and River Lyari flow through the city and the harbor is situated on the southwest part of the city.

In 2013, Karachi had a population of 23.5 million and a density of 3521 people/km^2 (Amer 2013). It is the 12th largest city in the world by population (UN 2014) and the country’s center for major financial institutions. It also houses the headquarters of numerous multinational companies. In 2007, the World Bank identified Karachi as the most business-friendly city in Pakistan (http://www.cipe.org/). Karachi's GDP accounts for about 20% of the country’s total GDP. Rapid urban population growth, inadequate provision of shelters to the urban poor, energy crisis, and vehicular traffic congestion are among the major problems in the Karachi metropolitan area today.

LULC changes in Karachi Metropolitan Area

Figs. 4.18(a) and 4.18(b) show the LULC classification results for Karachi using the maximum likelihood supervised classification method. Fig. 4.18(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that Karachi’s built-up lands (urban dense and urban sparse) are concentrated north of the harbor. The maps also show that built-up lands have been expanding towards the northern and eastern parts of the city. A large proportion of urban sparse around the city center have also been converted into urban dense.

In 2000, urban dense had an area of 8.04 thousand ha, covering 0.80% of the whole landscape (Table 4.18). In 2014, its area increased to 17.12 thousand ha, resulting in a net gain of 9.08 thousand ha. In 2000, urban sparse had an area 33.67 thousand ha only (3.37%), but in 2014 its area increased to 47.51 thousand ha (4.75%), with a net gain of 13.84 thousand ha. Aside from water, the other dominant LULC type in the area was bareland, covering 443.42 thousand ha (44.34%) in 2000 and 385.83 thousand ha (38.58%) in 2014. The overall results show that except bareland and water, the area of each of the other LULC categories has increased over the past 14 years (2000-2014).

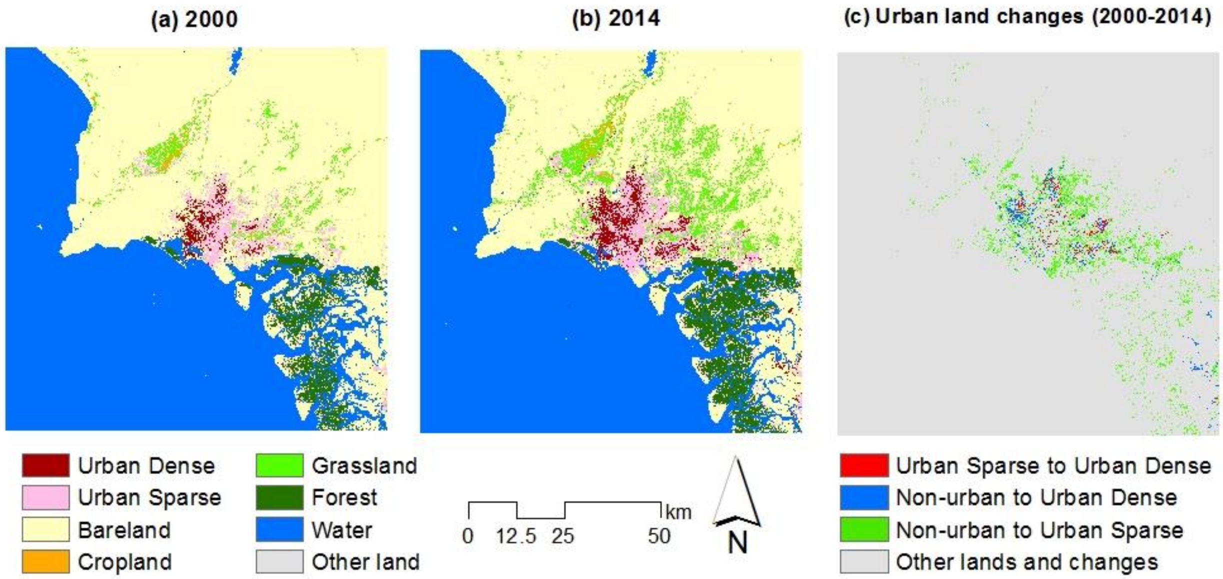

Fig. 4.18. LULC maps and spatial distribution of urban land changes in Karachi Metropolitan Area.

Table 4.18. LULC changes in Karachi Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	8.04	0.80	17.12	1.71	9.08	112.97
Urban Sparse	33.67	3.37	47.51	4.75	13.84	41.11
Forest	30.03	3.00	42.62	4.26	12.59	41.93
Cropland	3.25	0.32	3.80	0.38	0.55	16.98
Grassland	16.38	1.64	49.17	4.92	32.79	200.19
Bareland	443.42	44.34	385.83	38.58	-57.59	-12.99
Water	465.32	46.53	454.05	45.40	-11.27	-2.42
Total	1000.10	100.00	1000.10	100.00		

4.19. Kathmandu Metropolitan Area, Nepal

Geographical and socioeconomic characteristics

Kathmandu, the political and cultural capital of Nepal, is the largest municipality in the country. It is the only city in Nepal with administrative status 'metropolitan city'. The city is located at the urban core of the Kathmandu Valley in the Himalayas. Kathmandu Valley also includes two sister cities, namely Patan or Lalitpur, 5 km to the southeast, and Bhaktapur, 14 km to the east (http://www.kathmandu.gov.np). The city stands at an elevation of approximately 1400 m in the bowl-shaped valley of central Nepal. It is surrounded by four major mountains: Shivapuri, Phulchoki, Nagarjun and Chandragiri.

Kathmandu has the highest population density in the country, and is home to about a twelfth of Nepal's population. According to the census data, Kathmandu's population increased from 671,846 to 1,003,285 people from 2001 and 2011. The metropolitan area is about 49.45 km^2 and has a population density of 20,289 per km^2 (http://www.citypopulation.de).

LULC changes in Kathmandu Metropolitan Area

Fig. 4.19(a) and 4.19(b) show the LULC classification results for Kathmandu using the maximum likelihood supervised classification method. Fig. 4.19(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue) and urban sparse to urban dense (red) between 2001 and 2013. The gray areas are other lands and changes.

The LULC maps show that Kathmandu's urban area is relatively small compared to the whole 100 km × 100 km study area. The urban expansion in the whole landscape from 2001 to 2013 only happened in a small part. Had the spatial extent of the LULC mapping been reduced, the urban expansion in Kathmandu would have been much clearer. Forest is the most dominant category since the area is located in a mountainous region covered with trees. The LULC maps also show a large portion of the landscape in the northeastern part that has been classified as "other land." Most of this area is covered with snow.

Table 4.19 shows that the area of urban dense and urban sparse increased from 2001 to 2013. In 2001, urban dense had an area of 6.75 thousand ha, accounting for 0.67% of the whole landscape. In 2013, its area increased to 11.67 thousand ha, resulting in a net gain of 4.92 thousand ha. During the same period, the area of urban sparse also increased remarkably by 16.49 thousand ha. These results show that the urban expansion in Kathmandu has been substantial. On the other hand, the proportion of cropland decreased from 17.21% to 11.87% due to its loss to urban area. The extent of grassland increased from 1.24% to 2.94%, while the proportion of forest increased from 44.85% to 50.66%. These changes might have been due to 'seasonal differences' between the two images used. The 2001 image was acquired at the end of December, while the 2013 image was acquired at the beginning of November. Further, it can be observed that the category "other land" decreased from 13.03% to 5.70%. Some areas covered with snow, cloud or shadow in the 2001 image were no longer covered in the 2013 image.

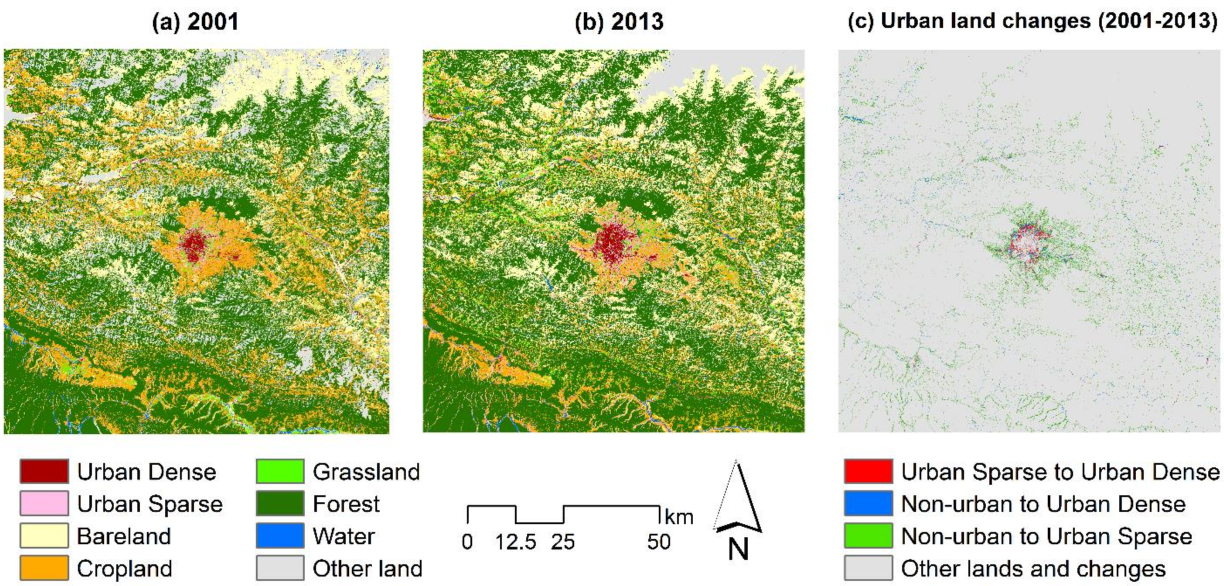

Fig. 4.19. LULC maps and spatial distribution of urban land changes in Kathmandu Metropolitan Area.

Table 4.19. LULC changes in Kathmandu Metropolitan Area (2001–2013).

	2001		2013		Net Changes (2001-2013)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	6.75	0.67	11.67	1.17	4.92	72.91
Urban Sparse	21.60	2.16	38.05	3.80	16.49	76.14
Forest	448.84	44.85	506.90	50.66	58.06	12.94
Cropland	172.23	17.21	118.82	11.87	-53.41	-31.01
Grassland	12.42	1.24	29.44	2.94	17.02	137.10
Bareland	197.53	19.74	231.18	23.10	33.65	17.04
Water	10.96	1.10	7.62	0.76	-3.34	-30.50
Other land	130.37	13.03	57.02	5.70	-73.35	-56.26
Total	1000.70	100.00	1000.70	100.00		

4.20. Khartoum Metropolitan Area, Sudan

Geographical and socioeconomic characteristics

Khartoum, the capital city of Sudan, is one of the largest cities in the country. Khartoum is a tripartite metropolis composed of three towns (Khartoum, Khartoum North, and Omdurman), covering a land area of about 22,000 km^2 (Elghazali 2006). It is located at the point where the White Nile flowing north from Uganda meets the Blue Nile flowing west from Ethiopia (Elghazali 2006). Geographically, Khartoum is located at 15° 33' N latitude and 32° 31' E longitude at an average elevation of about 381 m above sea level.

Khartoum is Sudan's primary city, not only in terms of absolute population, but also politically, economically, and socially (Pantuliano et al. 2011). It is the commercial and industrial center of country and has the highest concentration of urban infrastructure and services among all the cities in the country (Taha 2015). This gap between Khartoum and the other cities in Sudan has promoted migration of people from the rural areas seeking for better work and living opportunities. The urban migration has also been caused by other complex factors, including the unsettled situation in the country related to political and social conflicts and civil wars, along with environmental factors related to desertification and drought in some regions (Taha 2015).

In recent years, the city has experienced rapid urbanization. According to the UN Habitat (2009), the population of Khartoum grew by a factor of eight between 1973 and 2005 at an estimated average annual growth rate of over 6%. Currently, the population of Khartoum is over 5 million (with an average growth rate of 8%) and is estimated to grow to over 8 million by 2030 (UN 2015).

LULC changes in Khartoum Metropolitan Area

Figs. 4.20(a) and 4.20(b) show the LULC classification results for Dakar using the maximum likelihood supervised classification method. Fig. 4.20(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that the urban area of Khartoum is characterized mainly by urban dense. The expansion of its built-up lands (urban dense and urban sparse) is generally influenced by the location of the two rivers: the White Nile and Blue Nile. However, Khartoum is primarily a desert with a vast tract of bareland especially in the North. Cropland is also one of the main LULC types in the Khartoum metropolitan area.

In 2000, urban dense had an area of 29.86 thousand ha, covering 2.99% of the whole landscape. In 2014, its area increased to 52.88 thousand ha, i.e. 5.22% of the landscape. From 2000 to 2014, urban dense had a net gain of 22.38 thousand ha. Conversely, urban sparse was only 0.39 thousand ha (0.04%) in 2000 and only increased to 5.09 thousand ha (0.51%) in 2014, resulting in a net gain of 4.70 thousand ha. In 2000, cropland accounted for 11.28% (112.78 thousand ha) and in 2014 it accounted for 15.34% (153.38 thousand ha), translating into a net gain of 40.59 thousand ha. As indicated above, Khartoum is primarily covered by desert; thus dominated by the bareland category, which covered 789.80 thousand ha (78.97%) in 2000 and 678.20 thousand ha (67.81%) in 2014. The net loss in the area of bareland from 2000 to 2014 was 111.60 thousand ha (14.13%). Overall, the LULC changes in Khartoum metropolitan area from 2000 to 2014 show that there has been a substantial built-up expansion.

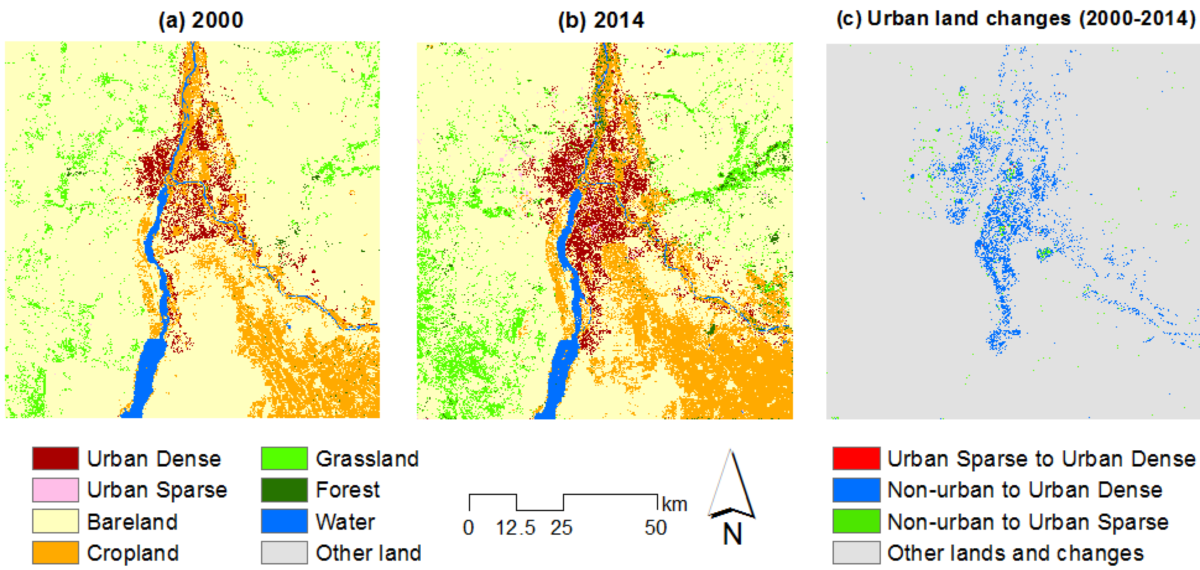

Fig. 4.20. LULC maps and spatial distribution of urban land changes in Khartoum Metropolitan Area.

Table 4.20 LULC changes in Khartoum Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	29.86	2.99	52.24	5.22	22.38	74.96
Urban Sparse	0.39	0.04	5.09	0.51	4.70	1209.12
Forest	3.86	0.39	14.09	1.41	10.23	265.09
Cropland	112.78	11.28	153.38	15.34	40.60	36.00
Grassland	41.12	4.11	74.42	7.44	33.30	80.98
Bareland	789.80	78.97	678.20	67.81	-111.60	-14.13
Water	22.29	2.23	22.68	2.27	0.39	1.76
Total	1000.10	100.00	1000.10	100.00		

4.21. Kuala Lumpur Metropolitan Area, Malaysia

Geographical and socioeconomic characteristics

Kuala Lumpur is the federal capital of Malaysia and the most populous city in the country. The urban area of Kuala Lumpur is more than 240 km^2 and it has an estimated population of 1.8 million (http://archive.today/toTM). Kuala Lumpur is located in the Klang Valley, bordered by the Titiwangsa Mountains in the east (http://www.visitkualalumpur.com). As one of the most important cities in Asia, it enjoys a booming economy and shows the vitality of an expanding city over the past two decades in response to globalization (http://archive.unu.edu).

Kuala Lumpur has a population of 1.67 million people, i.e. in an area of just 243 km^2 (http://www.dbkl.gov.my). This gives the city proper a very high population density of 6890 km^2. The Greater Kuala Lumpur, or the Klang Valley, is a large urban agglomeration with an estimated population of 7 million in 2014 and a population density that is nearly equal to that of the city proper (http://worldpopulationreview.com). Over the past three decades, Kuala Lumpur has been continuously growing.

LULC changes in Kuala Lumpur Metropolitan Area

Figs. 4.21(a) and 4.21(b) show the LULC classification results for Kuala Lumpur using the maximum likelihood supervised classification method. Fig. 4.21(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue) and urban sparse to urban dense (red) between 2001 and 2014. The gray areas are other lands and changes. Table 4.21 shows the statistics of LULC changes between 2001 and 2014 in Kuala Lumpur.

The urban area of Kuala Lumpur is concentrated mainly in the low-lying regions, west of the mountain range. From 2001 to 2014, the area of urban dense increased by almost 60%, while the area of urban sparse increased by 76% (Table 4.21). The results also show a net loss of 36% for cropland and 21% for forest over the same period due to urbanization. Most of the changed areas are located in the western side of the mountain range. It can be observed that for the classification in 2014, the northeastern part of Kuala Lumpur was filled with clouds and shadow, affecting the classification and change detection results.

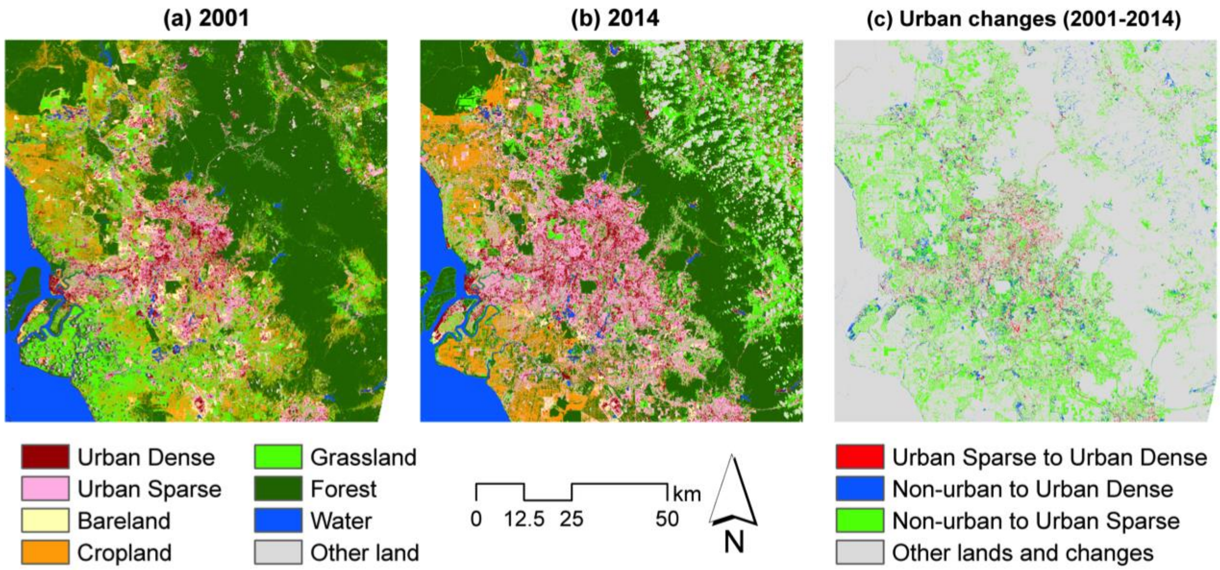

Fig. 4.21. LULC maps and spatial distribution of urban land changes in Kuala Lumpur Metropolitan Area.

Table 4.21. LULC changes in Kuala Lumpur Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	34.56	3.45	55.22	5.52	20.66	59.77
Urban Sparse	121.34	12.13	213.88	21.37	92.54	76.26
Forest	468.94	46.86	368.21	36.80	-100.72	-21.48
Cropland	142.02	14.19	90.39	9.03	-51.63	-36.35
Grassland	130.14	13.00	130.50	13.04	0.36	0.28
Bareland	31.84	3.18	23.01	2.30	-8.84	-27.75
Water	64.46	6.44	63.90	6.39	-0.55	-0.86
Other land	7.40	0.74	55.59	5.55	48.19	651.23
Total	1000.70	100.00	1000.70	100.00		

4.22. Lagos Metropolitan Area, Nigeria

Geographical and socioeconomic characteristics

Lagos is a large port city in southwestern Nigeria located at 6° 27' N latitude and 3° 23' E longitude. Lagos is the largest city in Nigeria and one of the fastest growing cities in the world. In 2007, the United Nations ranked Lagos 9th among the 28 current and prospective megacities in the world. Lagos is a classic example of a modern city, having transformed from a small farming and fishing village in the 15th century to a burgeoning megacity in 2010, when its population rose to over 10 million (Filani 2012). Its population was estimated at just 11.2 million in 2011 by the United Nations, overtaking the Egyptian capital Cairo as Africa's biggest city (WPR 2016). As of 2014, Lagos has a population estimated at 21 million (WPR 2016)

Nowhere in West Africa is the rate of urbanization in the last few years as unprecedented as Lagos, the economic focal point of Nigeria (Braimoh & Onishi 2007). As the economic and financial nerve center with the most extensive infrastructural facilities, it accounts for over 70% of Nigeria's industrial and commercial establishments (Braimoh & Onishi 2007). As a result, Lagos continues to receive migrants from rural regions of Nigeria in search of economic opportunities. This has substantially contributed to the high population growth rates. The rapid population growth has in turn put pressure on land available for housing. Consequently, this has also lead to the increase of informal settlements with very poor conditions, i.e. lack of basic services (water, electricity, sanitation etc.), and severe flooding.

LULC changes in Lagos Metropolitan Area

Figs. 4.22(a) and 4.22(b) show the LULC classification results for Addis Ababa using the maximum likelihood supervised classification method. Fig. 4.22(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2002 and 2014. The LULC maps show that the urban area Lagos City is located in the south-central part, with the spatial expansion of built-up lands (urban dense and urban sparse) occurring in the northern direction.

Table 4.22 shows the LULC statistics and changes between 2002 and 2014 in Lagos. The statistics show that urban dense has been expanding rapidly. In 2002, it only had an area of 16.35 thousand ha (1.63%), but in 2014 its area increased to 26.53 thousand ha (2.65%), resulting in a net gain of 10.18 thousand ha. The increase in the area of urban sparse was even more remarkable. Its area increased from 30.45 thousand ha (3.04%) in 2002 to 55.40 thousand ha (5.54%) in 2014, with a net gain of 24.95 thousand ha. The rapid expansion of built-up lands was at the expense of the other LULC categories. From 2002 to 2014, the area of forest decreased from 9.48% (94.91 thousand ha) to 5.22% (52.25 thousand ha). The area of cropland decreased from 6.76% (67.62thousand ha) to 4.82% (48.23 thousand ha), while the area of bareland decreased from 3.85% (38.56 thousand ha) to 0.36% (3.58 thousand ha). The net losses in forest, cropland and bareland were 42.66 thousand ha, 19.39 thousand ha and 34.97 thousand ha, respectively. The grassland however, increased from 30.45 thousand ha (3.04%) in 2002 to 55.40 thousand ha (5.54%) in 2014, with a net gain of 64.10thousand ha.

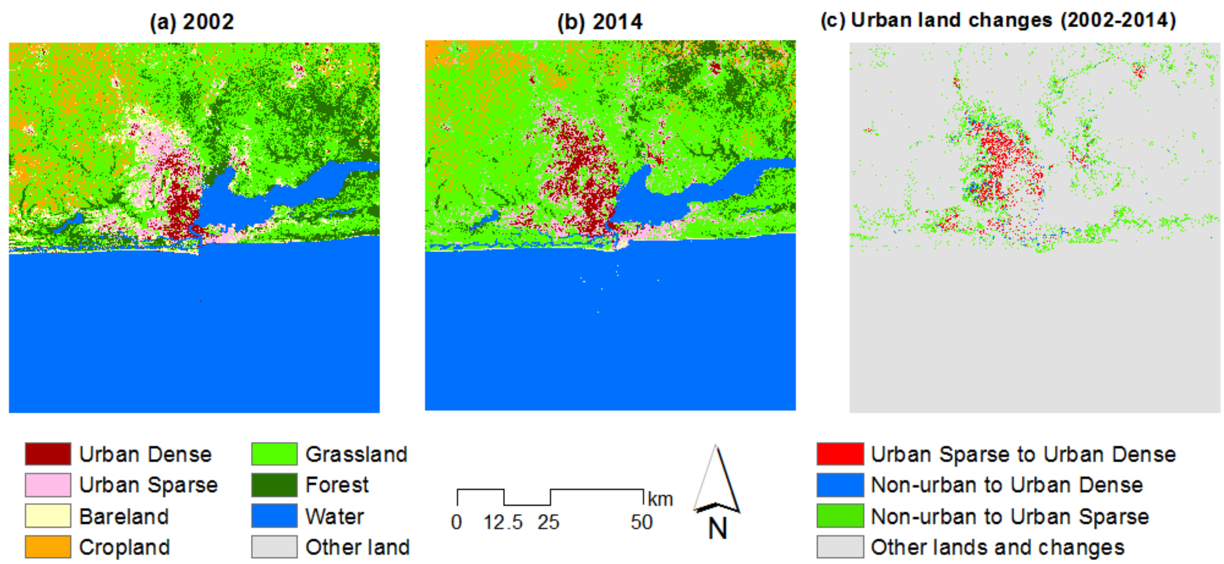

Fig. 4.22. LULC maps and spatial distribution of urban land changes in Lagos Metropolitan Area.

Table 4.22. LULC changes in Lagos Metropolitan Area (2002–2014).

	2002		2014		Net Changes (2002-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2002
Urban Dense	16.35	1.63	26.53	2.65	10.18	62.28
Urban Sparse	30.45	3.04	55.40	5.54	24.95	81.93
Forest	94.91	9.48	52.25	5.22	-42.66	-44.95
Cropland	67.62	6.76	48.23	4.82	-19.39	-28.68
Grassland	259.71	25.95	323.80	32.36	64.10	24.68
Bareland	38.56	3.85	3.58	0.36	-34.97	-90.71
Water	493.10	49.28	490.89	49.06	-2.21	-0.45
Other land	0.00	0.00	0.00	0.00	0.00	
Total	1000.70	100.00	1000.70	100.00		

4.23. Lusaka Metropolitan Area, Zambia

Geographical and socioeconomic characteristics

Lusaka, the capital city of Zambia, is one of the cities in Sub Saharan Africa that has been experiencing rapid urban growth. Over the past three decades, Lusaka City has expanded rapidly both in population size and spatial extent (Mulenga 2003; Mayerhofer et al. 2010). The population of Lusaka City has increased from approximately 535,830 in 1980, 761,064 in 1990, 1,083, 703 in 2000 and 1,742,979 in 2010 (Central Statistics Office (CSO) 1994, 2001, 2011). These statistics show that the population of the city has grown more than three times between 1980 and 2010. The estimated annual growth rate for Lusaka City between 2000 and 2010 was 4.9%, which was almost twice the estimated 2.8% national average (CSO 2011). Lusaka City currently dominates the urban system in Zambia, hosting about 32% of the urban population in the country (Chama et al. 2009). It is also the political, cultural, and economic center of the country and the home of central government.

The population growth of the city has largely been attributed to rural-urban migration from other parts of the country, which has been driven by economic prospects, expectations for opportunities of higher education and employment (LCC 2008). Other causes include natural growth resulting from high fertility rates (UNDP 1996) and boundary extensions on the city (Mulenga 2003). The rapid growth of population in the city has created both environmental and social problems. It has outstripped the supply of land for development (Chama et al. 2009). Major problems in Lusaka City include the lack of serviced land, complex procedures and poor record keeping regarding land ownership and land use, inadequate human resources, the slow pace in issuing security of land tenure, the failure of master planning, an increase in illegal/informal settlements, and political interference in land allocation (Chama et al. 2009). The rapid urban population growth has also created an increase in demand for social services such as housing, water and sanitation, employment, education and other basic services (UNDP 1996).

LULC changes in Lusaka Metropolitan Area

Figs. 4.23(a) and 4.23(b) show the LULC classification results for Lusaka metropolitan area using the maximum likelihood supervised classification method. Fig. 4.23(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2001 and 2014. The LULC maps show that Lusaka's built-up lands (urban dense and urban sparse) have been expanding in all directions, but in close proximity to the existing built-up lands. The area is also characterized by a vast tract of bareland. Grasslands and forests are found mostly in the south-eastern part of the area.

Table 4.23 shows the LULC statistics and changes between 2001 and 2014 in Lusaka. The statistics show that the area of urban dense has increased considerably over the 13-year period. In 2001, it had an area of 9.08 thousand ha (0.91%), but in 2014 its area increased to 11.81 thousand ha (1.18%), resulting in a net gain of 2.72 thousand ha. The increase in the area of urban sparse was even greater, from 1.18 thousand ha (0.12%) in 2001 to 9.38 thousand ha (0.94%) in 2014, with a net gain of 8.19 thousand ha. Over the same period, the area of all the other LULC categories, except for forest, also increased. The area of forest decreased from 14.11% (141.16 thousand ha) in 2001 to 7.94% (79.46 thousand ha) in 2014, resulting in a net loss of 61.70 thousand ha.

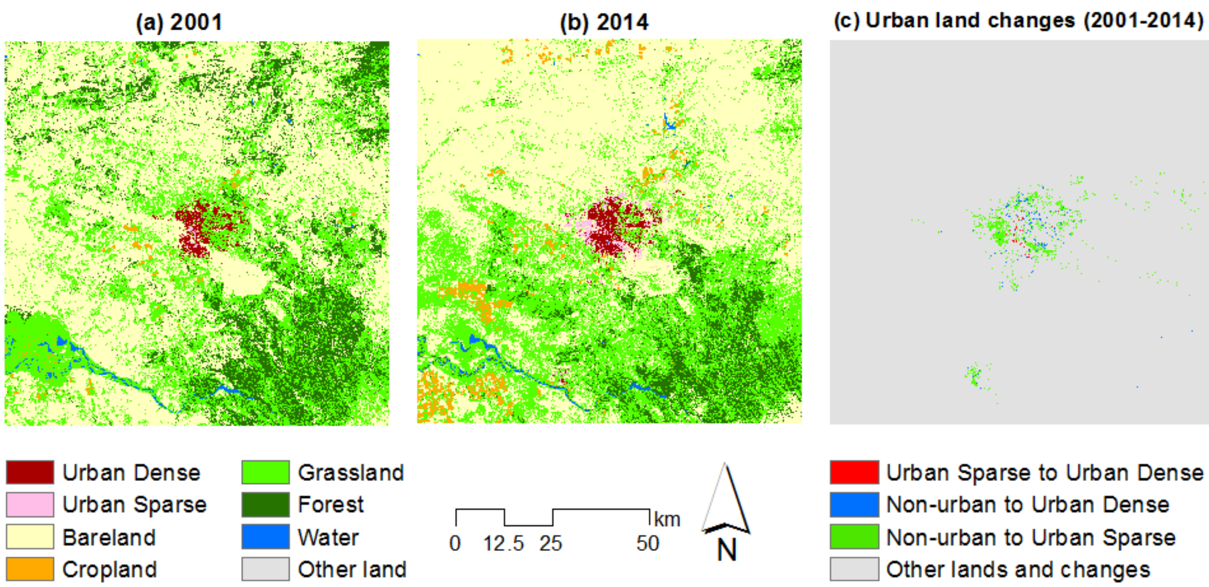

Fig. 4.23. LULC maps and spatial distribution of urban land changes in Lusaka Metropolitan Area.

Table 4.23. LULC changes in Lusaka Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	9.08	0.91	11.81	1.18	2.72	29.98
Urban Sparse	1.19	0.12	9.38	0.94	8.19	689.18
Forest	141.16	14.11	79.46	7.94	-61.70	-43.71
Cropland	5.20	0.52	26.03	2.60	20.83	400.29
Grassland	288.86	28.87	316.28	31.61	27.42	9.49
Bareland	550.30	55.00	552.84	55.25	2.54	0.46
Water	4.82	0.48	4.83	0.48	0.01	0.13
Total	1000.62	100.00	1000.62	100.00		

4.24. Manila Metropolitan Area, Philippines

Geographical and socioeconomic characteristics

Metropolitan Manila, commonly known as Metro Manila, is the center of government, economy, education and culture of the Philippines. Composed of 16 cities and one municipality, including the City of Manila – the country's capital – Metro Manila has a total land area of 636 km^2, i.e. 0.2% of the country's land area. Geographically, Metro Manila is located at 14° 35' N latitude and 121° 00' E longitude, with Manila Bay on the western side and Laguna de Bay on the southeastern side. Among Metro Manila's 17 towns, Quezon City is the largest (171.71 km^2), while the smallest is San Juan (5.95 km^2). The governance of Metro Manila is exercised by the Metropolitan Manila Development Authority (MMDA).

Metro Manila is the country's largest manufacturing location and the second-largest employer after the wholesale and retail sectors (Lambino 2010). It also serves as the nation's principal port, with its excellent protected harbor (ADB 2014). The lands at the fringe of Metro Manila are in demand for residential subdivisions, sports and leisure centers, memorial parks and industrial complexes (Magno-Ballesteros 2000).

In 2000, Metro Manila had a population of 9.93 million (i.e. 12.98% of the country's population) and a density of 15,617.23 people/km^2, and in 2010 it had 11.86 million (i.e. 12.84% of the country's population) and 18,641.47 people/km^2, respectively (http://web0.psa.gov.ph). Metro Manila also exhibits the problems of many large cities, such as overpopulation, where the local government struggles to keep up with the demand for services (ADB 2014). In addition, 31% of Metro Manila's land area is also flood prone, including the cities of Manila, Navotas, Malabon and some parts of Caloocan (Magno-Ballesteros 2000).

LULC changes in Manila Metropolitan Area

Figs. 4.24(a) and 4.24(b) show the classified LULC maps of Metro Manila, while Fig. 4.24(c) highlights the detected urban land changes between 2001 and 2014, including the changes from urban sparse to urban dense (red), non-urban to urban dense (blue) and non-urban to urban sparse (green). Due to the presence of the two main bodies of water (Manila Bay and Laguna de Bay), the spatial urban expansion of Metro Manila is concentrated mostly towards the north and south directions (Fig. 4.24). There are indications for an urban sprawl as shown by the substantial urban land changes in the northern and southern parts. However, there are also signs for an infilling pattern as indicated by the urban land changes in the city center (Fig. 4.24).

In 2001, urban dense had an area of 27.57 thousand ha, accounting for 2.76% of the whole landscape (Table 4.24). In 2014, it increased to 49.80 thousand ha, i.e. 4.98% of the landscape, resulting in a net gain of 22.24 thousand ha over the 13-year period. The increase in the area of urban dense was due to its gains from urban sparse and non-urban areas (Fig. 4.24(c)). The increase in the area of urban sparse was even greater, from 59.43 thousand ha (5.94%) in 2001 to 104.67 thousand ha in 2014 (10.47%), with a net gain of 45.24 thousand ha over the same period (Table 4.24). The increase in the area of urban sparse was at the expense of the other LULC categories (Fig. 4.24(c); Table 4.24).

Cropland had a net loss of 10.75 thousand ha (21.76%), while grassland had a net loss of 82.02 thousand ha (27.05%). The presence of clouds and shadows, especially in the forested areas, classified in this project as other land (Figs. 4.24(a) and 4.24(b)), complicates the detection of the gains and losses of forest cover over the same period. However, there are indications that green spaces, including patches of forest, in the city center have been decreasing over the years. Overall, the data show that Metro Manila has been experiencing remarkable landscape changes, especially in its fringe areas, posing many challenges in the context of sustainable landscape and urban development planning.

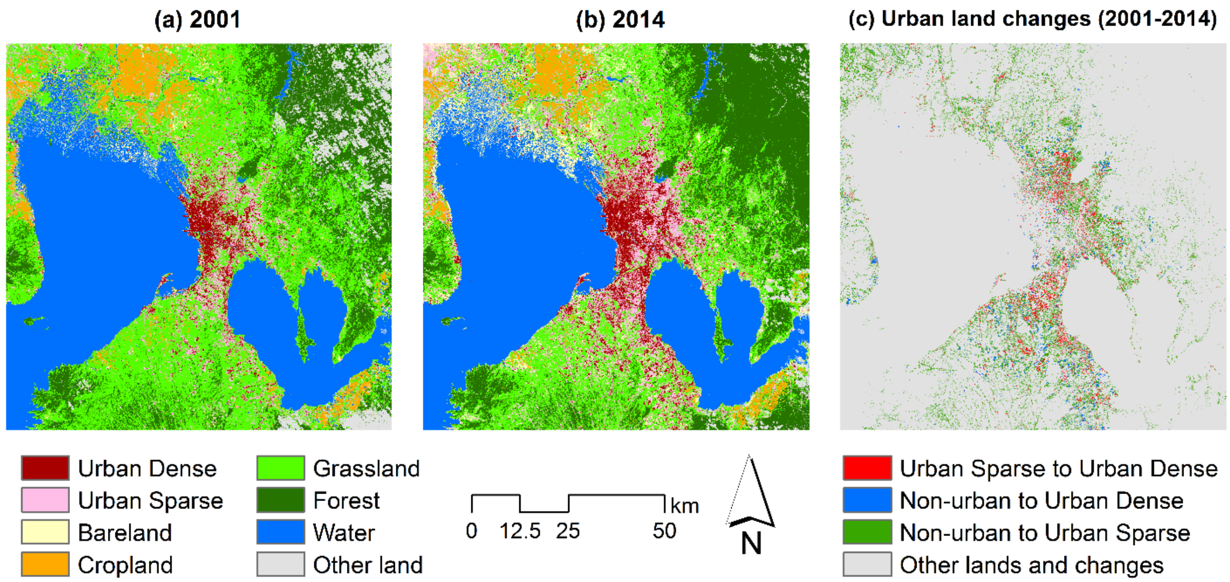

Fig. 4.24. LULC maps and spatial distribution of urban land changes in Metro Manila.

Table 4.24. LULC changes in Metro Manila (2001–2014).

	2001		2014		Net Changes (2001–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	27.57	2.76	49.80	4.98	22.24	80.67
Urban Sparse	59.43	5.94	104.67	10.46	45.24	76.12
Forest	156.63	15.66	190.99	19.09	34.37	21.94
Cropland	49.40	4.94	38.65	3.86	-10.75	-21.76
Grassland	303.26	30.31	221.24	22.11	-82.02	-27.05
Bareland	16.91	1.69	57.21	5.72	40.30	238.37
Water	337.40	33.73	322.75	32.26	-14.65	-4.34
Other land	49.81	4.98	15.08	1.51	-34.72	-69.72
Total	1000.40	100.00	1000.40	100.00		

4.25. Maputo Metropolitan Area, Mozambique

Geographical and socioeconomic characteristics

Maputo is the capital city of Mozambique. It is located in the southern part of the country at 25° 57' S latitude and 32° 34' E longitude. It has an area of 675 km^2 and a population of 1.3 million, which accounts for 20% of the country's total urban population (UN Habitat 2010). As stated by UN Habitat (2010), only 320 km^2 is densely populated, and most (96%) of the city's population live there. The remaining 355 km^2 are occupied by just 4% of the population, with largely rural occupation patterns.

Like many other major cities in Sub Saharan Africa, Maputo has been experiencing rapid urban growth driven by population growth emanating from rural-urban migration. As such, the city is characterized by unplanned informal settlements where the majority of the people live. Pestana et al. (2014) contend that Maputo has a dualistic structure: (1) a rich city defined by its tall buildings; and (2) a second city behind this area, defined by a series of small buildings. The small buildings represent the unplanned informal settlements and are referred to as the city's poverty belt.

Maputo also serves as the main administrative and economic center of the country. The economic growth of Mozambique has, to a certain extent, been concentrated or channeled through the capital Maputo (Jenkins & Wilkinson 2002). Given its location as a port city having most of its economic activities located at the harbor, Jenkins & Wilkinson (2002) describe Maputo as a favored urban area which channels foreign investments. It also has relatively strong secondary and tertiary sectors, especially the transport services sector, compared to other cities nationwide.

LULC changes in Maputo Metropolitan Area

Figs. 4.25(a) and 4.25(b) show the LULC classification results for Maputo using the maximum likelihood supervised classification method. Fig. 4.25(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that the built-up lands (urban dense and urban sparse) of Maputo are concentrated around the port which is also close the city center. There are indications, however, that Maputo's built-up lands have been expanding from the port towards the north. Maputo is generally a small city in terms built-up area in relation to the extent of the LULC maps (10,000 km^2) and compared to other African cities.

In 2000, urban dense had an area of 2.35 thousand ha, covering only 0.23% of the whole landscape. In 2014, its area increased to about 5.45 thousand ha, i.e. 0.55% of the landscape, resulting in a net gain of 3.10 thousand ha (Table 4.25). The increase in the area of urban sparse (see northern part of the city; Fig. 4.25) was even more remarkable, with a net gain of 20.33 thousand ha over the same period (Table 4.25). On the other hand, there were losses of forest and grassland due to the expansion of built-up lands. The area of forest decreased from 16.26% (162.63 thousand ha) to 9.73% (97.35 thousand ha), while the area of grassland decreased from 27.31% (273.19 thousand ha) to 26.08% (260.94 thousand ha).

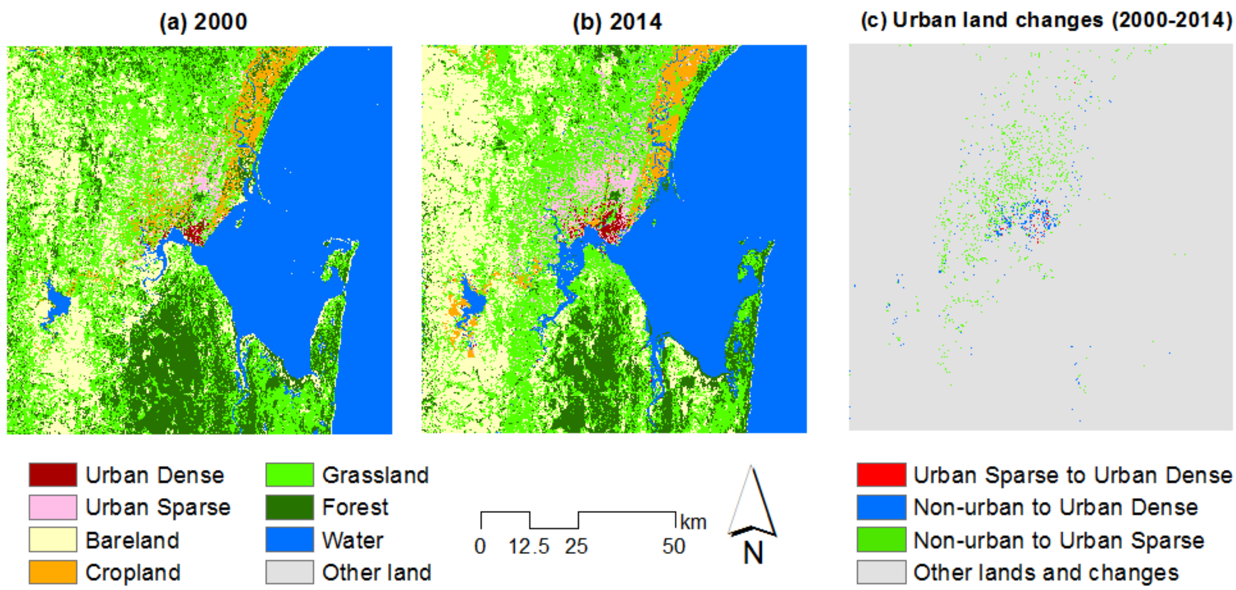

Fig. 4.25. LULC maps and spatial distribution of urban land changes in Maputo Metropolitan Area.

Table 4.25 LULC changes in Maputo Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	2.35	0.23	5.45	0.55	3.10	132.15
Urban Sparse	18.19	1.82	38.53	3.85	20.33	111.75
Forest	162.63	16.26	97.35	9.73	-65.28	-40.14
Cropland	28.11	2.81	28.11	2.81	0.00	0.02
Grassland	273.19	27.31	260.94	26.08	-12.25	-4.48
Bareland	183.28	18.32	219.09	21.90	35.81	19.54
Water	332.66	33.25	350.94	35.08	18.28	5.50
Total	1000.41	100.00	1000.41	100.00		

4.26. Nairobi Metropolitan Area, Kenya

Geographical and socioeconomic characteristics

Nairobi is the capital and largest city of Kenya. It is known for having the Nairobi National Park, the world's only game reserve found within a major city (https://nextcity.org). It has an area of 684 km^2, which lies adjacent to the eastern edge of the rift valley and is situated 1661 m above sea level (http://www.nairobi.com). The Ngong hills occupy the western part of the city. Mount Kenya is located in the north, while Mount Kilimanjaro lies on the southeastern side of the city. The Nairobi River, along with its tributaries, passes through Nairobi Province.

Nairobi, since its foundation in 1899, has grown to become the second largest city in the African Great Lakes, despite being one of the youngest cities in the region. According to the census data from the Kenyan government, Nairobi's population increased from 2,143,254 to 3,133,518 at from 1999 to 2009 (http://www.citypopulation.de). With a growth rate of 3.87% per year, Nairobi's population is expected to reach 5 million by 2025. The City Square is located in the heart of Nairobi, while the Kenyan Parliament buildings, Nairobi Law Courts, Kenyatta Conference Centre, the Holy Family Cathedral and the Nairobi City Hall surround the square.

LULC changes in Nairobi Metropolitan Area

Figs. 4.26(a) and 4.26(b) show the LULC classification results for Nairobi using the maximum likelihood supervised classification method. Fig. 4.26(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue) and urban sparse to urban dense (red) between 2000 and 2014. The gray areas are other lands and changes.

The LULC maps show that urban dense and urban sparse both dominate the city proper, while cropland, grassland and forest dominate the northern and eastern parts of the city (Fig. 4.26). The southern and western parts, where Ngong hills are located, are dominated by bareland. That said, the urban area, especially the urban dense, is very small. This is because the area of Nairobi City is small relative to the whole study area. Fig. 4.26(c) shows that most of the gains of urban dense are found in the city proper, while the gains of urban sparse are relatively more scattered. This spatial pattern of the gains of urban sparse might have been due to the increasing number of small houses around the city proper.

Table 4.26 shows that from 2000 to 2014, the area of urban dense and urban sparse increased substantially by 124.38% and 219.69%, respectively. By contrast, except for water, the area of all the other LULC types decreased. All these changes give indications that indeed Nairobi has been experiencing a rapid urbanization. Cropland and grassland decreased by almost 25,000 and 15,000 ha, respectively, while bareland, the dominant LULC type in the area, decreased only by just over 4,000 ha. This indicates that most of the gains of urban dense and urban sparse came from the other LULC categories, including the valuable vegetated areas. The change in the area of water also needs to be mentioned because it increased by 33.86%. Normally the area of water does not change too much. But for the case of Nairobi, it was due to the ponds constructed after 2000.

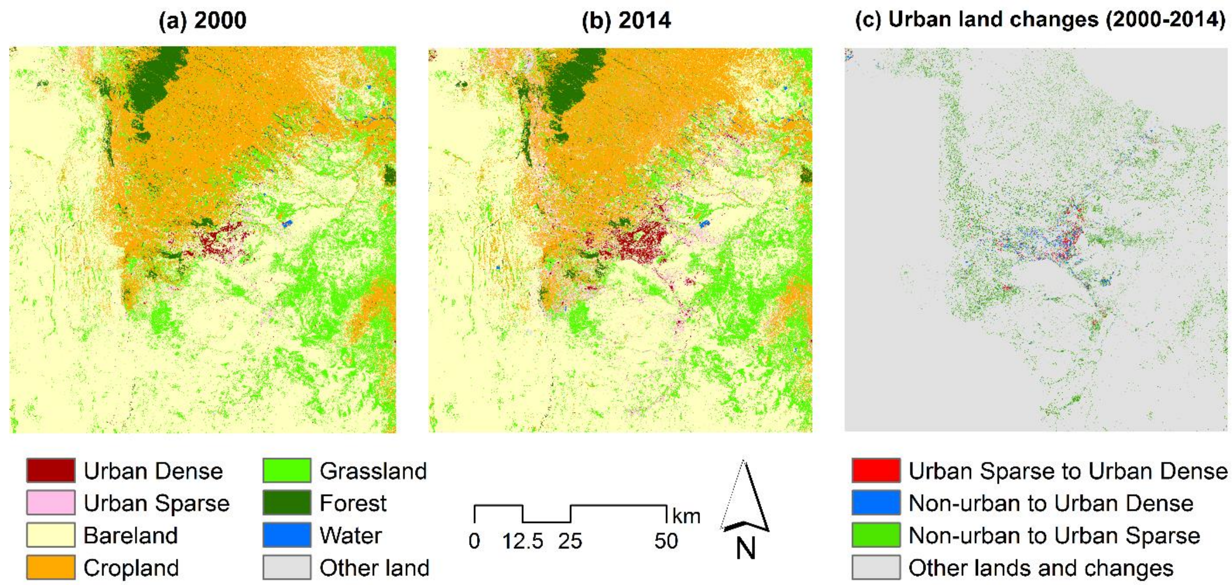

Fig. 4.26. LULC maps and spatial distribution of urban land changes in Nairobi Metropolitan Area.

Table 4.26. LULC changes in Nairobi Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	5.24	0.52	11.75	1.17	6.51	124.38
Urban Sparse	16.00	1.60	51.15	5.11	35.15	219.69
Forest	30.57	3.06	29.78	2.98	-0.79	-2.60
Cropland	219.03	21.89	194.71	19.46	-24.32	-11.11
Grassland	151.97	15.19	137.39	13.73	-14.58	-9.59
Bareland	576.29	57.61	571.92	57.17	-4.37	-0.76
Water	1.30	0.13	1.74	0.17	0.44	33.86
Other land	0.00	0.00	1.97	0.20	1.97	---
Total	1000.40	100.00	1000.40	100.00		

4.27. Nanjing Metropolitan Area, China

Geographical and socioeconomic characteristics

Nanjing, which literally means 'southern capital', is the provincial capital of Jiangsu Province, China. It is located at the heartland of the lower Yangtze River region and the western border of the Yangtze River Delta, one of the largest economic zones of China. Nanjing, which includes eleven districts, has a land area of 6597 km^2 (Yuan et al. 2016). It has a humid subtropical climate with four seasons. The mean annual temperature in the area is around 15.5 °C, with average monthly temperature ranging from 2.4 °C in January to 27.8 °C in July. The city has fairly hot and muggy summers. In fact, due to the perennial high temperatures in the city during summer, Nanjing has been considered as one of the "Three Furnace-like Cities" along the Yangtze River.

In 2000, Nanjing had a population of 4.04 million. In 2010, its population increased to 5.82 million, with an annual growth rate of 3.73% (http://www.citypopulation.de). In 2014, its population has gone up to 7.13 million (United Nations 2014). Nanjing is also home to a large number of migrants. From 2000 to 2013, the number of employed people in Nanjing nearly doubled, i.e. from 2.67 million to 4.52 million. Like most cities in eastern China, Nanjing has recorded economic growth in the past 15 years. In 2000, it only had a gross domestic product (GDP) of 107.35 billion yuan, but in 2013 its GDP increased remarkably to 801.18 billion yuan. Nanjing's GPD has been continuously increasing, except during the global financial crisis (2007–2008) (Yuan et al. 2016).

LULC changes in Nanjing Metropolitan Area

Figs. 4.27(a) and 4.27(b) show the LULC classification results for Nanjing using the maximum likelihood supervised classification method. Fig. 4.27(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2000 and 2014. The gray areas are other lands and changes. In 2000, the urban area of Nanjing was concentrated on the southern side of the Yangtze River (Fig. 4.27(a)). The small patches of built-up lands (urban dense and urban sparse) along the river were small cities and towns. Fig. 4.27(b) shows that in 2014, the built-up lands of Nanjing have already expanded into the northern side of the Yangtze River. Some patches of urban sparse in the suburban area have also been converted into urban dense. In both time points, cropland was the most dominant among the eight LULC categories. The Yangtze River and the lakes are the main sources of irrigation water for agricultural activities. The loss of cropland to bareland in the southeast and northwest of the city was due to 'seasonal differences', i.e. the 2000 image was acquired at the beginning of autumn (September), while the 2014 image was acquired at the end of autumn (November). Most of the forest patches in both time points were located in the mountainous regions.

Table 4.27 shows the statistics of LULC changes between 2000 and 2014 in Nanjing. Among the eight LULC categories, urban dense had the largest increase (392.27%). The decrease in the area of urban sparse was due to its loss to urban dense. The rapid expansion of built-up lands, especially urban dense, was at the expense of the other LULC categories, including cropland and grassland. Cropland had a net loss of 140.91 thousand ha, while grassland had a net loss of 21.76 thousand ha. By contrast, forest had a net gain of 30.19 thousand ha. If this was not due to 'seasonal differences', it could indicate that there might have been a great effort to protect Najing's forest resources.

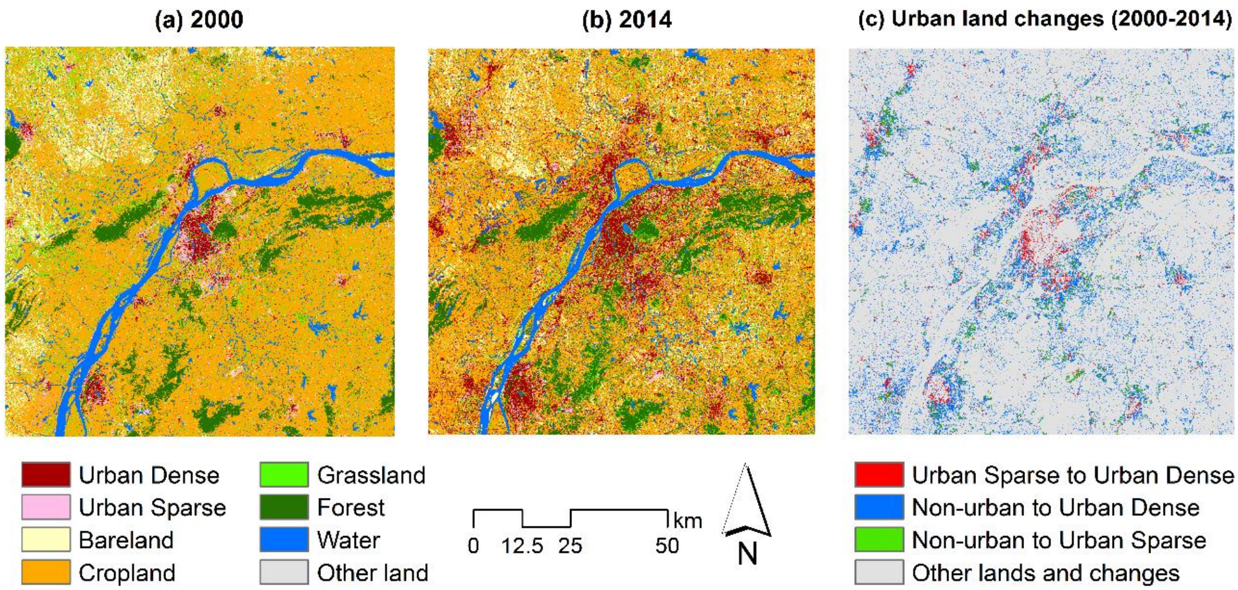

Fig. 4.27. LULC maps and spatial distribution of urban land changes in Nanjing Metropolitan Area.

Table 4.27. LULC changes in Nanjing Metropolitan Area (2000–2014)

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	28.14	2.81	138.51	13.85	110.37	392.27
Urban Sparse	30.94	3.09	29.59	2.96	-1.35	-4.38
Forest	72.62	7.26	102.81	10.28	30.19	41.57
Cropland	631.88	63.16	490.97	49.08	-140.91	-22.30
Grassland	75.24	7.52	53.48	5.35	-21.76	-28.92
Bareland	82.07	8.20	114.16	11.41	32.09	39.10
Water	79.52	7.95	70.88	7.09	-8.63	-10.86
Total	1000.40	100.00	1000.40	100.00		

4.28. Pyongyang Metropolitan Area, North Korea

Geographical and socioeconomic characteristics

Pyongyang, which literally means 'Flat Land', is the capital of North Korea and the largest city in the country. The city lies on a flat plain, about 50 km to the Korea Bay. Pyongyang has a humid continental climate, with a warm, humid summer and a cold, dry winter. The average temperature in Pyongyang ranges from -10.7 to 28.6 °C during the whole year, with transition months in April, May, October and November (http://worldweather.wmo.int/en/).

In 1993, Pyongyang had a population of 2.44 million. In 2008, its population increased to 3.26, with an annual growth rate of 1.17% (http://www.citypopulation.de/). Pyongyang is the first industrial city and industrial center of North Korea. It also serves as the main transport hub of the country, having a dense road network, railways and air routes.

LULC changes in Pyongyang Metropolitan Area

Figs. 4.28(a) and 4.28(b) show the LULC classification results for Pyongyang using the maximum likelihood supervised classification method. Fig. 4.28(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2001 and 2014. The gray areas are other lands and changes. The LULC maps show that Pyongyang's urban area is situated along the Taedong River. The eastern side of Pyongyang City is mountainous, dominated by forests (2001 and 2014) and grasslands (2014) (Fig. 4.28).

Table 4.28 shows the statistics of LULC changes between 2001 and 2014 in Pyongyang. Both the urban dense and urban sparse LULC categories had a substantial increase in their respective land area. Urban dense had a net gain of 12.44 thousand ha, while urban sparse had 30.92 thousand ha. Despite these gains, the total built-up lands (urban dense and urban sparse) of Pyongyang in 2014 was still below 10% relative to the whole landscape. This shows that Pyongyang is still a small capital as compared with other Eastern Asian capitals. Grassland also had a high net gain (76.71 thousand ha). However, this increase might have been due to the 'confusion' between grassland and cropland during the LULC classification process. Both forest and cropland had an individual net loss of about 27 thousand ha.

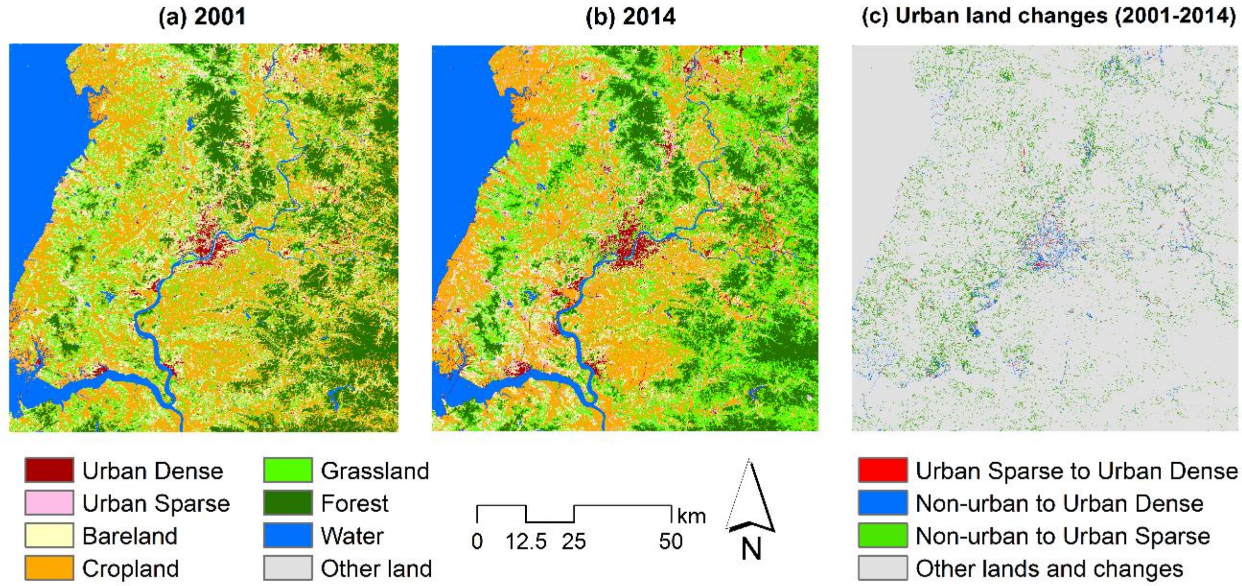

Fig. 4.28. LULC maps and spatial distribution of urban land changes in Pyongyang Metropolitan Area.

Table 4.28. LULC changes in Pyongyang Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2001
Urban Dense	12.71	1.27	25.16	2.51	12.44	97.87
Urban Sparse	36.85	3.68	67.77	6.77	30.92	83.92
Forest	169.51	16.94	142.78	14.27	-26.73	-15.77
Cropland	306.80	30.67	279.97	27.99	-26.83	-8.74
Grassland	184.57	18.45	261.28	26.12	76.71	41.56
Bareland	165.39	16.53	101.90	10.19	-63.49	-38.39
Water	124.57	12.45	119.88	11.98	-4.68	-3.76
Other land	0	0	1.65	0.17	1.65	---
Total	1000.4	100	1000.4	100		

4.29. Riyadh Metropolitan Area, KSA

Geographical and socioeconomic characteristics

Riyadh is the capital of the Kingdom of Saudi Arabia (KSA) and the largest city in the country. Geographically, the city is located at 24° 38' N latitude and 46° 43' E longitude. Historically, the city was a poor desert. But after the oil reserves were discovered, the city developed rapidly. Riyadh has a very dry climate and surrounded by deserts. The region is generally characterized by a landscape with a rocky plateau.

In 2012, Riyadh had a population of 7 million and a density of 4000 people/km^2 (http://www.citypopulation.de/). Riyadh is an important financial, business, and manufacturing center of Saudi Arabia, producing machinery equipment, metallurgical goods, chemicals, and textiles, among others.

LULC changes in Riyadh Metropolitan Area

Figs. 4.29(a) and 4.29(b) show the LULC classification results for Riyadh using the maximum likelihood supervised classification method. Fig. 4.29(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. Situated in the Arabian Desert, the area is dominated by bareland (desert). The more aggregated and less fragmented build-up lands (urban dense and urban sparse) of Riyadh is an important distinct characteristic of its urbanization pattern.

In 2000, urban dense had an area of 28.81 thousand ha, covering 2.88% of the whole landscape (Table 4.29). In 2014, its area increased to 49.73 thousand ha, with a net gain of 20.92 thousand ha. For urban sparse, its area increased from 49.25 thousand ha (4.92%) in 2000 to 80.71 thousand ha (8.07%) in 2014, with a net gain of 31.46 thousand ha. As the most dominant LULC category, bareland accounted for 89.53% (895.95 thousand ha) in 2000 and 83.59% (836.48 thousand ha) in 2014. The data also show that the decline in the area of cropland was substantial (47.65%). The details of the changes for the other LULC categories are summarized in Table 4.29.

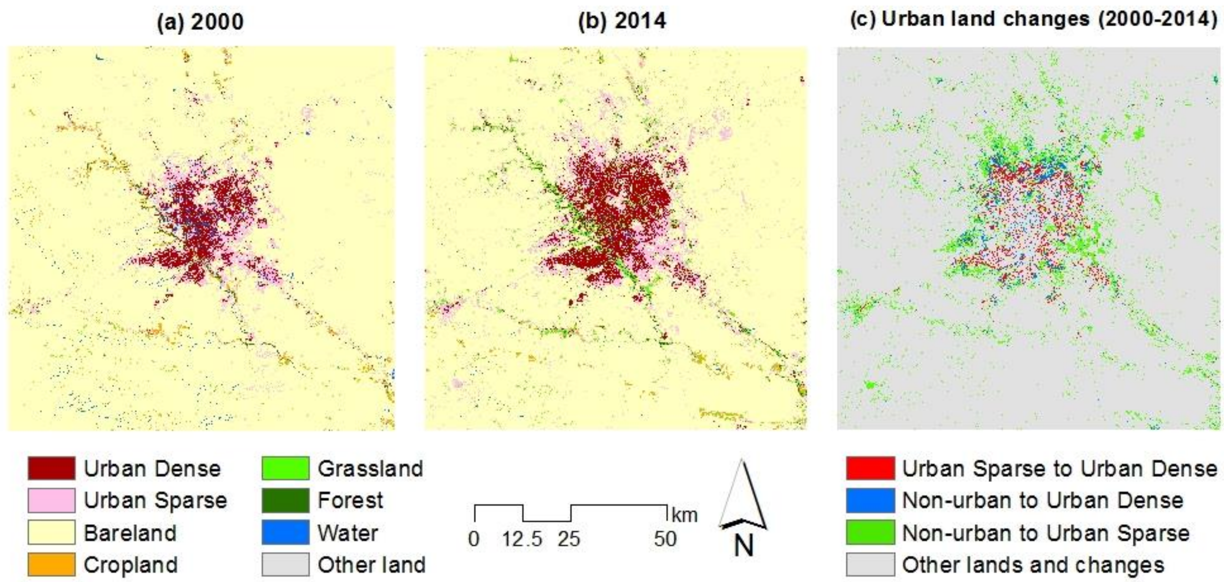

Fig. 4.29. LULC maps and spatial distribution of urban land changes in Riyadh Metropolitan Area.

Table 4.29. LULC changes in Riyadh Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	28.81	2.88	49.73	4.97	20.92	72.61
Urban Sparse	49.25	4.92	80.71	8.07	31.46	63.88
Forest	2.83	0.28	3.64	0.36	0.81	28.62
Cropland	14.48	1.45	7.58	0.76	-6.90	-47.65
Grassland	1.93	0.19	21.07	2.11	19.14	991.71
Bareland	895.95	89.53	836.48	83.59	-59.47	-6.64
Water	7.45	0.74	1.49	0.15	-5.96	-80.00
Total	1000.70	100.00	1000.70	100.00		

4.30. Seoul Metropolitan Area, South Korea

Geographical and socioeconomic characteristics

The Seoul Capital Area (SCA) is the metropolitan area of South Korea and is commonly referred to as the Sudogwon or Gyeonggi region. It includes three administrative districts, namely Incheon, Seoul and Gyeonggi-do. Seoul is the capital city. Geographically, it is located at 37° 32' N latitude and 127° 00' E longitude and is situated in the northwestern part of South Korea, near the Yellow Sea and the border of North Korea. The SCA covers a wide, relatively flat land around the Han River valley. The total land area of SCA is about 11,704 km^2, while Seoul City has an area of about 605 km^2.

The Seoul metropolitan area had a population of 21 million in 2000, representing 46% of the country's population (ADB 2014). The UN ranked Seoul as the 29th largest population agglomeration in the world in 2014. In 1990, it was ranked 9th (UN 2014). However, in recent years, Seoul's population growth rate started to decline (http://worldpopulationreview.com).

Over the years, the industrial sector of Seoul has changed from the traditional labor-intensive manufacturing to information technology, electronics and assembly-type industries. Today, Seoul is considered one of the leading and rising global cities. However, rapid urbanization, characterized by rapid built-up expansion and high level of industrialization and consumerism, poses a great pressure on the natural environment of the SCA.

LULC changes in Seoul Metropolitan Area

Figs. 4.30(a) and 4.30(b) show the LULC classification results for Seoul using the maximum likelihood supervised classification method. Fig. 4.30(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2000 and 2014. The LULC maps show that in both time points, urban dense areas are found mainly on both sides of the main river, passing through the city. Many industries and administrative centers are located on the main riverbanks. Built-up lands (urban dense and urban sparse) are also highly concentrated in areas close to the sea. It can also be observed that vast tracts of forests surround the urban area. Cropland is also mixed with built-up lands and forests.

In 2000, urban dense had an area of 31.63 thousand ha, covering 3.16% of the whole landscape (Table 4.30). In 2014, its area increased to 84.70 thousand ha, i.e. 8.47% of the landscape, resulting in a net gain of 167.81%. The area of urban sparse in 2000 was 65.29 thousand ha (6.53%). In 2014, it increased to 201.40 thousand ha (20.13%), with a remarkable net gain of 208.48%.

Cropland had an area of 298.44 thousand ha (29.83%) in 2000 and 214.96 thousand ha (21.49%) in 2014, resulting in a net loss of 83.48 thousand ha. The area of forest also decreased from 360.18 thousand ha (36%) in 2000 and 357.47 thousand ha (35.73%) in 2014. The net loss in the area of grassland from 2000 to 2014 was also substantial (94.20% or 90.80 thousand ha). The details of the changes for the LULC categories are summarized in Table 4.30. Overall, the LULC changes in SCA show a great expansion of built-up lands, as indicated by the increase in the area of urban dense, but more especially that of urban sparse.

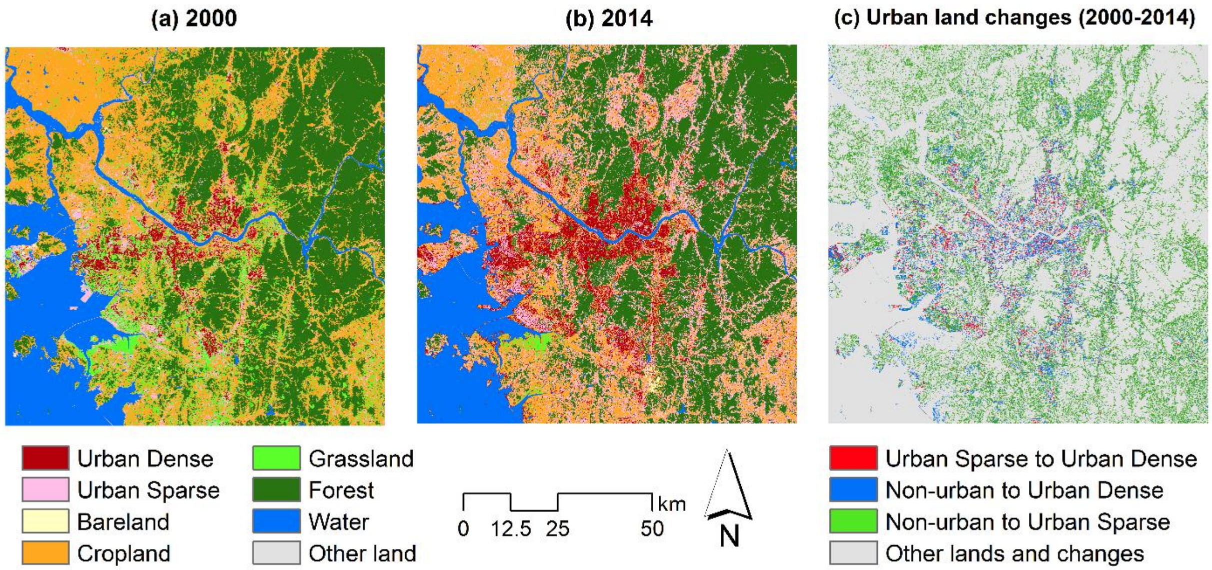

Fig. 4.30. LULC maps and spatial distribution of urban land changes in Seoul Metropolitan Area.

Table 4.30. LULC changes in Seoul Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	31.63	3.16	84.70	8.47	53.07	167.81
Urban Sparse	65.29	6.53	201.40	20.13	136.11	208.48
Forest	360.18	36.00	357.47	35.73	-2.70	-0.75
Cropland	298.44	29.83	214.96	21.49	-83.48	-27.97
Grassland	96.39	9.64	5.59	0.56	-90.80	-94.20
Bareland	2.15	0.21	2.42	0.24	0.27	12.78
Water	146.33	14.63	133.85	13.38	-12.47	-8.53
Total	1000.40	100.00	1000.40	100.00		

4.31. Shanghai Metropolitan Area, China

Geographical and socioeconomic characteristics

Shanghai is one of the most widely known Chinese cites. It is the city that links Chinese culture with foreign cultures. It also serves as a gateway to mainland China. Shanghai is located on the broad, flat, alluvial plain of the Yangtze River Delta in East China. This area has a humid subtropical monsoon climate, with an average annual precipitation of approximately 1100 mm and average annual temperature of approximately 16 °C. The city experiences four distinct seasons, with an average temperature of 4 °C during winter and 28 °C during summer.

Shanghai is one of the four “direct-controlled” municipalities of China. Its total area is approximately 6340 km^2, composed of 16 main administrative districts, including seven districts in the city center (namely Huangpu/HP, Changning/CN, Xuhui/XH, Putuo/PT, Jing’an/JA, Hongkou/HK, and Yangpu/YP), eight suburban districts (namely Minghang/MH, Pudong new area/PD, Jiading/JD, Baoshan/BS, Songjiang/SJ, Qingpu/QP, Fengxian/FX, and Jingshan/JS), and the Chongming county (CM). The Pudong district (“The east bank”) is a new part of Shanghai’s urban and suburban region, located on the east bank of the Huangpu River. Since the establishment of a special economic zone in the area in 1993 by the Chinese government, the Pudong district has been governed by the ‘Pudong new area’.

Since the late 1980s, under the second stage of the Chinese economic reform, Shanghai has been undergoing rapid re-development. In recent decades, its population has grown rapidly, with 16.41 million in 2000 and 24.26 million in 2014 (http://www.citypopulation.de). The local annual per capita gross domestic product (GDP) has also increased from 1,365 USD in 1988 to 14,547 USD today (Shanghai Civil Affairs Bureau 2014). Today, Shanghai plays a vital role in China’s economy, contributing about 5% to the country’s total GDP. No other cities had such a huge and intense change as Shanghai over a short period of time.

LULC changes in Shanghai Metropolitan Area

Figs. 4.31(a) and 4.31(b) show the classified LULC maps of Shanghai metropolitan area, while Fig. 4.31(c) highlights the detected urban land changes between 2000 and 2015, including the changes from urban sparse to urban dense (red), non-urban to urban dense (blue) and non-urban to urban sparse (green). The LULC maps show that Shanghai’s built-up lands (urban dense and urban sparse) have been expanding towards the southeast and southwest directions, but more especially towards the northwest direction. The maps also show that some islets (grasslands) have been formed over the years (2000-2015), and these are the results of the continuous accumulation of silts carried down by the Yangtze River. The Huangpu River (the thin blue line) divides the city into two parts (east and west). About a hundred years ago, the economic city center of Shanghai was established in the waterfront area at the mouth of the river.

In 2000, urban dense had an area of 56.51 thousand ha, accounting for 5.65% of the whole landscape (Table 4.31). In 2015, it increased to 171.30 thousand ha, i.e. 17.12% of the landscape, resulting in a net gain of 203.13%. The increase in the area of urban dense was due to its gains from urban sparse and non-urban areas (Fig. 4.31(c)). Urban sparse also had a high net gain of 24.56%. In 2000, it had an area of 213.89 thousand ha (21.38%), which increased to 266.41 thousand ha (26.63%) in 2015. Combining urban dense and urban sparse together, the total built-up land of Shanghai in 2000 was already about 27% of the whole landscape, and this further increased to more than 43% in 2015. On the other hand, the area of forest and cropland has decreased by 34.27 thousand ha and 85.34 thousand ha, respectively, over the same period. Overall, the data show that Shanghai metropolitan area has experienced a remarkable landscape change (especially built-up expansion) over the period of 15 years. And because such change will likely to continue in the future, proper landscape and urban planning is needed for Shanghai's future sustainable urban development.

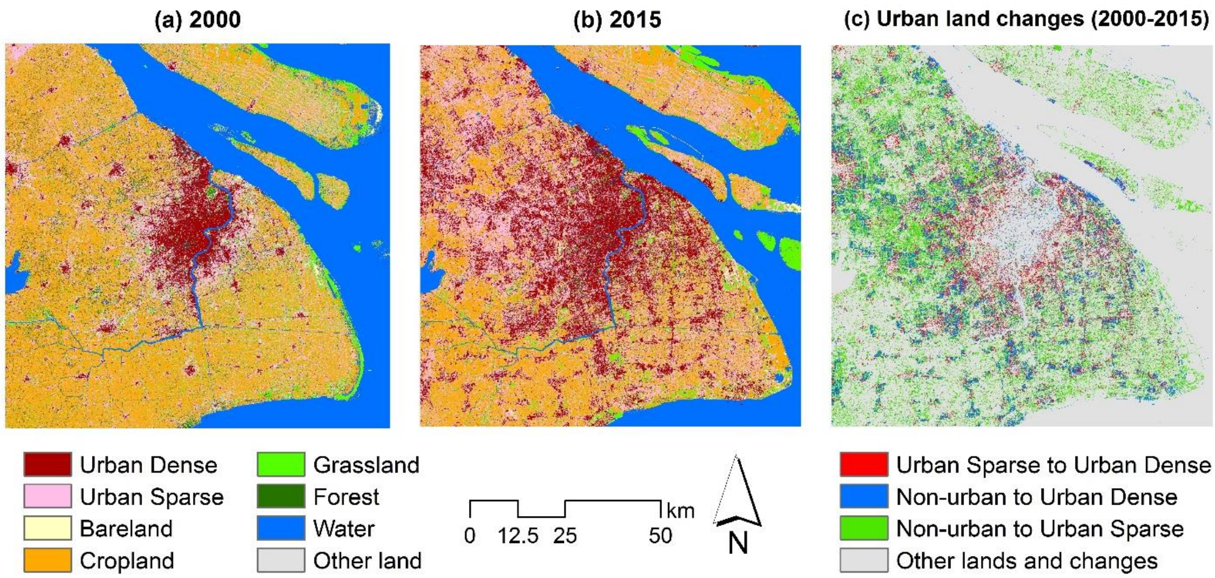

Fig. 4.31. LULC maps and spatial distribution of urban land changes in Shanghai Metropolitan Area.

Table 4.31. LULC changes in Shanghai (2000-2015).

	2000		2015		Net Changes (2000-2015)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	56.51	5.65	171.30	17.12	114.79	203.13
Urban Sparse	213.89	21.38	266.41	26.63	52.53	24.56
Forest	42.99	4.30	8.71	0.87	-34.27	-79.73
Cropland	343.28	34.31	257.94	25.78	-85.34	-24.86
Grassland	59.95	5.99	43.98	4.40	-15.97	-26.64
Bareland	10.69	1.07	16.47	1.65	5.78	54.11
Water	273.10	27.30	235.58	23.55	-37.51	-13.74
Total	1000.40	100.00	1000.40	100.00		

4.32. Suzhou Metropolitan Area, China

Geographical and socioeconomic characteristics

Suzhou, a famous historic and 'culture city' in China, is located at the lower reaches of the Yangtze River and the shores of Lake Tai. Like Hangzhou and Nanjing, Suzhou also belongs to the Yangtze River Delta region, approximately 110 km from Shanghai. The municipality of Suzhou covers a land area of 8488.42 km^2, while the urban area measures 2742.62 km^2 (http://www.suzhou.gov.cn/szgl/szgl.shtml). Suzhou is located on a plain, about 2-3 meters above the sea level. The hilly parts of the area are found in the southwestern part, along the Tai Lake. The Qionglu hill is the highest among the hills, with an elevation of 342 m above sea level (Wang et al. 2015). Suzhou has a humid subtropical climate with four distinct seasons. The hottest month in Suzhou is July, with an average temperature at 28 °C, and the coldest month is January, with an average temperature at 4 °C (http://www.chinahighlights.com/).

In 2000, Suzhou had a population of 2.16 million, which increased to 4.08 million in 2010 at an annual change rate of 6.57% (http://www.citypopulation.de/). After 2010, Suzhou's population continued to increase, reaching 5.16 million in 2014 and becoming the 17th city in China with a population of more than 5 million (United Nations 2014). The urban development in Suzhou is quite unique because of the conflict between cultural preservation and modernization (modern industrial city). In the urban core of Suzhou, informally called 'Old Town Suzhou', the traditional characteristics or features of the city are kept amidst the fast development. In the suburban and rural areas, development zones at various levels have been built to attract foreign direct investments. Over the past decade, Suzhou has been producing the largest GDP output in the Jiangsu province. Suzhou is also one of the most liveable cities in China today.

LULC changes in Suzhou Metropolitan Area

Figs. 4.32(a) and 4.32(b) show the LULC classification results for Suzhou using the maximum likelihood supervised classification method. Fig. 4.32(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2000 and 2014. The LULC maps show that in 2000, there were two big urban cores and several small urban patches in the area. The urban core in the central part of the map is the city of Suzhou while the other core in the northwestern part is Wuxi. In 2014, Suzhou's built-up lands (urban dense and urban sparse) have expanded in almost all directions, diffusing from the original urban cores in 2000. The lakes that surround Suzhou play an important role to the agricultural and fishery industries in the area.

Table 4.32 shows the statistics of LULC changes between 2000 and 2014 in Suzhou. The data show that among the eight LULC categories, urban dense had the highest net gain (181.99 thousand ha) over the past 14 years. The area of urban sparse also increased by 10.91 thousand ha. Interestingly, the area forest also increased by 0.86 thousand ha amidst the rapid built-up (urban dense and urban sparse) expansion. Cropland had the highest net loss among all categories (114.85 thousand ha). Grassland and bareland had a net loss of 15.63 thousand ha and 7.21 thousand ha, respectively. The area of water also decreased (from 338.20 thousand ha to 282.14 thousand ha) possibly due to land reclamations and the differing conditions of the paddy fields in 2000 and 2014.

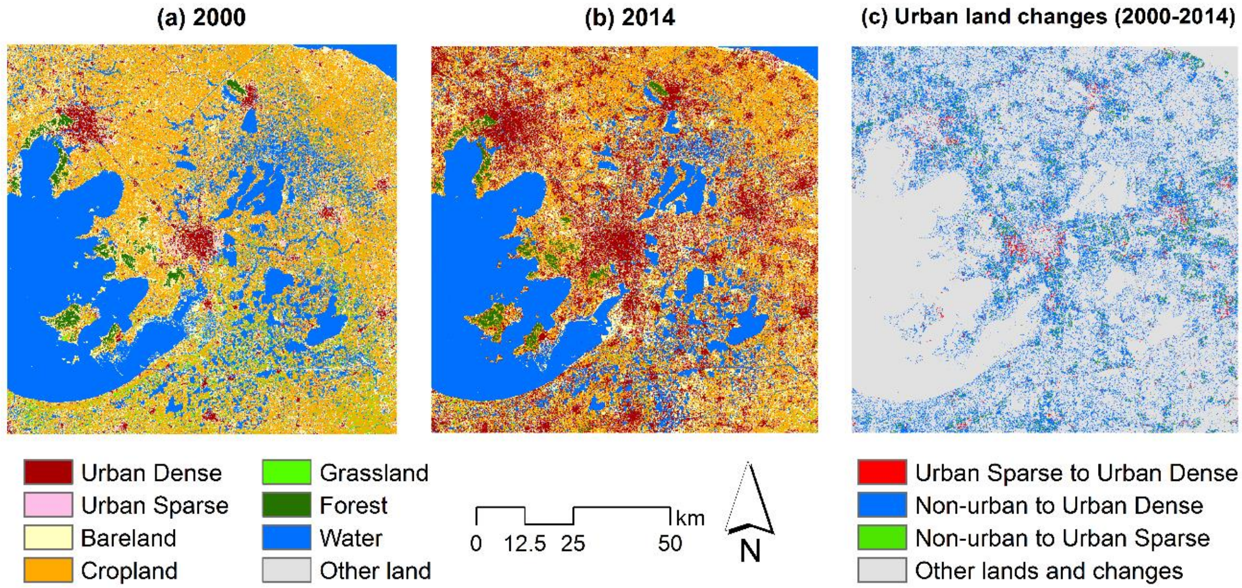

Fig. 4.32. LULC maps and spatial distribution of urban land changes in Suzhou Metropolitan Area.

Table 4.32. LULC changes in Suzhou Metropolitan Area (2000–2014)

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	47.14	4.71	229.13	22.90	181.99	386.05
Urban Sparse	16.58	1.66	27.49	2.75	10.91	65.76
Forest	13.30	1.33	14.16	1.42	0.86	6.45
Cropland	358.25	35.81	243.40	24.33	-114.85	-32.06
Grassland	29.45	2.94	13.82	1.38	-15.63	-53.08
Bareland	197.47	19.74	190.26	19.02	-7.21	-3.65
Water	338.20	33.81	282.14	28.20	-56.06	-16.57
Total	1000.40	100.00	1000.40	100.00		

4.33. Taipei Metropolitan Area, Taiwan

Geographical and socioeconomic characteristics

The Taipei–Keelung metropolitan area or the Greater Taipei area is the largest metropolitan area in Taiwan. Geographically, Taipei is located at 25° 5' N latitude and 121° 33' E longitude. The Taipei metropolitan area covers Taipei City, New Taipei City and Keelung City. The total land area of the metropolitan is about 2457 km^2, while Taipei City has an area of about 271 km^2. Taipei City is situated in a basin of northern Taiwan, and includes the hilly areas in the northeast and southeast sides of the city. The generally low-lying terrain covers the western side. The elevation in the hilly areas in the northeastern and southeastern sides in the Cising mountain area reaches up to 1120 m above sea level.

The estimated population of the Taipei metropolitan area was 7,028,583 in 2014 (http://www.demographia.com), i.e. approximately 30.04% of the total population of Taiwan. As the center of Taiwan's economy, Taipei has experienced rapid economic development over the years. It has also become a leading high-technology producer. The rapid economic growth of Taipei over the past few decades has resulted in the expansion of urban areas and an increased per capita consumption rates. The main economic goods produced in the metropolitan area include electronic products and components, electrical machinery and equipment, printed materials, precision equipment, foods and beverages, and textiles.

LULC changes in Taipei Metropolitan Area

Figs. 4.33(a) and 4.33(b) show the LULC classification results for Taipei using the maximum likelihood supervised classification method. Fig. 4.33(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), urban sparse to urban dense (red) and other lands and changes (gray) between 2001 and 2014. The LULC maps show that southern part of the city is mostly covered with forest and the southwestern part is dominated by cropland. Urban dense and urban sparse are also observed in the coastal areas. The spatial pattern of urban sparse follows the road network, which connects major urban dense areas.

In 2001, urban dense had an area of 29.19 thousand ha, covering 2.92% of the whole landscape (Table 4.33). In 2014, its area increased to 42.38 thousand ha, i.e. 4.24% of the landscape, resulting in a net gain of 45.20%. The area of urban sparse in 2001 was 85.43 thousand ha (8.54%). In 2014, it increased to 89.69 thousand ha (8.96%), with a net gain of 4.98%. Cropland also had a substantial net gain (10.45 thousand ha). The details of the changes for the other LULC categories are summarized in Table 4.33.

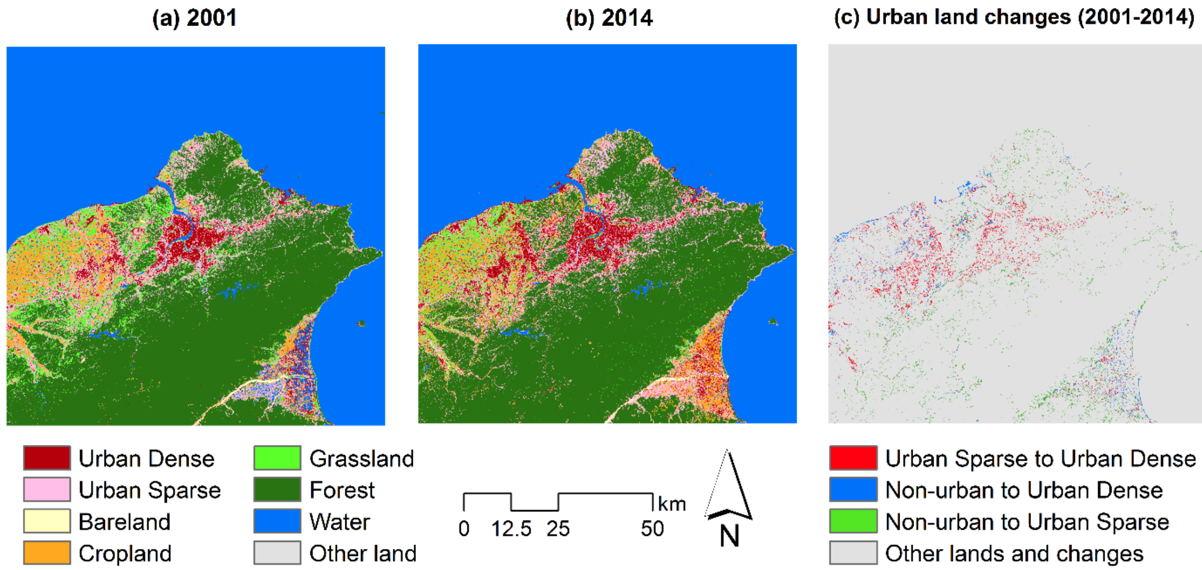

Fig. 4.33. LULC maps and spatial distribution of urban land changes in Taipei Metropolitan Area.

Table 4.33. LULC changes in Taipei Metropolitan Area (2001–2014).

	2001		2014		Net Changes (2001–2014)	
	ha (‘000)	% of total	ha (‘000)	% of total	ha (‘000)	% of 2001
Urban Dense	29.19	2.92	42.38	4.24	13.19	45.20
Urban Sparse	85.43	8.54	89.69	8.96	4.26	4.98
Forest	329.54	32.94	328.43	32.83	-1.11	-0.34
Cropland	35.42	3.54	45.87	4.59	10.45	29.49
Grassland	44.65	4.46	26.51	2.65	-18.14	-40.63
Bareland	1.79	0.18	1.56	0.16	-0.24	-13.18
Water	474.38	47.42	465.96	46.58	-8.41	-1.77
Total	1000.40	100.00	1000.40	100.00		

4.34. Tehran Metropolitan Area, Iran

Geographical and socioeconomic characteristics

Tehran is a mountainside city situated at an altitude of 900-1700 m above sea level. It covers an area of 1500 km^2 located on the slope of the Alborz Mountain. Its urban area spreads entirely over the Iranian plateau, on the slopes of a very high and dense mountain barrier (known as Towchal) whose peak of 3933 m is 2200 m higher than the city's residential areas (http://en.tehran.ir).

As the capital city of Iran, Tehran has the largest population in the country among other cities and is the center of cultural, economic, political and social activities. In 1996, Tehran had a population of 6,758,845, and in 2011 its population increased to 8,154,051 (http://www.citypopulation.de). About 30% of Iran's public-sector workforce and 45% of large industrial firms are located in Tehran.

LULC changes in Tehran Metropolitan Area

Figs. 4.34(a) and 4.34(b) show the LULC classification results for Tehran using the maximum likelihood supervised classification method. Fig. 4.34(c) highlights the detected LULC changes from non-urban to urban sparse (green), non-urban to urban dense (blue), and urban sparse to urban dense (red) between 2000 and 2014.

Since Tehran has a dry climate, bareland is the most dominant LULC type in the area. The central area is dominated by urban dense and urban sparse, which also spread along the roads toward the west, southwest and southeast directions. The north side of Tehran is almost bareland because of the Alborz Mountain. Cropland and grassland are found in areas close to local people's residential areas (urban dense or urban sparse).

Table 4.34 shows a 71.35% and 368.52% net gain in the area of urban dense and urban sparse, respectively, from 2000 to 2014. Although it had a substantial increase over the past 14 years, the area of urban sparse is still small relative to the whole landscape (3.96%). In 2014, the dominant LULC type, bareland, still covered around 70% of the landscape. The decrease in the area of bareland and cropland from 2000 to 2014 was due to urban expansion, while the increase in the area of grassland and forest might have been due to 'seasonal differences' between the two images used.

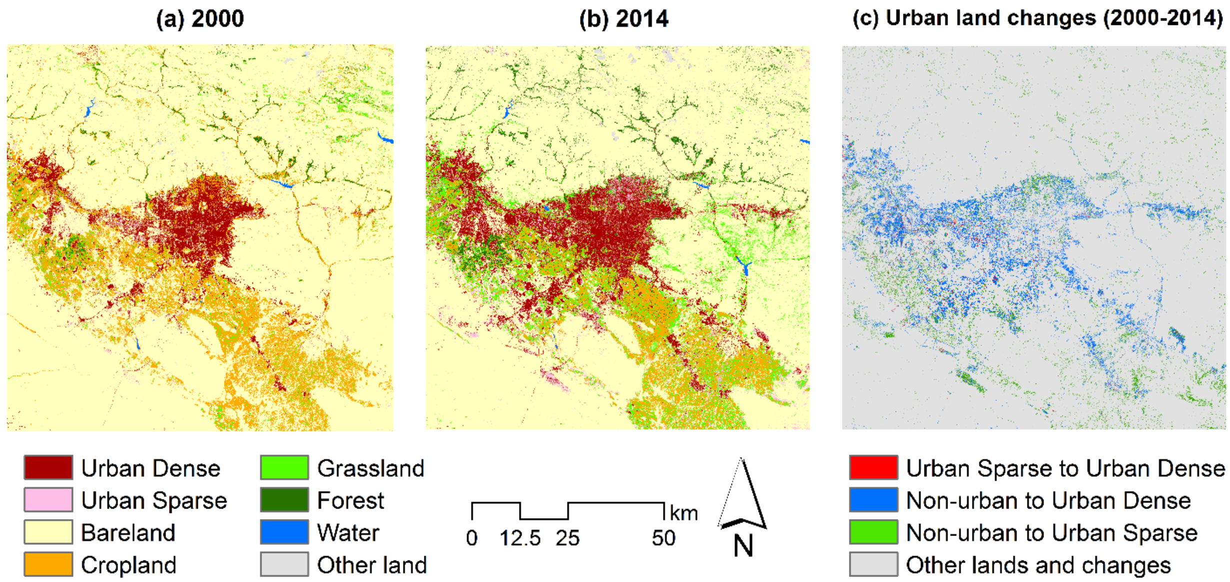

Fig. 4.34. LULC maps and spatial distribution of urban land changes in Tehran Metropolitan Area.

Table 4.34. LULC changes in Tehran Metropolitan Area (2000–2014).

	2000		2014		Net Changes (2000-2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 2000
Urban Dense	52.48	5.24	89.92	8.99	37.44	71.35
Urban Sparse	8.46	0.85	39.64	3.96	31.18	368.52
Forest	9.84	0.98	24.37	2.44	14.53	147.60
Cropland	123.58	12.35	72.31	7.23	-51.27	-41.48
Grassland	24.02	2.40	74.57	7.45	50.56	210.50
Bareland	777.59	77.70	693.96	69.35	-83.63	-10.75
Water	1.12	0.11	1.18	0.12	0.06	5.47
Other land	3.61	0.36	4.74	0.47	1.13	31.34
Total	1000.70	100.00	1000.70	100.00		

4.35. Yangon Metropolitan Area, Myanmar

Geographical and socioeconomic characteristics

Yangon region is one of the 15 current states/regions of Myanmar. Its capital is Yangon City, which is also the former capital of the country. Its metropolitan area, known as Yangon Metropolitan Area (YMA) or the Greater Yangon (with an area of 1500 km^2), includes Yangon City (with an area of 784 km^2) and parts of the six neighboring townships of Kyauktan, Thanlyin, Hlegu, Hmawbi, Htantabin, and Twantay (JICA and YCDC 2013). In this report, the LULC change analysis, which is based on the extent of the LULC maps measuring approximately 75 km × 75 km (Fig. 4.35), also includes the neighboring areas of YMA.

The Greater Yangon is geographically located between 17° 06' and 16° 35' N latitude and between 95° 58' and 96° 24' longitude, east of the Ayeyarwaddy River delta, Yangon City is located 34 km upstream from the mouth of Yangon River, in the Gulf of Martaban of the Andaman Sea. In terms of urban population, Yangon region also had the highest among the country's current states/regions with 5.16 Million urban dwellers, accounting for 34.7% of the country's total urban population in 2014 (14.88 Million) (Census Report 2015). As the economic center of Myanmar, Yangon region accounts for 22% of the gross domestic product (GDP) of the country (JICA and YCDC 2013).

LULC changes in Yangon Metropolitan Area

Figs. 4.35(a) and 4.35(b) show the classified LULC maps of YMA for 1989 and 2014, respectively, while Fig. 4.35(c) highlights the detected urban land changes during the 1989-2014 period, including the changes from urban sparse to urban dense (red), non-urban to urban dense (blue), and non-urban to urban sparse (green). In both time points, i.e. 1989 and 2014, the landscape of YMA was dominated by bareland (Fig. 4.35; Table 4.35). However, it should be noted that most, if not all, of these barelands were basically croplands. These misclassifications were due to the classification scheme used for YMA in which 'cover' had been given more emphasis over 'use', which resulted in the classification of most croplands into bareland.

Spatially, YMA's built-up lands (urban dense and urban sparse) have been expanding outward of the city core, to the eastern and western parts, but more especially to the norther part (Fig. 4.35). In 1989, urban dense had an area of 2.79 thousand ha only (0.49%), but in 2014, its area increased to 14.22 thousand ha (2.53%), resulting in a net gain of 11.44 thousand ha (Table 4.35). The expansion of urban dense was due to its gains from urban sparse, but more especially from the non-urban categories such as bareland and grassland. Despite its loss to urban dense, urban sparse also expanded from 53.50 thousand ha (9.50%) in 1989 to 82.72 thousand ha (14.69%) in 2014 (Table 4.35), resulting in a net gain of 29.22 thousand ha. The expansion of urban sparse was due to its gains from cropland and forest, but more especially from grassland.

The other important LULC of YMA, i.e. forest and cropland, also had substantial changes in their respective extents between 1989 and 2014. The data show that approximately 85% of YMA's forest cover was lost during the 1989-2014 period. During the same period, its cropland (excluding the barelands which should have been classified as croplands) also decreased by about 66%. Overall, the data show that YMA has been experiencing remarkable landscape changes, posing many challenges in the context of landscape and urban planning.

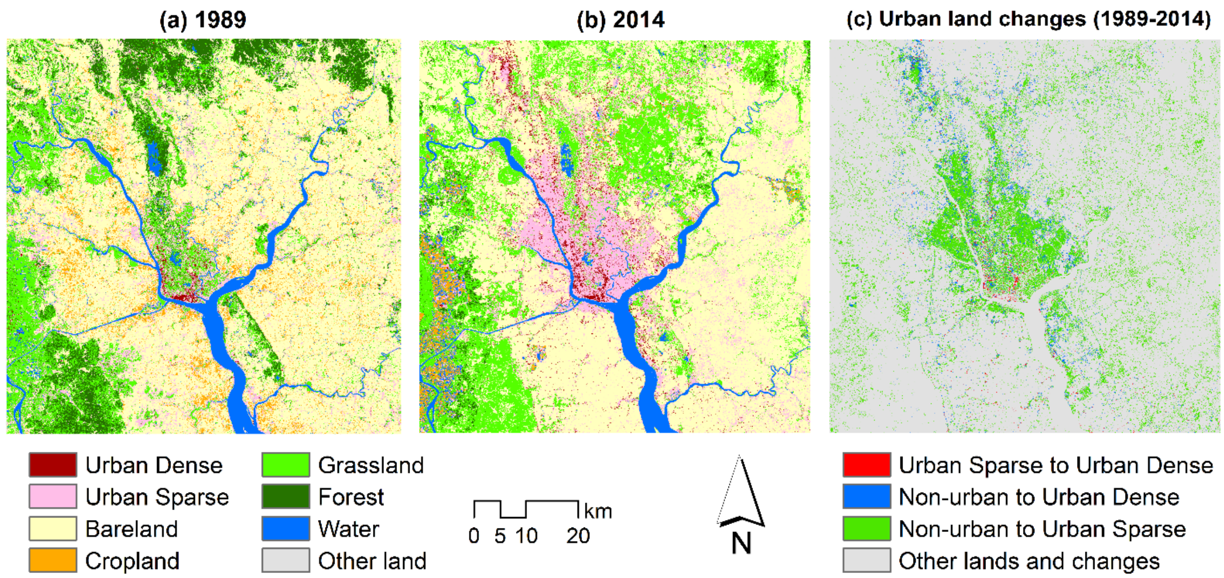

Fig. 4.35. LULC maps and spatial distribution of urban land changes in Yangon Metropolitan Area.

Table 4.35. LULC changes in Yangon Metropolitan Area (1989–2014).

	1989		2014		Net Changes (1989–2014)	
	ha ('000)	% of total	ha ('000)	% of total	ha ('000)	% of 1989
Urban Dense	2.79	0.49	14.22	2.53	11.44	410.63
Urban Sparse	53.50	9.50	82.72	14.69	29.22	54.63
Forest	51.12	9.08	7.89	1.40	-43.23	-84.57
Cropland	30.96	5.50	10.40	1.85	-20.56	-66.41
Grassland	82.63	14.68	117.23	20.82	34.59	41.87
Bareland	315.43	56.03	300.94	53.46	-14.48	-4.59
Water	26.53	4.71	29.54	5.25	3.02	11.37
Total	562.95	100.00	562.95	100.00		

5. Summary

LULC mapping is an important component of the practical applications of remote sensing technology. LULC maps can be used for various purposes in the realms of sustainability, global environmental change, landscape ecology, and urban and geographical studies. Furthermore, remote sensing-derived LULC maps are of particular importance to the developing countries, where the availability of multi-temporal and spatially consistent LULC maps is still limited.

As part of the ongoing effort to establish a database of remote sensing-derived LULC maps, the LULC maps of 24 major Asian cities (including 6 Chinese cities) and 11 major African cities for the 2000 and 2014 epochs have been classified from remote sensing satellite images (Landsat images). The classified LULC maps, including some descriptions and analyses of the detected LULC changes for each city, have been presented in this report (Sections 4.1–4.35).

Fig. 5.1 presents the summary of the LULC classification and change detection results, highlighting (a) the density of total built-up lands (urban dense + urban sparse) in 2000 and 2014 epochs, and (b) the percentage increase of total built-up lands (c. 2000–2014) for the 35 major cities. Based on the 100 km × 100 km landscape unit of analysis (except Yangon, see Section 4.35), it can be observed that in the 2000 epoch, Beijing had the highest built-up density with 32.55%, while Lusaka had the lowest with 1.03% (Fig. 5(a)). In the 2014 epoch, Beijing still had the highest with 49.47%, while Dakar had the lowest with 1.74%. In terms of percentage increase from 2000 to 2014, Chongqing had the highest with 410.80%, while Taipei had the lowest with 15.18% (Fig. 5(b)).

In this project, we acknowledge that the LULC classification process has been very challenging due to some technical issues, including the 'seasonal differences' between the images used, presence of clouds, shadows and snows (in Kathmandu), spectral confusion between categories (e.g. between urban dense, urban sparse, cropland and bareland, including coastal sand dunes, river wash and exposed mountain rocks; between cropland and grassland; between grassland and forest; and between water channels and roads), as well as the inherent complex nature of each city's landscape pattern. Nevertheless, we paid careful attention to these issues during the classification process, with the aim of producing accurate LULC maps.

All the LULC maps (Figs. 4.1–4.35) have been uploaded in a WebGIS website (http://giswin.geo.tsukuba.ac.jp/mega-cities/), designed and developed for the purpose of visualizing the urban land changes in the 35 major cities.

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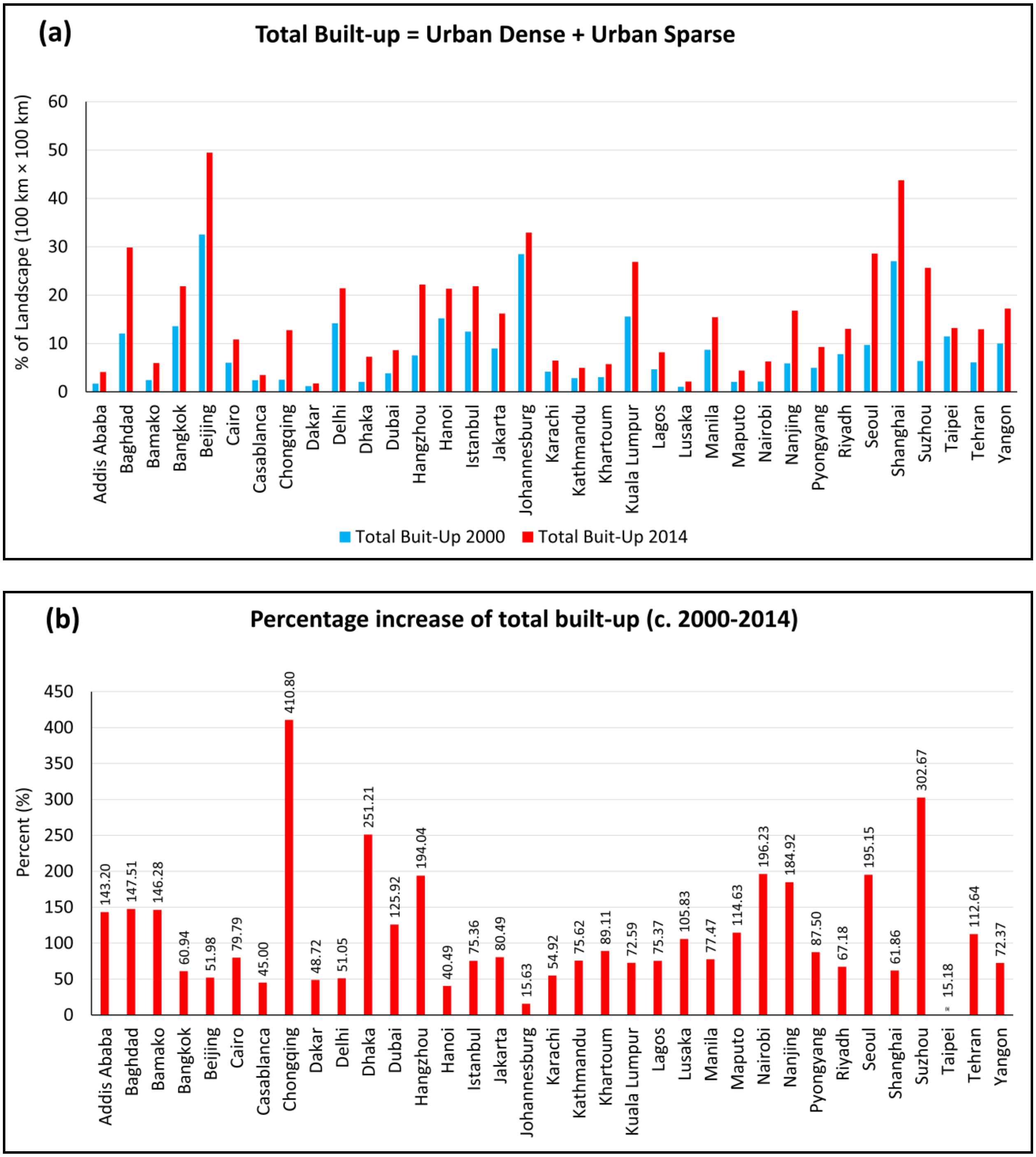

Fig. 5.1. Summary of the LUC classification and change detection results, highlighting (a) the density of total built-up lands (urban dense + urban sparse) in the 2000 and 2014 epochs, and (b) the percentage increase of total built-up lands (c. 2000–2014). Note: Time 1 for Yangon is 1989.

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