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Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city, Bangladesh

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Abstract As in many other developing countries, cities in Bangladesh have witnessed rapid urbanization, resulting in increasing amounts of land being taken over and therefore land cover changing at a faster rate. Until now, however, few efforts have been made to document the impact of land use and land cover changes on the climate, environment, and ecosystem of the country because of a lack of geospatial data and time-series information. By using open source Landsat data integrated with GIS technologies and other ancillary data, this study attempts to classify land use and create land cover maps, enabling post-classification change detection analysis. By this method, we document the spatial and temporal trajectory of urban expansion in Chittagong, the second largest city in Bangladesh, over a 36-year period. The findings suggest that, over the study period, 56 % of the land cover has undergone change, mainly because of the expansion of built-up areas and other human activities. During the 36-year period, the built-up area around Chittagong city has expanded by 618 %, with an average annual rate of increase of 17.5 %. As a result of rapid urbanization, the vegetated hills near urban development areas face serious threats of further encroachment and degradation, given that 2178 ha of hills have already been intruded over the study period. Because urbanization processes in Bangladesh have traditionally been viewed as the result of population growth and economic development, very little work has been done to track the potential growth trajectory in a physical or spatial context. This study, therefore, will contribute to the current understanding of urban development in Bangladesh from a temporal and spatial point of view. Findings will be able to assist planners, stakeholders, and policy makers in appreciating the dynamism of urban

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growth and therefore will facilitate better planning for the future to minimize environmental impacts.

Keywords Land use/land cover · Urban growth · OLI–TIRS · Environmental sustainability · Chittagong

1 Introduction

In the twenty-first century, major threats to human welfare are anticipated to arise from climate change, sea-level rise, and other unknown potential effects of global environmental change. Much of this change has been driven by increasing anthropogenic activities across the earth's surface (Lambin et al. 2001; Carlson and Arthur 2000) and the resultant modification of landscape configurations at various global, regional, and local scales (Weng 2001; Liu et al. 2009). Landscape change is caused mainly by the expansion of impervious surfaces alongside human settlements (Yin et al. 2005) and other infrastructure development, resulting in encroachment into arable agricultural land (Batisani and Yarnal 2009) and water bodies, as well as continuous deforestation (Torbick et al. 2006). Empirical studies suggest that landscape alteration has a multiplying effect on biodiversity (Rojas et al. 2013), water quality, and carbon emissions with many other negative impacts on aquatic and terrestrial ecosystems (Jianchu et al. 2005).

In recent decades, accelerated population growth in developing countries, accompanied by unprecedented rates of urbanization, has placed tremendous pressure on the surrounding land and its biotic and abiotic resources. It is claimed by many that this pressure is responsible for the increasing rate of landscape change in these regions. Numerous studies have shown that urbanization, resulting in land cover change, has an enormous impact on the radiative, thermodynamic, and hydrological processes that can lead to a change in the local climate (McCarthy et al. 2010), in terms of, for example, temperature, precipitation, and cloudiness (Kaufmann et al. 2007). Such local changes may thus make the environment more variable and climatic parameters more susceptible to global temperature change as well as increasing the vulnerability of local people and places to climatic stresses (Carlson and Arthur 2000; Jianchu et al. 2005). Hence, understanding and monitoring the trends of changing land use from a physical, social, and spatiotemporal point of view are becoming increasingly important. Such work represents a multidisciplinary research frontier within academia and should involve researchers from both landscape and ecosystem ecology.

In current practices, remote sensing in conjunction with GIS technology can provide advanced, powerful synoptic tools to aid in better understanding and monitoring the spatial, temporal, and spectral characteristics of land use and land cover changes at global, continental, and national scales (Weng 2001). Moreover, remote sensing techniques are extremely useful in periodic assessment of urban land covers, allowing monitoring and better land management (Taubenböck et al. 2014). The use of Landsat data to monitor urban expansion and the resultant land cover changes has become a common approach in recent years, and techniques are widespread among researchers and practitioners (Kalnay and Cai 2003; Carlson and Arthur 2000; Turner et al. 2007).

Bangladesh is currently a developing country and is one of the most populated in the world. In recent times, it has witnessed rapid, unplanned urban expansion accompanied by serious environmental degradation. Currently, the country has seven major cities and 506 urban centers, which together contain nearly 28 % of the national population (BBS 2011), and which make an estimated 65 % contribution to the country's GDP (Nazem et al. 2011). It is expected that, in coming decades, one in two people in Bangladesh will live in urban areas, which will ultimately generate more than 75 % of the GDP. The pace of urbanization, however, is not sustainable, and development inconsistent and spatially imbalanced across the country (Rana 2011). The rapid urbanization has necessitated an unplanned and chaotic expansion of urban infrastructure, in the process of which filling of lowlands, cutting of hills, deforestation and the destruction of arable agricultural land have resulted in uncountable losses of natural resources and significant environmental damage across the country.

The study area for this work, Chittagong, is the second largest metropolitan city in Bangladesh, sharing 19.7 % of the country's urban population and contributing 30 % of the national GDP (BBS 2011). Due to the increasing population and availability of jobs during the last four decades, the city has expanded in all directions, mostly in unplanned and chaotic ways. Typically, expansion in peripheral areas takes place without forward planning, and housing projects are initiated, both with and without approval, in agricultural lowlands and hilly areas, leading to indiscriminate filling, flattening, subdivision, and sale of plots with no standards for provision of infrastructure or amenities. The study area is also a hotspot of biodiversity and is situated at the intersection of many biogeographic divisions (Islam 2009). Owing to the accelerated urban growth, however, the area has experienced serious environmental degradation and a number of ecological problems, including deforestation, biodiversity loss, soil erosion, and changes to the carbon sink in aquatic ecosystems (Rana 2011; Hasan et al. 2013; Banu 1995). In particular, the hills and associated forests that are closest to the urban fringe or near to villages are under the most severe anthropogenic pressures.

Due to constraints imposed by limited resources, detailed geospatial data on urban areas in Bangladesh are limited in scope and quality. In many cases, the availability of spatial information and digital maps of cities are poor or nonexistent. Where maps do exist, they are often outdated or classified as restricted information and very difficult for public departments to access. Even the latest land use map, made in 2006 and used by the Chittagong city authority, is outmoded, inaccurate and spatially inconsistent; it is rarely used for public consultation or planning purposes. As a result, the precise spatial dimensions, size, and locations of the city's urban expansion have yet to be mapped or conclusively determined in a spatial and temporal context. In addition, different estimates of urban expansion, as reported from various different sources, are also inconsistent. The aim of this study is therefore to make use of current state-of-the-art remote sensing and GIS technologies alongside open source Landsat imagery to monitor spatial and temporal land use and land cover change, map the urban growth dynamics, and to assess the environmental sustainability of Chittagong, the second largest city in Bangladesh.

2 Study area

The study area is located between 22°13 and 22°30 north latitudes and between 91°40 and 91°55 east longitudes along the southeast coast of Bangladesh, bounded by the Karnaphuli River and its tributary the Halda River to the south and east, by the Bay of Bengal to the west and by a range of hills to the north (Fig. 1). Geographically, the region is generally

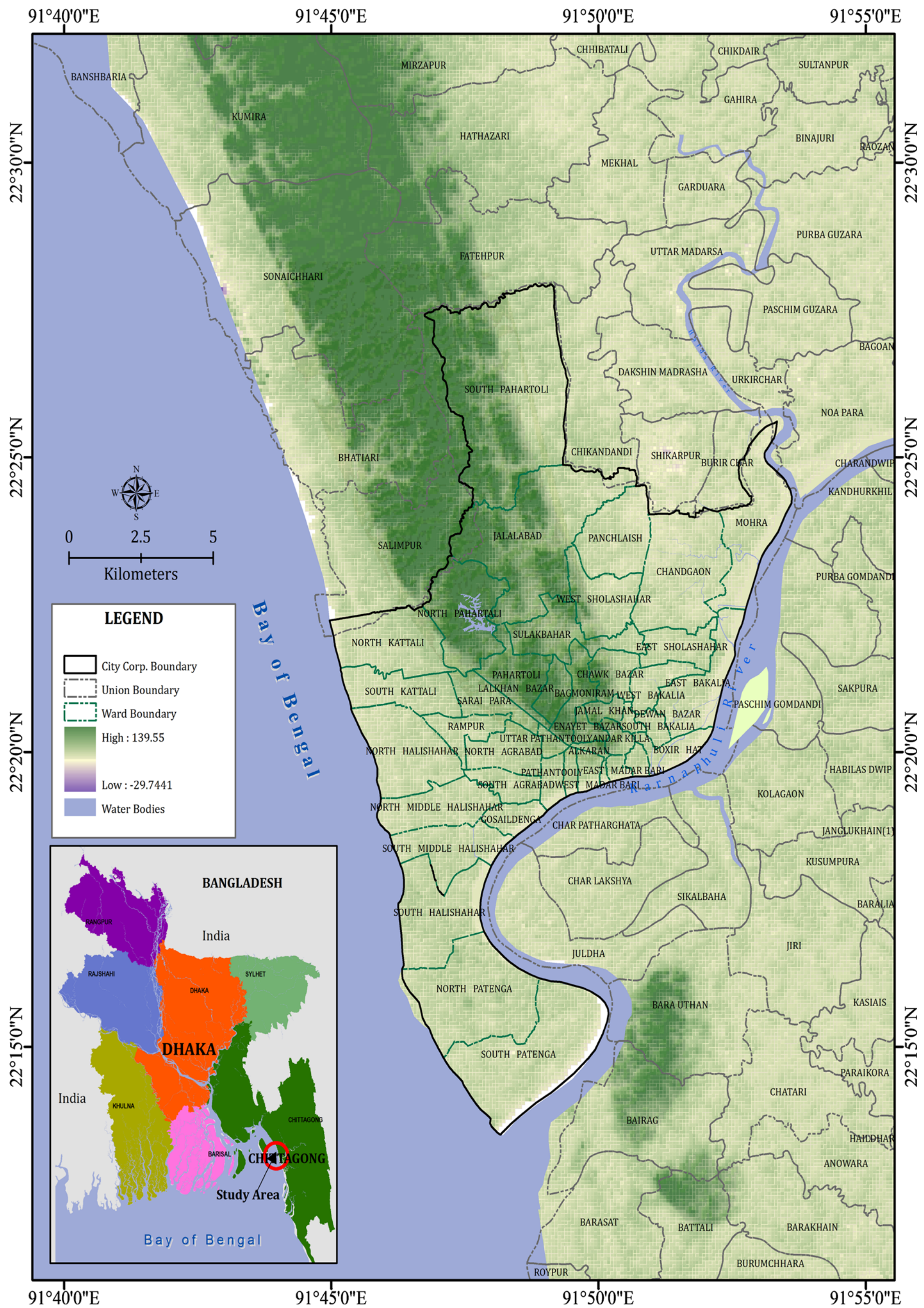

Fig. 1 Location map and digital elevation model of the study area

hilly and the topography and physiography of Chittagong is unique within the country, characterized by a combination of undulating low-level hillocks and plains. The noticeable piedmont and valley topography collectively occupies around 16 % of the city area (Islam

2009), while the remainder of the city generally covers flat alluvial plains. The early growth of the city was confined to these alluvial plains, near the Sadarghat area (Kotwali Thana), later expanding along the Nasirabad Valley due to rapid population increase and industrial growth. The average altitude of the plains is around 7 m above sea level, while the elevation of the northern hills ranges from 30 to 140 m above sea level. The climate of the region is predominantly tropical monsoon, with hot and humid summers and moderately cold winters. The maximum summer temperature reaches 32.3 °C, while the minimum temperature in winter does not drop below 13 °C. Annual rainfall in the region ranges between 2400 and 3000 mm (BMD 2013).

Chittagong is an important historical and strategic city within the region and the country as a whole due to its grand seaport, which provides links to the Indian subcontinent, including ports of Karachi, Kolkata, and Mumbai and the rest of the world. The city, in common with Dhaka and, to a lesser extent, the other cities and urban centers in Bangladesh, is a valuable generator of national wealth, as it holds 40 % of the country's large-scale industries (BBS 2013) and shares in the major seaborne trades of Bangladesh, accounting for 85 % of imports and 80 % of exports (www.chittagongchamber.com). Currently, the city and the adjoining areas are home to nearly 4.5 million people, making it the second largest metropolitan city in the country (BBS 2011). The study area, including the core of the city, areas of suburban development, shallow coastal waters, and the vast area of agricultural land, hills forests cover, a total of 557 km^2, of which 186 km^2 comprise existing city corporation areas, and a further 164 km^2 are marine waters and rivers.

3 Data and methodology

3.1 Data acquisition and preparation

A series of comprehensive geospatial datasets and Landsat images were used to produce a thematic land cover map of the study area. These geospatial data were collected from diverse sources, including the Survey of Bangladesh (SoB), the Chittagong Development Authority (CDA), the Chittagong City Corporation (CCC), Urban Development Directorate (UDD), and the Centre for Urban Studies (CUS). The data include road networks, drainage networks, electricity, telecommunication networks, water bodies, jurisdiction boundaries, vacant land, government properties, location of slums, and important establishments in the city. A full list of data collected and used in this study is given in Table 1. To produce the land cover maps and corresponding transition matrix, a time series of Landsat data, including imagery from MSS 1977 (60 m spatial resolution), TM 1989(30 m spatial resolution), ETM 1999(30 m spatial resolution), and the latest Landsat-8 (OLI–TIRS, 30 m spatial resolution) 2013 instruments, were used. All Landsat images are cloud-free and were acquired between November and December of the respective year. Data were obtained from the Landsat open access global land cover services (www.glovis.usgs.gov). To investigate urban expansion during the pre-satellite age, this study also makes use of topographic maps from 1955 and 1960, produced by the US Navy and the Survey of Bangladesh (SoB), respectively. Both maps were scanned and the land use properties were digitized in GIS for manual interpretation of various land use features and further analysis.

Prior to image preprocessing, the Landsat images were subset with respect to the study area, in order to reduce computation and image analysis time. In selecting the area of interest, the left boundary of the study area was relaxed to include part of the shallow sea,

Table 1 Data types and sources used in this study

Data types	Year	Producer	Scale
Base map	2001, 2006	Chittagong Development Authority (CDA)	1:250,000
Chittagong metropolitan master plan (urban development plan, structure plan, traffic and transport plan) and detailed area plan	1995, 2008	Chittagong Development Authority (CDA)	
Landsat MSS, TM, ETM, and OLI–TIRS	1977, 1989, 1999, 2013	USGS global land cover facilities	60, 30 m spatial resolution
Physical features, road network data	2006, 2011	CDA, UDD, CUS	
Socioeconomic data, population census, urban area report	2001, 2011, 2013, 2008	Bangladesh Bureau of Statics (BBS)	
Topographic map	1955, 1960	US Navy, Survey of Bangladesh	1:250,000
Aerial photograph, city guide map	1960, 1985, 2000	Survey of Bangladesh	1:25,000 1:20,000
Urban poor settlement survey	2011	Center for Urban Studies (CUS)	

in order to ensure that the area of intertidal silt deposition that occurred during the study period was included. Using road network data, a comparatively high-resolution image from OLI to TIRS was geo-referenced mostly through GIS; other images were subsequently co-registered to this OLI–TIRS image as a reference. The results of this image-to-image registration were examined using three different methods, including examining the root mean square error (which was <0.5 pixels), using image overlays, and image flickering/blending. In the latter methods, the images were overlaid onto the reference image and any mis-registration or dislodgement was visually investigated. Image overlay and flickering/blending were used to evaluate the overall accuracy of the image co-registration. In addition, road networks and physical features were also overlaid onto the geometrically rectified image in order to ensure the accuracy of the image rectification and the correct alignment of other spatial features onto the geo-referenced image. In cases where the co-registration results were not satisfactory, additional image-to-image control points were sought, and the registration was performed again, with the results being examined using the above methods. The process was repeated until a satisfactory co-registration was achieved. All images were registered and re-projected to local coordinates (Bangladesh Transverse Mercator with datum Everest 1830), and a first-order polynomial transformation with nearest neighbor resampling was applied. By overlaying road network and physical feature data, all Landsat images were thoroughly investigated and the DN values of each image were carefully examined. To remove geometric distortion that mainly occurs in mountainous areas, and to be consistent with other spatial data, a rigorous orthorectification method based on a colinearity equation was performed on all four sets of Landsat data, incorporating the DEM value (Wang and Wang 2013; Batisani and Yarnal 2009).

To illustrate spatial distribution of urban expansion, eight transect zones, forming fan-shaped areas, were created with reference to a predetermined city center (Xu et al. 2007;

Yin et al. 2010). The fan-shaped transects were drawn in GIS, referenced around the location of CDA avenue in the center of the old town, Kotwali Thana. Using a GIS overlay, the built-up areas that fall within each zone were aggregated and the total area of each category within each sector was calculated. Finally, these values were displayed as line graphs (Fig. 5), allowing the spatial distribution of built-up areas to be visualized and illustrated.

3.2 Image classification

Due to the heterogeneous character of land uses, a classification scheme was developed based on previous knowledge and field investigations combined with additional information from previous research in the study area. Land use types were determined by a combination of supervised and unsupervised (ISODATA) classification (Pabi 2007; Suribabu et al. 2012; Wondrade et al. 2014; Bui et al. 2013), as well as manual interpretation of satellite images (Bui et al. 2013), aerial photographs, topographic maps, survey data, and ground truth information (Yagoub and Kolan 2006; Liu et al. 2009). Since the aim of this study was to examine land cover changes and the spatial extent of built-up areas, rather than focusing on the internal variation of various urban structures, we adopted a simple classification system, partly derived from Anderson's (Anderson et al. 1976) first-order hierarchical classification system. In this way, seven thematic land use and land cover categories were generated (Table 2) and classified using training sites or signature files that appeared fairly homogeneous on the image. Nearly 150 signatures were collected for each year and were submitted for statistical analysis of similarities (Wondrade et al. 2014; Rojas et al. 2013). This analysis indicates the relative degree of similarity, based on spectral distance. Water bodies, vegetation cover, crop fields, and core urban areas, for example, can easily be traced out since they show a distinct pattern of spectral reflectance. For other categories, such as beaches and dunes, fallow land, coastal wetlands, and the rural–urban interface, it was more challenging to separate their spectral values, as there was a smaller distance between nearby class pairs. Using aerial photographs, Google Earth, and GPS field survey data in addition to an image enhancement technique, these land covers were manually distinguished and a reasonable signature was extracted from each land use class. Using these signature files, supervised classification was carried out with a maximum likelihood algorithm (Yuan et al. 2005). Finally, to reduce potential salt-and-pepper effects, a 3 × 3 majority filter was applied before the classified land covers were used for further analysis (Yin et al. 2005; Bui et al. 2013).

Table 2 Land use/land cover classification scheme

Land cover types	Description
Urban/built-up area	These include all developed land, including commercial, residential, industrial, and other infrastructure
Crop field	Land used for agriculture, paddy field, vegetables, fruits, and other cultivable lands
Beach and dune	Sandy beaches, dune and river bank
Water bodies	Lake, ponds, lagoon, river, aqua fishing, and vast sea water
Forest and vegetation	Hilly forest, homestead vegetation, coastal mangrove, bush and shrubs
Fallow land	Fallow land, uncultivated land, open hill, exposed hilly soil, landfill, barren land, bare soil
Lowland/wetland	Accretion land, deposited land, river bank

Accuracy assessment was carried out using field observation GPS data, aerial photographs, topographic maps, and random sampling. The validation method was varied from image to image. For example, the 1977 thematic map was validated using topographic maps from 1960 with 200 random sampling points, and the 1989 and 1999 land cover map was validated by using aerial photographs from 1985, a land use map from 1995, and a city guide map from 2001, each with 200 random sampling points. In 2013, the thematic map was validated using 146 ground survey GPS data in addition to road network data. Although prior survey data were available, containing 2465 GPS points and featuring important establishments in the city, further field study was carried out, placing particular focus on the urban–rural interface where image interpretation may be problematic. These field survey data, in combination with previous GPS feature surveys and accompanying road network information, greatly enhanced the accuracy of land use classification. The resulting overall classification accuracy was 85.2 % in 1977, 87.5 % in 1989, 89.2 % in 1999, and 93.1 % in 2013, with a kappa accuracy index (Congalton 1991) of 0.79, 0.84, 0.89, and 0.91 in 1977, 1989, 1999, and 2013, respectively. Owing to the differing spatial resolutions of remotely sensed images (MSS, 60 × 60 m, TM, ETM, and OLI–TIRS 30 × 30 m), all classification results were resampled at 30 × 30 m for further analysis (Yagoub and Kolan 2006).

3.3 Land cover change detection analysis

Change detection analysis is one of the major uses of remotely sensed data and is useful for scientific innovation, monitoring environmental quality, economic resource management, and human well-being (Turner et al. 2007). Remotely sensed data are frequently used in many fields, including water resource management, damage and disaster assessment (Schöpfer et al. 2007), agricultural and forest resource management (Liu et al. 2009), observation of local or regional climate change (Kalnay and Cai 2003; Kaufmann et al. 2007), and monitoring land cover change. The importance of remote sensing in monitoring urban growth patterns and mapping the changes in land cover is widely recognized (Longley 2002). There is currently demand for more widespread GIS-compatible data for integration with other spatial information, and so visual change detection techniques have only limited application in monitoring ecosystem, land use, and land cover change. Scientists, therefore, have developed and employed a number of methods to address the problem of land cover change detection with the aid of digital imagery. Change detection analysis techniques can therefore be broadly divided into either post-classification change detection or pre-classification spectral change detection. Both Singh (1989) and Coppin et al. (2004) have summarized and reviewed eleven different change detection methods, including composite analysis (Muchoney and Haack 1994), image differencing (Singh 1989), subtraction and thresholding (Howarth and Wickware 1981), principle component analysis (Lillesand and Kiefer 1999), change vector analysis (Lambin and Strahler 1994), and spectral mixture analysis methods (Zhang et al. 2011).

Although various limitations affect each change detection method, this study employed the more commonly used post-classification change detection method to determine land use and land cover changes between different study years (Suribabu et al. 2012; Yagoub and Kolan 2006). The main advantages of post-classification change detection are that it provides relatively accurate change detection while avoiding the difficulties associated with the analysis of images acquired at different times of year or by different sensors (Peterson et al. 2004; Singh 1989; Coppin et al. 2004). The post-classification change detection method was employed to identify conversions of one particular land use category to other land use categories over different time periods, locations, and areal extents. Thematic maps of the land use change matrix of each land use category are also represented in Fig. 3.

4 Results, analysis, and discussion

4.1 Land use and land cover dynamics and urban expansion

In general, Chittagong and its surrounding area have experienced rapid urbanization, which has resulted in significant changes in land use over the 36-year period studied here. The static distributions of land uses/land covers for each study year, as generated from the thematic maps, are presented in Table 3 in "Appendix" and Fig. 2 below. Together they indicate that 25,000 ha accounting for 56 % of the total land area has undergone change during the study period. During this time, the built-up area increased by 618 %, with an annual rate of increase of 17.17 %, from 1309.68 ha in 1977 to 9401.85 ha in 2013 (Fig. 3). The rate of growth was most dramatic in the city corporation area where the rate of urban increase reached 14 % per year (Fig. 4). This rapid urban growth has resulted in the degradation of agricultural land, forests, and vegetated areas, and wetlands and water bodies across the whole region. Through comparison of land cover maps generated in this study, along with close investigation of historical topographic maps and literature, it has been observed that before 1977, city growth was limited to the northern bank of the Karnaphuli River and along the inter-regional (previously the Assam–Bengal) railway line. The topographic map from 1960 used in this study corresponds quite closely to the urban growth pattern seen in the thematic map from 1977, generated by Landsat MSS. The built-up area throughout this period is, therefore, estimated to be constant, at nearly 1275 ha; this is 7.55 % of the current city corporation area.

Agricultural and forest cover were the dominant land uses during the early part of the study period, together comprising nearly 85 % of the total area. The accretion low land near the coast also occupied a considerable proportion of the area, estimated at 604 ha. Built-up areas in 1977 occupied the smallest area of all the classes, which may be due to the short 7 years between the independence war in 1971 in which Bangladesh was established as an independent state, and the year in which the image was taken. During this time, agricultural sectors dominated in terms of contribution to national GDP and employment. During this period, development within the city was primarily driven by activities surrounding the port, which is the largest in the country. The urban core is located around Kotwali and Double Mooring Thana, which together are the most densely populated and developed zones in the city. Land use in the city core comprised a mixture of small industries, commercial buildings, offices, and dwellings (Islam 2009). Moving away from the city core to the north, south, east, and west, land was more rural in character and predominately agricultural in use. The main built-up and industrial installations could be found at the port along the river, around the railway in Phartali, near to the airport, along the major trunk road and within the Kalurghat industrial zone. The national urban growth recorded throughout the pre-independence period was quite slow, which may be connected to the political upheaval following control and decontrol of state power; however, phenomenal growth was seen during the post-independence era, reaching 6.7 % per year.

In the period between the last four censuses, from 1981 to 2011, the national population increased from 89.9 to 160 million. This indicates an average annual increase of 2 million

Fig. 2 Time series of land use/land cover maps for 2013–1977

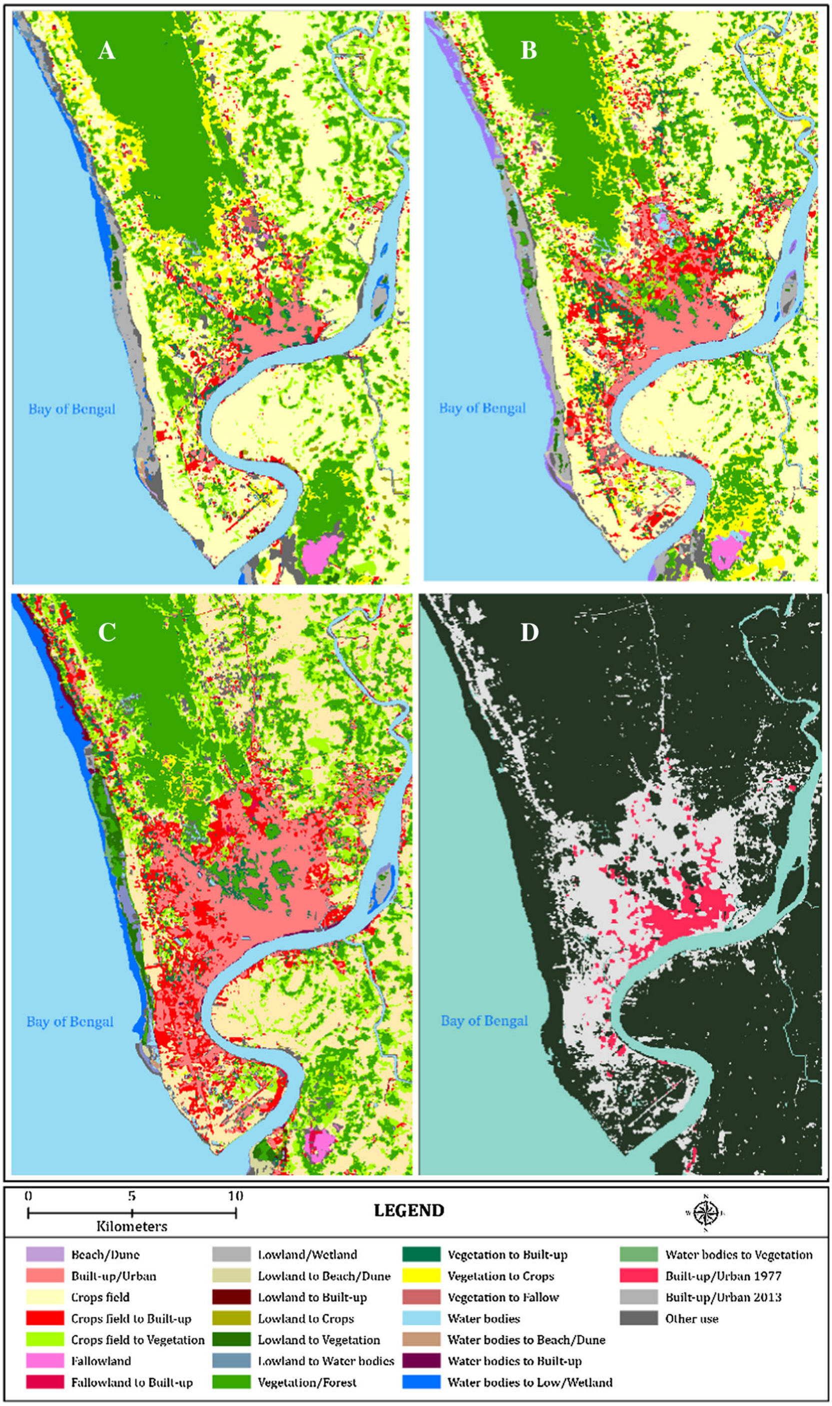

Fig. 3 Land use/cover conversion map. **a** 1977–1989, **b** 1989–1999, **c** 1999–2013, **d** built-up expansion 1977–2013

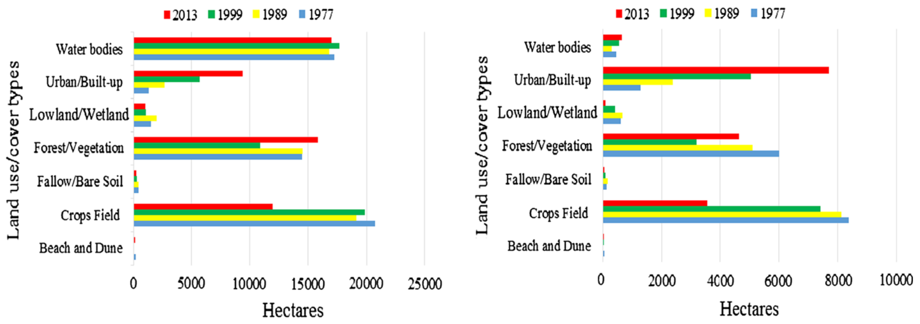

Fig. 4 Categorical change in land use/land cover. (*Left*) entire study area, (*right*) city corporation area

people nationally. Meanwhile, urban areas across the country increased their share of the total national population from 15.7 to 28 % (BBS 2011). As with other cities in Bangladesh, Chittagong also witnessed remarkable urban expansion, accompanied by substantial population growth during 1977–1989. The average annual urban population growth rate in the study area was 4.8 % during the 1974–1991 census period, while the average national population growth rate was only 2.1 %. The land cover map produced in this study, however, reveals that the urban built-up area expanded at an annual rate of 8.58 % during this period. The built-up area, therefore, increased to 2368 ha in 1989, which was almost double that from the previous year. At this time, vegetation cover and crop fields still occupied the greatest area, making up 78 % of the total. The land use conversion matrix reveals that during 1977–1989, a total 10,938 ha of land, comprising 20 % of the study area, had undergone change. Major change took place around the immediate periphery of the old town, where the dominant land use was originally mixed urban–rural and agriculture. The net conversion of various land covers to urban areas during this period is estimated to be 1484 ha, among which 960 ha (68 %) and 436 ha (29 %) were conversions from crop fields and vegetation cover, respectively. Despite these losses due to urban expansion and other land cover change, some 168 and 141 ha of crop fields and vegetation, respectively, were regained by the conversion of lowlands near the coast to the west of the city. Water bodies also decreased significantly during this period, among which 4.28 % of the losses were mainly due to urban expansion.

The increasing urban growth over this period is linked to multiple possible drivers, including spontaneous population growth, increased job opportunities, and social–cultural advantages to urban life, but most importantly increased rural to urban migration, resulting from a natural disasters, river erosion, landlessness, and economic insolvencies in the countryside (Islam 2011). In comparison with population growth, the built-up area of the city continued to increase in size, as can be seen in a comparison of land cover maps in 1989 and 1999. During this time, urban expansion took place at a rate of 11.33 % per annum, while annual population growth in the study area was just 3.7 %. Between 1989 and 1999, the urban area grew by 5052 ha, accounting for 30.16 % of the total land cover in the city corporation area. Vegetation and agriculture remained the major land cover classes; however, their areal extent was declining at a rate of 3.75 and 0.86 % per annum, respectively. The areas of lowland and fallow land also decreased by 5.14 and 3.59 % per year, respectively. During 1989–1999, the total areas of agricultural land, vegetation cover, lowland/wetland, and fallow land declined by 705.89, 1913.49, 35.19, and 236.79 ha, respectively. Water bodies seemed to increase by 144.66 ha, caused by an increase in aqua farming on the accretion lowlands on the coast to the west of the city. During this period, the terrestrial area also increased significantly due to silt deposition, and the land–sea demarcation line clearly moved toward the west into the ocean.

The huge physical expansion of the city during this period may be attributed to several factors, including the change in city status as it was upgraded to a City Corporation in 1991, and a massive political shift in the country, from an autocratic dictatorship to a democratic state. In addition, a master plan was formulated in 1995 to encourage urban expansion to the west of the city, within a new coastal embracement. As a result, many infrastructure development projects were begun after the creation of the City Corporation and its associated planning guide (CDA 2008). During this period, most of the urban development occurred away from the old town, and in places other than on the north bank of the Karnaphuli River. To the south and west, urban development took place in Agrabad and beyond, toward the Patenga peninsula. To the northwest, built-up areas expanded onto the gently sloping land, which is protected from cyclone surges and is easily serviced along the main Dhaka–Chittagong rail and road corridor. To the northeast, urban expansion is observed along CDA Avenue to Hathazari road. To the east, however, development was limited to some extent, due to regular flooding of the low-lying land. The total area experiencing land use change during this period (1989–1999) is estimated to be 11,495 ha. At this time, urban areas are still the main land conversion, but at a more rapid rate than in previous years. Built-up areas grew by 3621.45 ha during this period, among which the major share was derived from croplands (62.58 %) and vegetation cover (33.62 %).

During 2001–2011, the pace of national urban population growth slowed to 3.5 % per annum. A similar pattern was also observed in the study area, where urban population growth was 3.3 % throughout the 2001–2011 census period (BBS 2011). Urban expansion continued to increase, however, at a slower rate of 5.31 % per annum, as estimated from the land cover maps spanning the 1999–2013 period. In 2013, urban expansion in city corporation area was 7712 ha, accounting for 47 % of the total land cover in the city. Expansion of built-up areas consequently reduced the amount of agricultural and fallow land.

The net decrease in agricultural land was 3865 ha, while the fallow land declined by 57.51 ha. Surprisingly, in 2013, vegetation cover had shown a substantial increase, at a rate of 4.55 % per year.

The increased vegetation cover may be partly due to the growth of coastal mangrove forests to the west of the city or to increasing rural settlements consuming agricultural land to the east and southeast. From the land conversion matrix, it can be seen that 28 % of the total land area, accounting for 15,099.23 ha, were transformed into various different land use categories between 1999 and 2013. The greatest land conversion resulted from crops and vegetation cover being changed to urban land. During this period, the rate of consumption of agricultural land as a means of expanding urban areas became dramatic. In total, 3407.40 ha (71.84 %) of the built-up area resulted from the consumption of agricultural and crop land. This indicates that urban expansion diffused out from the city limits to distant agricultural fields.

Over the entire study period, the city has expanded vastly, as the land cover maps indicate. Urban land use increased in area by 505 % in the Chittagong City Corporation region and by 618 % in the study area as a whole. Compared to Dhaka city, the observed urban growth was significantly higher in Chittagong. During 1975–1992 and 1992–2003, annual urban expansion in Dhaka city was 6.13 and 3.15 %, respectively (Dewan and Yamaguchi 2009), while the annual urban growth over similar periods in Chittagong city was 6.59 % during 1977–1989, and 11.33 % during 1989–1999. These huge urban increases were spatially diffused from the old city center toward the west (24.68 %), south–west (15.69 %), and north–west (20.63 %), inside the coastal embankment (Fig. 5). Some 17 % of the built-up area also expanded toward the north, by encroaching into the hills (Fig. 6).

During the urbanization process, the negative effects of physical factors such as slope and elevation on urban expansion have been well documented (Ye et al. 2011; Li et al. 2013). In the case of Dhaka city, the capital of Bangladesh elevation played a critical role in guiding urban expansion (Dewan and Yamaguchi 2009). Physical factors has the greatest influence on urban expansion in the study area during the early stage of development, during 1977–1989, when urban expansion took place on comparatively level and easily serviced land. Due to rapid urban growth, however, the limiting effects of physical factors gradually decreased and higher topography such as the hilly areas to the north also began to be urbanized, because of the unavailability of more suitable land for urban expansion. The areas outside the main city have seen undesirable ribbon development along the edges of regional roads and around existing growth centers. On the south bank of the Karnaphuli River, currently of a mixed rural agricultural, both urbanization and industrialization are occurring more rapidly due to a new crossing across the Karnaphuli, which has made these areas more accessible to the existing urban area.

As industrialization and urbanization are complementary to one another (Acemoglu et al. 2005), the city of Chittagong has traditionally been a major center for trade, commerce, and industrial agglomerations. Historically, the city's port was used as a trading post by Greek, Portuguese, Arabic, and British traders. Large-scale manufacturing industries began to emerge in the early 1950s with the construction of an oil refinery, a cement clinker plant, and a steel mill on the Patenga Peninsula. The first planned industrial sites were developed in Kalurghat, Mohra, Fouzderhat Sagarika, and Sholashar during 1960–1970, followed by the Nasirabad industrial area (CDA 1995). Later, in 1983, the country's first export processing zone, CEPZ was established in South Halishahar, followed by KEPZ in North Patenga; these industries currently employ an estimated 227,723 people (BEPZA 2013). Moreover, the proximity of the country's largest oil refinery industry, fertilizer industry, steel industry, and shipbuilding and breaking yards further increase the rate of urban growth. However, such rapid urbanization has led to environmental degradation and considerable human suffering in the city. One immediate consequence is the growth of slums and squatter settlements in and around the city (CUS 2005). A recent study shows that in Chittagong city, slums or squatter settlements cover nearly 6 % of the city land area (UPPR 2011) and 40 % of the total city population (BBS 2011).

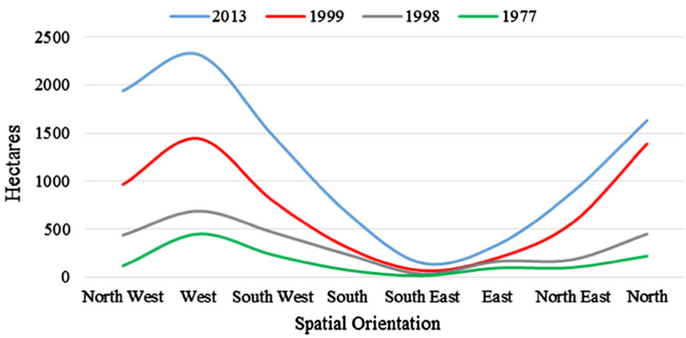

Fig. 5 Spatial orientation of urban growth over the study period

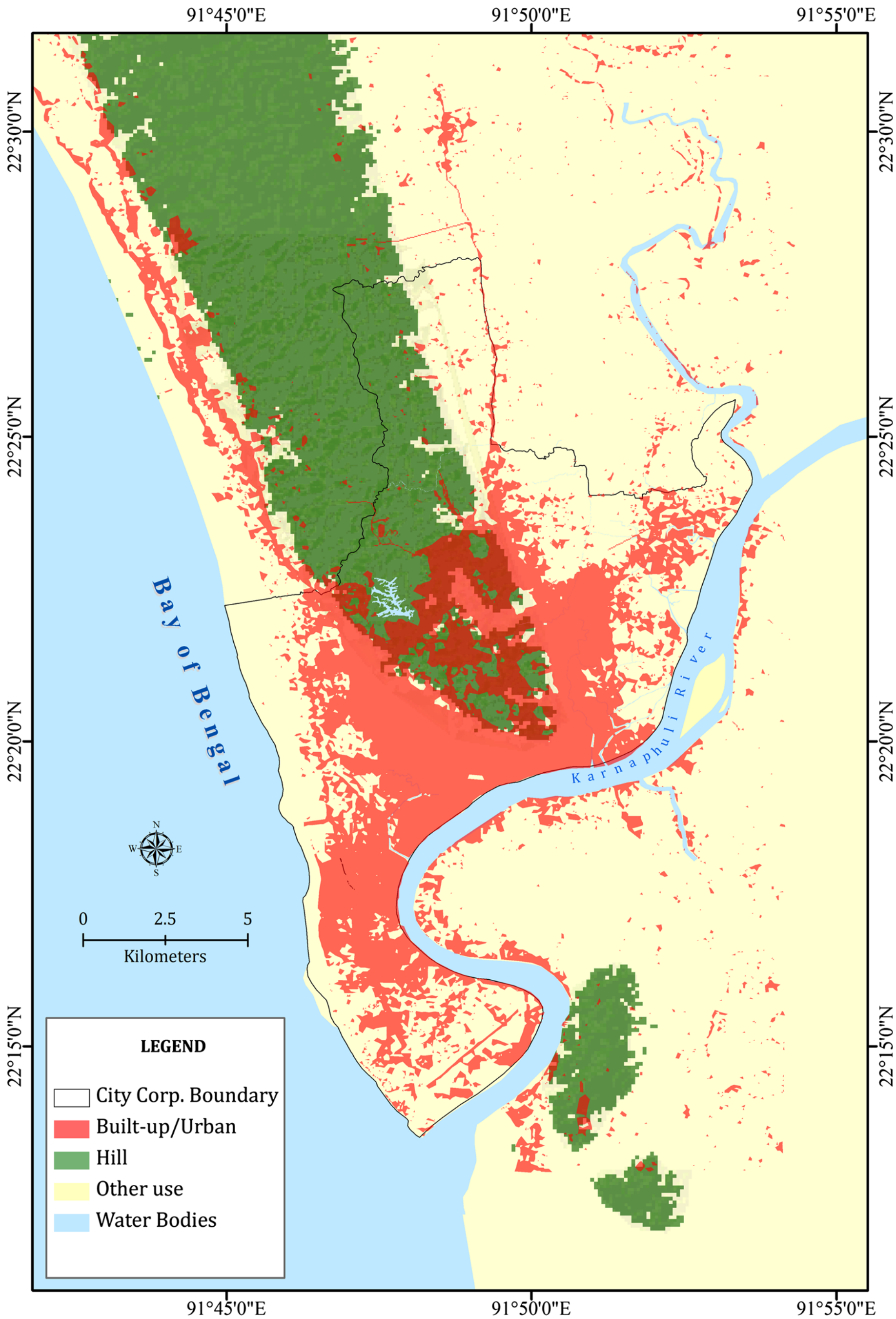

Fig. 6 Hill encroachment map (*dark red* indicates hills that are intruded upon by urban expansion)

4.2 Socioeconomic and environmental sustainability in Chittagong city

The study area has already suffered and will continue to suffer more acutely in the future, from socioeconomic and environmental issues related to substantial growth of slums (UPPR 2011), hill cutting (Murshed 2013), ground water pollution, encroachment into the Karnaphuli River (Banu 1995), unregulated ship breaking activities (Hossain and Islam 2006) and overall unplanned urban development. As of now, the socioeconomic and environmental sustainability of Chittagong city, which is essential for city growth planning and management, has received relatively little attention. This has resulted in far-reaching environmental problems across the city, largely driven by unplanned urbanization, extensive urban poverty, regular occurrences of flooding, sizeable growth of slums, and mismanagement of limited land resources.

Hill cutting and encroachment (Fig. 6) have been identified as a source of considerable environmental concern (Rahman et al. 2001), which had led to a series of environmental and human catastrophes, including notable human deaths as a result of massive landslides. Several estimates suggest that nearly 200 hills across the city have been illegally cut, leveled, and subdivided for the purposes of residential or infrastructure development. From spatial analysis in GIS, this study found that nearly 2178 ha of hill had been encroached upon over the last 36 years. The fallow land categorized in this study is mainly hill surfaces that are exposed after cutting or leveling for infrastructure or housing development. Such indiscriminate hill cutting has damaged not only the environment, but also human lives and the city's vibrancy, as well as having a long-term economic impact on the region. Indiscriminate hill cutting has put the lives of people living at the foot of the hills at risk from landslides during the rainy season; these people are mostly poor slum dwellers. Various reports (UNB 2014; DoE 2014) suggest that nearly 200 people were buried in landslides over the last four decades, including locations such as Lalkhan bazaar, Tigerpass, Kusumbag, Mothijhorna, Baizid Bostami, Foy's Lake, Khulshi, and Sholoshahar. Moreover, hill cutting accompanied by deforestation has increased the rate of soil erosion, which has consequently aggravated the problem of waterlogging in the city and put the main seaport of the entire country at risk, due to massive siltation in the Karnaphuli River (CDA 1994, 2008). Hill cutting also alters the isotactic balance in the region, making it more susceptible to earthquakes (Ansary 2004). The data presented here indicate that the current trend of urbanization in the region is inevitable and that the resulting pressure on land will continue to increase, targeting open ground, agricultural land, low-level hilly areas, river banks, and other environmentally sensitive locations. However, using GIS and remote sensing techniques, the proper utilization of limited land resources may be addressed by planners during urban development, in order to mitigate the adverse effects of unmanaged urban growth on human life, biodiversity, and ecosystems in this region.

5 Conclusion

In the study of rapid urbanization, accurate assessment of urban growth and the spatiotemporal changes in land use has become increasingly critical for understanding urban dynamics and environmental impacts, as well as guiding sustainable urban development. This study quantitatively examined changes in land use/land cover and urban expansion in Chittagong, the second largest metropolitan city in Bangladesh, using Landsat data in conjunction with socioeconomic and geospatial information. The findings of the study reveal that the area has experienced rapid urbanization and undergone dramatic changes in land cover, as evidenced by a rapid increase in extent of built-up areas, resulting in a loss of croplands, vegetation cover, fallow lands, water bodies, and lowlands. These rapid urban expansions have been mainly driven by a huge growth in industry, infrastructure development, population growth, increasing port-related activities, and expansion of residential development, resulting in the consumption of agricultural land, vegetation cover, and hill encroachment. Major urban expansion occurred toward the west, south–west, and north–west, where agricultural land was consumed. Physical factors such as slope and elevation had little impacts on the urbanization process, as evidenced from the northward distribution of built-up areas, encroaching into hilly areas. The rapid urbanization has also resulted in a series of urban problems, related to environmental degradation, socioeconomic sustainability, and a decline in overall city vibrancy. The findings of this study and the geospatial information generated from the land use mapping can be used as an important reference for planners, policy makers, stakeholders and other interested groups, to aid in the rational utilization of limited land resources. Additionally, the information may assist in making decisions regarding future land use plans and urban development, in order to mitigate the adverse effects of land use change and its concomitant environmental impact.

Appendix

See Table 3.

Table 3 Absolute quantities for each land use classes

Land use/land cover types	1977		1989		1999		2013	
	Hectares	%	Hectares	%	Hectares	%	Hectares	%
City corporation area								
Beach and dune	55.44	0.33	7.92	0.05	26.19	0.17	34.11	0.20
Crops field	8368.56	49.59	8128.89	48.55	7423	44.33	3557.61	21.24
Fallow land/bare soil	119.52	0.71	173.52	1.04	84.33	0.50	57.51	0.34
Forest/vegetation	6008.04	35.60	5099.49	30.45	3186	19.03	4637.52	27.70
Lowland/wetland	604.08	3.58	659.79	3.94	422.3	2.52	97.11	0.58
Urban/built-up	1274.4	7.55	2367.99	14.14	5052	30.16	7711.83	46.05
Water bodies	446.04	2.64	307.44	1.84	552.1	3.29	649.35	3.88
Total	16,876.08	100.00	16,745.04	100.00	16,745.92	100.00	16,745.04	100.00
Study area								
Beach and dune	210.24	0.38	68.67	0.12	52.38	0.09	143.01	0.26
Crops field	20,732.04	37.11	19100.79	34.37	19,841.94	35.70	11,947.59	21.50
Fallow land/bare soil	433.80	0.78	449.01	0.81	307.26	0.55	238.41	0.43
Forest/vegetation	14,446.8	25.86	14,519.43	26.12	10,898.19	19.61	15,816.69	28.46
Lowland/wetland	1508.04	2.70	1962.81	3.53	1078.38	1.94	1019.25	1.83
Urban/built-up	1309.68	2.34	2693.7	4.85	5730.12	10.31	9401.85	16.92
Water bodies	17,225.64	30.83	16,782.03	30.20	17,668.17	31.79	17,009.64	30.60
Total	55,866.24	100.00	55,576.44	100.00	55,576.44	100.00	55,576.44	100.00

References

Acemoglu, D., Simon, J., & James, A. R. (2005). The rise of Europe: Atlantic trade, institutional change and economic growth. *American Economic Review, 95*(3), 546–579.

Anderson, J. R., Hardy, E. E., Roach, J. T, & Witmer, R. E. (1976). A land use and land cover classification system for use with remote sensor data. U.S.GS. Prof. Paper (Vol. 964, pp. 1–26).

Ansary, M. A. (2004). Seismic risk in urban areas of Bangladesh. People's report 2002–2003: Bangladesh environment. Unnayan Shamannay, Ministry of Environment and Forest and United Nations Development Program.

Banu, S. A. (1995). Study on accumulation of trace metal (Ni, Pb, Cr, Cu, Mn, Cd, Zn and Fe) in the sediments of the Karnafuli river mouth, Chittagong, Bangladesh. M.Sc. dissertation, Institute of Marine Sciences and Fisheries, University of Chittagong, Bangladesh, p. 80.

Batisani, N., & Yarnal, B. (2009). Urban expansion in Centre County, Pennsylvania: Spatial dynamics and landscape transformations. *Applied Geography, 29*, 235–249.

BBS. (2011). Population & housing census, national Vol. 3, urban area report, Bangladesh Bureau of Statistics. Ministry of Planning. Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

BBS. (2013). Economic census, Zila series: Chittagong, Bangladesh Bureau of Statistics. Ministry of Planning. Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

BEPZA. (2013). Bangladesh Export Processing Zone Authority, Year Wise-Employment. http://www.epzbangladesh.org.bd. Accessed March 04, 2014.

BMD. (2013). Bangladesh Metrological Department, annual rainfall and temperature analysis. http://www.bmd.gov.bd/. Accessed February 12, 2014.

Bui, T. D., Maier, S. T., & Austin, C. M. (2013). Land cover and land use change related to shrimp farming in coastal areas of Quang Ninh, Vietnam using remotely sensed data. *Environmental Earth Sciences,*. doi:10.1007/s12665-013-2964-0.

Carlson, T. N., & Arthur, S. T. (2000). The impact of land cover changes due to urbanization on surface microclimate and hydrology: A satellite perspective. *Global and Planetary Change, 25*, 49–65.

CDA. (1994). Chittagong development Authority. Chittagong Metropolitan Master Plan, Chittagong Stormwater Drainage and Flood Control Master Plan.

CDA. (1995). Chittagong development Authority. Chittagong Metropolitan Master Plan, Chittagong Structure Plan.

CDA. (2008). Chittagong development Authority. Chittagong Metropolitan Master Plan, Urban Development Plan.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment, 37*, 35–46.

Coppin, P., Jonckheere, K., Nackaerts, K., & Muys, B. (2004). Digital change detection methods in ecosystem monitoring: A review. *International Journal of Remote Sensing, 25*(9), 1565–1596.

CUS, Center for Urban Studies. (2005). National Institute of Population, Research and Training (NIPORT) and MEASURE evaluation: slums in urban Bangladesh, mapping and census, 2006. CUS, Dhaka.

Dewan, A. M., & Yamaguchi, Y. (2009). Land use and land cover change in Greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Applied Geography, 29*(3), 390–401.

DoE. (2014). Department of Environment, Chittagong office, Ministry of Environment &Forests, Govt. of the People Republic of Bangladesh.

Hasan, A. B., Kabir, S., Reza, A. H. M., Zaman, M. N., Ahsan, M. A., Akbor, M. A., & Rashid, M. M. (2013). Trace Metals pollution in seawater and groundwater in the ship breaking areas of Sitakund upazila, Chittagong, Bangladesh. *Marine Pollution Bulletin, 71*(1–2), 317–324.

Hossain, M. M, & Islam, M. M. (2006). Ship breaking activities and its impact on the coastal zone of Chittagong, Bangladesh: Towards Sustainable Management. Young Power in Social Action (YPSA), Chittagong, Bangladesh.

Howarth, P. J., & Wickware, G. M. (1981). Procedures for change detection using Landsat. *International Journal of Remote Sensing, 2*, 277–291.

Islam, M. S. (2009). Geomorphological control of urban land development and geo-environmental settings in Chittagong city, Bangladesh. *Plan Plus, 5*, 1–11.

Islam, N. (2011). Urbanization in Bangladesh, International Seminar on Urbanization, Asiatic Society of Bangladesh, Dhaka.

Jianchu, J., Fox, J., Vogler, J. B., Peifang, Z., Yongshou, F., Lixin, Y., et al. (2005). Land use and land cover change and farmer vulnerability in Xishuangbanna Prefecture in Southwestern China. *Environmental Management, 36*(3), 404–413.

Kalnay, E., & Cai, M. (2003). Impact of urbanization and land-use change on climate. *Nature, 423*(6939), 528–531.

Kaufmann, R. K., Seto, K. C., Schneider, A., Liu, Z., Zhou, L., & Wang, W. (2007). Climate response to rapid urban growth: Evidence of a human-induced precipitation deficit. *Journal of Climate, 20*(10), 2299–2306.

Lambin, E. F., & Strahler, A. H. (1994). Change-vector analysis in multitemporal space: A tool to detect and categorize land-cover change processes using high temporal-resolution satellite data. *Remote Sensing of Environment, 48*, 231–244.

Lambin, E. F., Turner, B. I., & Geist, H. J. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change, 11*, 261–269.

Li, X., Zhou, W., & Ouyang, Z. (2013). Forty years of urban expansion in Beijing: What is the relative importance of physical, socioeconomic, and neighborhood factors*?*. *Applied Geography, 38*, 1–10.

Lillesand, T. M., & Kiefer, R. W. (1999). *Remote sensing and image interpretation*. New York: Wiley.

Liu, M., Hu, Y., Chang, Y., He, X., & Zhang, W. (2009). Land use and land cover change analysis and prediction in the upper reaches of the Minjiang River, China. *Environmental Management, 43*, 899–907.

Longley, P. A. (2002). Geographic information systems: Will developments in urban remote sensing and GIS lead to 'better' urban geography? *Progress in Human Geography, 26*(2), 213–239.

McCarthy, M. P., Best, M. J., & Betts, R. A. (2010). Climate change in cities due to global warming and urban effects. *Geophysical Research Letters, 37*, L09705.

Muchoney, D. M., & Haack, B. N. (1994). Change detection for monitoring forest defoliations. *Photogrammetric Engineering and Remotesensing, 60*(10), 1243–1251.

Murshed, M. M. (2013). Cutting of hills and human tragedy: An example of law enforcement loophole in the southeastern region of Bangladesh. *International Journal of Geodetics and Geosciences, 4*(2), 417.

Nazem, N. I., Chowdhury, A. I., & Mahbub, A. Q. M. (2011). Economic geography of urbanization and development, Bangladesh Urban Forum edited by Sarwar Jahan and Nurul Islam Nazem.

Pabi, O. (2007). Understanding land-use/cover change process for land and environmental resources use management policy in Ghana. *GeoJournal, 68*, 369–383.

Peterson, D. L., Egbert, S. L., Price, K. P., & Martinko, E. A. (2004). Identifying historical and recent land-cover changes in Kansas using post-classification change detection techniques. Transactions of the Kansas Academy of Science.

Rahman, M. M., Dewan, A. M., & Islam, M. S. (2001). Degradation of urban environment: A case study of citizen's perception in Chittagong. *Oriental Geographer, 45*(1), 35–52.

Rana, M. M. P. (2011). Urbanization and sustainability: challenges and strategies for sustainable urban development in Bangladesh. *Environment, Development and Sustainability, 13*, 237–256.

Rojas, C., Pino, J., Basnou, C., & Vivanco, M. (2013). Assessing land-use and -cover changes in relation to geographic factors and urban planning in the metropolitan area of concepcion' (Chile). Implications for biodiversity conservation. *Applied Geography, 39*, 93–103.

Schöpfer, E., Tiede, D., Lang, S., & Zeil, P. (2007). Damage assessment in townships using VHSR data. The effect of operation Murambatsvina/restore order in Harare, Zimbabwe. In *Proceedings of the urban remote sensing joint event, Paris, France*.

Singh, A. (1989). Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing, 10*(6), 989–1003.

Suribabu, C. R., Bhaskar, J., & Neelakantan, T. R. (2012). Land use/cover change detection of Tiruchirapalli City, India, using integrated remote sensing and GIS tools. *Journal of the Indian Society of Remote Sensing, 40*(4), 699–708.

Taubenböck, H., Wiesner, M., Felbier, A., Marconcini, M., & Dech, T. E. (2014). New dimensions of urban landscapes: The spatio-temporal evolution from a polynuclei area to a mega-region based on remote sensing data. *Applied Geography, 47*, 137–153.

Torbick, N. M., Qi, J., Roloff, G. J., & Stevenson, R. J. (2006). Investigating impacts of land-use land cover change on wetlands in the Muskegon river watershed, Michigan, USA. *Wetlands, 26*(4), 1103–1113.

Turner, B. L, I. I., Lambin, E. F., & Reenberg, A. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 20666–20671.

UNB. (2014). United News of Bangladesh, Ctg gets warning system for landslide forecast. http://www.unb.com.bd/print/landslide-warning. Accessed November 25, 2014.

UPPR. (2011). Poor settlement in Bangladesh, urban partnership for poverty reduction, local government engineering department.

Wang, S., & Wang, S. (2013). Land use/land cover change and their effects on landscape patterns in the Yanqi Basin, Xinjiang (China). *Environmental Monitoring and Assessment, 185*, 9729–9742.

Weng, Q. (2001). A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China. *International Journal of Remote Sensing, 22*, 1999–2014.

Wondrade, N., Dick, O. B., & Tveite, H. (2014). GIS based mapping of land cover changes utilizing multi-temporal remotely sensed image data in Lake Hawassa Watershed, Ethiopia. *Environmental Monitoring and Assessment, 186*, 1765–1780.

Xu, J. G., Liao, B. G., Shen, Q., Zhang, F., & Mei, A. X. (2007). Urban spatial restructuring in transitional economy—Changing land use pattern in Shanghai. *Chinese Geographical Science, 17*, 19–27.

Yagoub, M. M., & Kolan, G. R. (2006). Monitoring coastal zone land use and land cover changes of Abu Dhabi using remote sensing. *Journal of the Indian Society of Remote Sensing, 34*(1), 57.

Ye, Y., Zhang, H., Liu, K., & Wu, Q. (2011). Research on the influence of site factors on the expansion of construction land in the Pearl River Delta, China: By using GIS and remote sensing. *International Journal of Applied Earth Observation and Geoinformation*, *21*, 366–373.

Yin, Z.-Y., Stewart, D. J., Bullard, S., & MacLachlan, J. T. (2005). Changes in urban built-up surface and population distribution patterns during 1986–1999: A case study of Cairo, Egypt. *Computers, Environment and Urban System, 29*, 595–616.

Yin, J., Yin, Z., Zhong, H., Zu, S., Hu, X., Wang, J., & Wu, J. (2010). Monitoring urban expansion and land use/land cove changes of Shanghai metropolitan area during the transitional economy (1977–2009) in China. *Environmental Monitoring and Assessment, 177*, 609–621.

Yuan, F., Sawaya, K., Loeffelholz, B., & Bauer, M. (2005). Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multi-temporal Landsat remote sensing. *Remote Sensing of Environment, 98*(2–3), 317–328.

Zhang, Y., Lu, D., Yang, B., & Sun, C. (2011). Coastal wetland vegetation classification with a Landsat Thematic Mapper image. *International Journal of Remote Sensing, 32*(2), 545–556.