

# Urbanization and green space dynamics in Greater Dhaka, Bangladesh

Talukder Byomkesh · Nobukazu Nakagoshi · Ashraf M. Dewan

Received: 16 September 2009/Revised: 25 November 2010/Accepted: 26 November 2010/Published online: 8 February 2011  
© International Consortium of Landscape and Ecological Engineering and Springer 2011

**Abstract** Green space is particularly indispensable for proper functioning of the ecosystem in an urban environment. This study was an attempt to dynamically map and monitor green spaces in Greater Dhaka of Bangladesh. Both primary and secondary data were acquired to document the spatial–temporal dynamics of green spaces in the study area. Using a supervised classification algorithm, multi-temporal land use/cover data were extracted from a set of satellite images. A number of spatial metrics were employed to understand the landscape condition in a multi-temporal manner. In addition, 50 key informants along with focus group discussion and observation techniques were used to document existing management aspects of green spaces and their conservation policies. The analysis revealed that green spaces in Greater Dhaka are rapidly disappearing over the course of time even though they provide a number of natural, economic and social benefits. The disappearance of green spaces was primarily attributed to a rapid increase in the urban population, mainly driven

by rural–urban migration. As a result, the landscape became highly fragmented and less connected. A substantial reduction of green patches is also leading to deterioration of the ecological condition of the landscape. The drastic reduction of green spaces in Greater Dhaka has been attributed to a lack of policy, low political motivation, and poor management. In order to ensure sustainability of green spaces and proper functioning of the city’s ecosystem, there is an urgent need for strategic green space planning.

**Keywords** Green space · Remote sensing · Matrix · Green space benefits · Green space destruction

## Introduction

The ecological system of a city is made up of social, economical and natural systems where green spaces are the focal point (Huang and Chen 2002). They play a crucial role in cleaning the air, adjusting the microclimate, eliminating noise, beautifying the surroundings, etc. (Davis et al. 2008). Apart from these benefits, they also support the construction of high-quality human settlements, since green spaces act as the “lungs” of the city (Jim and Chen 2006).

Increasing urbanization is consistently blamed for the conversion of a great deal of green spaces into impermeable surfaces around the world, which has many detrimental effects on the environment (Mabuhay et al. 2005; Nakagoshi et al. 2006; Kong and Nakagoshi 2006; Phan and Nakagoshi 2007). As urbanization requires more and more infrastructure for housing, business and transport networks, the demand for such development is generally being met through the development of natural lands (e.g.,

---

T. Byomkesh  
Bangladesh Public Administration Training Centre (BPATC),  
Savar, Dhaka 1343, Bangladesh

N. Nakagoshi (✉)  
Graduate School for International Development  
and Cooperation, Hiroshima University,  
Higashihiroshima, Japan  
e-mail: nobu@hiroshima-u.ac.jp

A. M. Dewan  
Department of Spatial Sciences,  
Curtin University of Technology, Perth, Australia

A. M. Dewan  
Department of Geography and Environment,  
University of Dhaka, Dhaka, Bangladesh

cultivated lands, open spaces, water bodies, etc.), which ultimately results in a considerable reduction in the open and green areas of that region (Kong and Nakagoshi 2006; Swanwick et al. 2003). This trend is more critical in developing nations than in developed countries (Shi 2002). Greater Dhaka or the Dhaka Metropolitan Area in Bangladesh is no exception to this.

Urban green spaces are those lands that are covered with natural or man-made vegetation but are present in built-up areas (Kong and Nakagoshi 2006; Phan and Nakagoshi 2007). The definition of green space has long been argued, and a universally accepted definition of urban green spaces is still lacking. Most developed countries have their own definitions of urban green spaces, while Bangladesh is yet to formulate any. A working definition of urban green spaces is therefore necessary to move this work forward. Following a rigorous literature review and after consulting with the city authority and urban planners, we tried to define urban green spaces in the context of Bangladesh. Hence, the study considers green spaces to be those land surfaces that are comprised of both cultivated lands (agricultural areas, crop fields, fallow lands) and vegetation cover (deciduous forest, mixed forest lands, palms, conifers, shrubs, and others).

Dhaka has been experiencing the continuous destruction of its parks, vacant lands and green areas in response to rapid urban expansion ever since the independence of Bangladesh (Chowdhury and Faruqui 1989; Islam 1996). For instance, a recent study estimated that almost 80% of the land in Greater Dhaka was non-urban in the 1960s (i.e., it contained vegetation, open spaces, wetlands and cultivated lands), but this figure had been reduced to about 40% by 2005 (Dewan and Yamaguchi 2008; BCAS 2006). In contrast, historical records reveal that the city was well planned and superbly furnished with many parks and gardens during the Mughal period (DCC 2008). Dhaka's urban growth is primarily attributed to the rapid increase in the human population driven by rural to urban migration (SDNPBD 2005; Islam 1996, 2005). Because of the decreased man:land ratio, the unsustainable nature of the rural economy, and the scarcity of natural resources, the growth of the urban population has become a matter of great concern for local governments and policy makers of the country, as it consumes expensive arable lands. To accommodate its ever-increasing population, both public and private sectors are continuously developing natural lands within and on the outskirts of the city, without considering the environmental costs of this action. As a result, ecological sustainability is at stake, leading to the rapid deterioration of Dhaka's total environmental quality (Amin et al. 2008).

Growing evidence suggests that this consistent loss of natural habitat is not only making the city vulnerable to

natural hazards such as flooding (Dewan and Yamaguchi 2008; Dewan et al. 2007), but that it is also reducing the quality of life (Amin et al. 2008). For example, a huge growth in slum clusters in recent years is very apparent (CUS 2005), and this diminishes the city's social and aesthetic fabric. In particular, the regular loss of urban green spaces is leading to the loss of biodiversity and important species (BCAS 2006; Khan et al. 2004), contributing to the emergence of infectious diseases (Quadir 2010) and increasing atmospheric pollution (Khalequzzaman et al. 2007; Azad and Kitada 1998; Hasan and Mulamootil 1994), all of which ultimately have harmful effects on the urban ecology and humans. These environmental disturbances not lead to degraded functioning of the ecosystem, but they can also have serious effects on the climate of Dhaka, which can severely impact urban dwellers. Though it is generally perceived that urban greeneries are fast disappearing in the study area, little is known about urban green space dynamics and landscape structure. This study aims to fill this knowledge gap. To achieve a sustainable urban environment, including its growth, historical accounts of land-use changes and the structure of the landscape should provide valuable information for the planning and management of urban green areas. It may also be useful for informing future urban land-use planning.

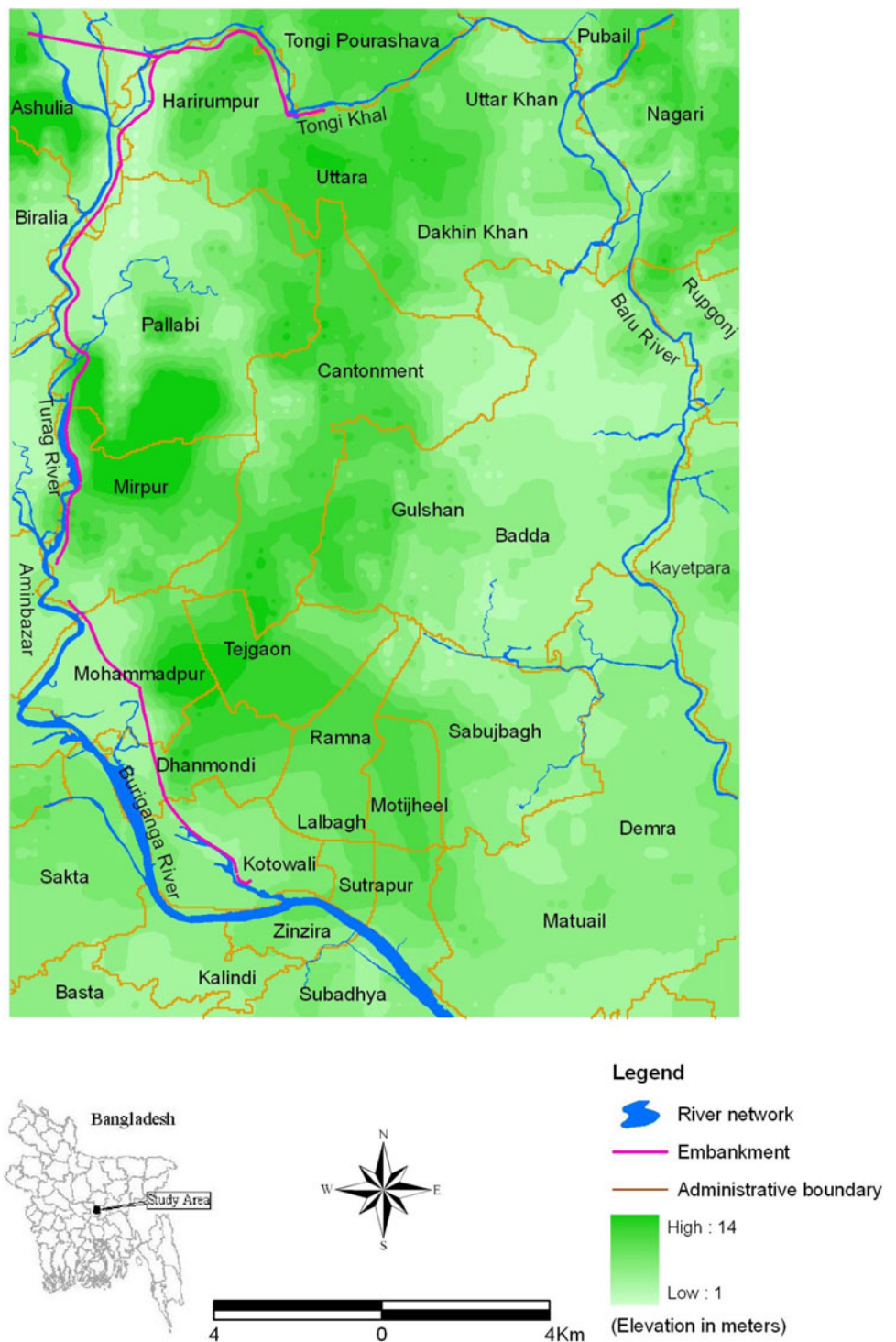
Considering the above facts, the objectives of this study were: (1) to quantify spatiotemporal changes in green spaces, (2) to analyze patterns in the condition of the landscape, in terms of its composition and configuration, and (3) to identify the major driving forces behind the changes in green spaces.

## Materials and methods

### The study area

This study considers Greater Dhaka, the capital of and largest metropolitan area in Bangladesh (Fig. 1). Geographically, the study area is located between latitudes 23°42' and 23°54'N and longitudes 90°20' and 90°28'E (JICA 1991). It is situated in the central region of the flat delta plain of the three major international rivers, namely the Ganges, the Brahmaputra and the Meghna, which enjoys distinct status in the national and regional hierarchies (Fig. 1). The area of investigation is surrounded by four major river systems: namely the Buriganga, Turag, Tongi and Balu. They flow to the south, west, north and east sides of the city (Fig. 1). Currently, the annual population growth rate of Dhaka is 5%, compared with the national average of 2.1% (BBS 2001). The process of urbanization in Dhaka is providing both challenges and

**Fig. 1** Location of the study area (Greater Dhaka)



opportunities. For instance, Dhaka contributes 19% of the gross domestic product (GDP) to the national economy (BBS 2001), and is playing a pivotal role in terms of socioeconomic development and cultural enhancement. It should be noted that the study area considered here represents a subset of the Dhaka Metropolitan Area (DMA), which encompasses an area of 1500 km<sup>2</sup> (BBS 1991).

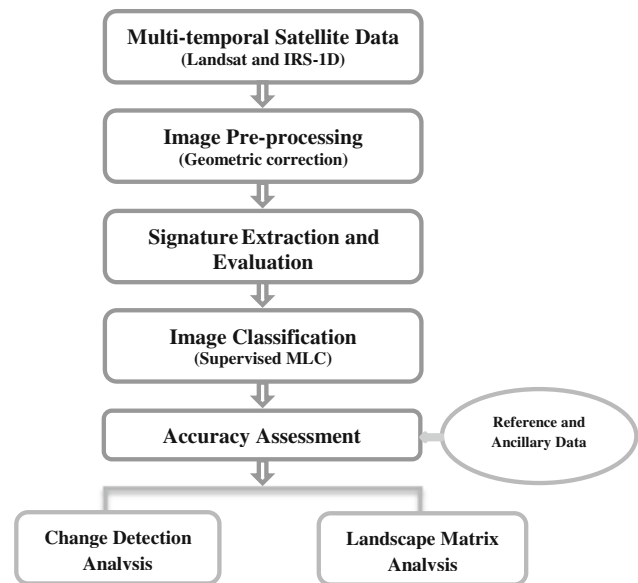
The data

Both primary and secondary data were used in this study. To understand the importance of green spaces and primary causes of loss, intensive field work was carried out in the study area, including face-to-face interviews, focus group discussions and observational techniques. Fifty key informants from different organizations were comprehensively

consulted so that an explicit understanding of the present status of green spaces and aspects of their management can be precisely documented. Prior to finalizing the questionnaire, a pilot survey was carried out in the study area. On the basis of the pilot survey, a questionnaire was formulated which constituted a number of open- and close-ended questions. Information pertaining to the current conditions of green spaces, environmental concerns, factors driving the changes in green spaces, and future management options were primarily recorded while interviewing key informants. It is worth noting that the key informants selected for this study were drawn from a range of professionals, including urban planners, researchers, architects, civil engineers, NGO activists, and high-level government officials. Apart from information gathering through interview, observational techniques (e.g., photographic assessments, tree density analysis) were also employed to evaluate the conditions of the urban green spaces. Members of the community in a number of areas in Greater Dhaka were considered for focus group discussions during field visits. In order to complement the primary data acquired through interview/observational methods, secondary information such as socioeconomic records, historical maps and research reports were also gathered from organizations relevant to the management of Greater Dhaka [e.g., the Dhaka City Corporation (DCC)].

Multi-temporal land-use and land-cover data are very important for studying the spatial and temporal conditions of green spaces (Irvine et al. 2010). It should be noted that Dhaka is greatly lacking in systematic records of land use and land cover data. For example, the area being investigated (Greater Dhaka) does not have any official statistics on land-use/cover patterns, and even the Master Plans are missing maps or quantitative statements on existing as well as historical land use/cover (Islam 1996, 2005). Therefore, this study solely relied on developing land use/cover data obtained using geospatial techniques.

Since data from Earth-observing satellites are an important alternative to (the absent) historical land-use records, a number of historical images from different platforms were acquired. To understand spatiotemporal changes in the green spaces in Greater Dhaka and the resulting landscape structure, remotely sensed data from the Landsat MSS (27 March 1975), Landsat TM (3 February 1988; 1 February 1999) and IRS-1D LISS III (26 December 2005) platforms were obtained and processed using both ArcGIS (ESRI 2005) and Erdas Imagine (Leica Geosystems 2006) software. The following section describes the procedures used to extract pertinent information from satellite images, which involved image preprocessing, reference data generation, analysis of images and accuracy assessment, in addition to the computation of green space dynamics and landscape composition and configuration (Fig. 2).



**Fig. 2** Flowchart of the methodology used in this study

### Analytical techniques

As there are unsystematic errors in commercially available remote sensing data, geometric correction was needed to subdue the errors. The images used in this study were first geometrically corrected using a Landsat TM image from 1997 as a reference. At least 61 well-distributed ground control points were used in the rectification process. The root mean square error (RMSE) varied from 0.25 to 0.45 pixels. Finally, a first-order polynomial fit was applied and all of the data were resampled to a pixel size of 30 m using the nearest neighbor method. The Bangladesh Transverse Mercator System (BTM) was used as the coordinate system; this is an area-specific standard UTM projection system for Bangladesh (EGIS/WARPO 1996).

Due to the retrospective nature of the study, a number of reference data were used to extract thematic information from remotely sensed data. Reference data for the 1975 MSS image were obtained from topographic maps (scale 1:50000) published by the Survey of Bangladesh (SOB) in 1973. The topographic maps were compiled from aerial photographs followed by ground truthing. In addition, the 1975 land-use map (scale 1:10000) from the Centre for Urban Studies (CUS 1975) was also obtained and used as reference. Topographic maps from 1991 and a SPOT panchromatic image from 1989 (10 m spatial resolution) were used to extract reference data for the land use/cover in 1988. The reference data were used for training area selection and for evaluating the results. The land-use map from 1991 (FAP 8A 1991) was also used to derive land-use/cover information from a Landsat TM image from 1988.

The 1999 reference data were obtained from one IRS-1D panchromatic image (with 5.8 m spatial resolution) from

February 2000. Additionally, topographic maps from 1997 and the Dhaka City Guide Map from 2001 (scale 1:20000) were used to locate training samples on the image and to check map accuracy. To assist with the analysis of the image from 2005, a number of strategies were employed. Firstly, an image from Google Earth<sup>®</sup> and a false color composite (FCC) of an IRS-1D LISS III image (RGB 321) depicting different land-cover types were printed on A0-size paper and taken into the field for data collection in 2008. In the field, these color hard copies were used to identify existing land-cover features, and particular attention was paid to spectrally similar land cover in IRS data. Thus, a ground truth map was prepared in order to locate training pixels on the image. Secondly, more than three hundred reference points were recorded by a handheld global positioning system (GPS) and put into a GIS to evaluate the accuracy.

A modified version of the Anderson Scheme Level I (Anderson et al. 1976) was adopted to evaluate urban green space dynamics, as this scheme is believed to produce superior results from medium-resolution satellite data in an urban setting (Shalaby and Tateishi 2007; Mundia and Aniya 2006; Yuan et al. 2005). Three separable land-use/cover types have been identified in this study: green spaces, built-up, and other land uses.

All of the remotely sensed images were thoroughly studied using spectral and spatial profiles to ascertain the digital numbers (DNs) of different land-cover categories prior to classification. Training samples were selected through reference data and the ancillary information mentioned above. Sixty to seventy training sites varying in size from 286 to 7800 pixels were used to train each of four images. Initially, the training samples for each class included 12–15 subclasses which eventually merged into three categories (i.e., built-up, green spaces, and other land uses). The training samples were then evaluated using class histogram plots. Training samples were refined, renamed, merged, and deleted after evaluating class histogram and statistical parameters. Note that the Landsat thermal band was excluded during the image analysis stage. A supervised maximum likelihood classification (MLC) algorithm was subsequently applied to each image; such an algorithm has generally been proven to yield superior results from remotely sensed data if each class has a Gaussian distribution (Bolstad and Lillesand 1991).

Misclassification was observed in the classified land-cover categories obtained from the supervised classification. For example, certain urban settlements were misclassified into the other land-use class due to their similar spectral properties. Likewise, classification error was noted between green spaces and the built-up category. Post-classification refinement was therefore used to improve the accuracy, as it is a simple, efficient and easy-to-implement method (Harris and Ventura 1995). As the urban surface is heterogeneous (Jensen 2000) and composed of a complex

combination of features (e.g., buildings, roads, grass, trees, soil, water), mixed pixels become a common problem in medium-resolution data (e.g., from Landsat). Despite this, Landsat continues to be an important source of data for urban applications across the world (Lu and Weng 2005). To surmount the mixed-pixel problem associated with green space identification, a normalized difference vegetation index (NDVI) was calculated from the Landsat data. Then, a rule-based technique using the NDVI, thematic information and GIS data (e.g., DEM, municipal map and water bodies, etc.) was employed in ERDAS's model maker to correct previously misclassified land-cover categories. The application of a rule-based technique greatly improved the MLC classification. Finally, a  $3 \times 3$  majority filter was applied to the classified land-cover data to reduce the salt-and-pepper effect (Lillesand and Kiefer 1999).

Generally, classification accuracy refers to the comparison of two datasets; one is based on the analysis of remotely sensed data, and the other is based on reference information (Congalton 1991). In order to assess the accuracy of green space maps extracted from Landsat and IRS data, a total of 200 stratified random pixels were first generated for each land-use map from 1975, 1988 and 1999. For the 2005 data, 310 points collected from the field were used. Using field data and the geographical features available on land-use maps, high-resolution images, and SOB topographic maps, an accuracy assessment was performed and the results were obtained in a confusion matrix. A nonparametric kappa test was also used to measure the classification accuracy, as it accounts for all of the elements in the confusion matrix rather than the diagonal elements (Rosenfield and Fitzpatrick-Lins 1986).

To determine the changes in the green spaces between years, a post-classification change detection comparison was used. Even though this technique presents few limitations (Singh 1989; Coppin et al. 2004), it is the approach most commonly used (Jensen 1996) to compare data from different sources and dates. An important advantage of post-classification comparison is that it bypasses the difficulties associated with the analysis of images acquired at different times of the year and/or by different sensors (Yuan et al. 2005; Coppin et al. 2004; Alphan 2003).

It is worth noting that only vegetation and cultivated lands are considered green spaces, and to quantify the spatio-temporal changes in green spaces among 1975, 1988, 1999 and 2005, land-use/cover maps derived from multi-temporal satellite data were employed. The annual rate of green space changes was then calculated using the formula below:

$$\text{Change rate of green spaces} = (UA_{i+n} - UA_i)/n,$$

where  $n$  is the length in years of the interval being assessed,  $UA_{i+n}$  is the green space area at time  $i + 1$ , and  $UA_i$  is the green space area at time  $i$ .

**Table 1** Landscape matrices selected in this study (see text for explanation)

Class level matrix					
Sl. no.	Name	Description	Formula	Range	Justification
1	Patch density (PD)	Abundance of patch types	$PD = \frac{n_i}{A}(10,000)(100)$ , $n_i$ is the number of patches in the landscape of patch type (class) $i$ ; $A$ is the total landscape area ( $m^2$ )	$PD > 0$ , constrained by cell size PD is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch. Therefore, cell size will ultimately determine the maximum number of patches per unit area. However, the maximum density of patches of a single class is attained when every other cell is of that focal class (i.e., in a checkerboard manner; because adjacent cells of the same class would be in the same patch)	Dominance index
2	Number of patches (NP)	Total number of patches in the class level	$NP = n_i$ , $n_i$ is the number of patches in the landscape of patch type (class) $i$	$NP \geq 1$ , without limit $NP = 1$ when the landscape contains only 1 patch of the corresponding patch type; that is, when the class consists of a single patch	Fragmentation index
3	Largest patch index (LPI)	The area of the largest patch in the landscape divided by total landscape area and multiplied by 100	$LPI = \frac{\max_{ij}(a_{ij})}{A}(100)$ , $a_{ij}$ is the area ( $m^2$ ) of patch $ij$ ; $A$ is the total landscape area ( $m^2$ )	$0 < LPI \leq 100$ LPI approaches 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; that is, when the largest patch comprises 100% of the landscape	Dominance index
4	Area-weighted mean shape index (SHAPE_AM)	Shape index adjusted for size	$AM = \sum_{j=1}^n \left[ X_{ij} \left( \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \right) \right]$ , AM (area-weighted mean) equals the sum, across all patches of the corresponding patch type, of the corresponding patch metric value multiplied by the proportional abundance of the patch [i.e., patch area ( $m^2$ ) divided by the sum of patch areas]		Fragmentation index
5	Patch cohesion index (COHESION)	Less physically connected	$COHESION = \left[ 1 - \frac{\sum_{j=1}^n p_{ij}}{\sum_{j=1}^n p_{ij} \sqrt{a_{ij}}} \right] \left[ 1 - \frac{1}{\sqrt{A}} \right]^{-1}$ , $p_{ij}$ is the perimeter of patch $ij$ in terms of the number of cell surfaces; $a_{ij}$ is the area of patch $ij$ in terms of number of cells; $A$ is the total number of cells in the landscape	$0 \leq COHESION < 100$ COHESION approaches 0 as the proportion of the landscape comprised of the focal class decreases and becomes increasingly subdivided and less physically connected. COHESION increases monotonically as the proportion of the landscape comprised of the focal class increases until an asymptote is reached near the percolation threshold (see background discussion). COHESION is given as 0 if the landscape consists of a single non-background cell	A measure of physical connectedness

Adapted from McGarigal et al. (2002)

To determine the impact of green spaces alteration on the landscape structure, we considered a range of spatial metrics using the FRAGSTATS<sup>®</sup> program (McGarigal and Marks 1995; McGarigal et al. 2002). Since many of the

indices overlap substantially with each other (Apan et al. 2002), we selected metrics (on the basis of a literature review) that are capable of elucidating landscape fragmentation (Turner 1989; Gardner and O'Neill 1991; Baker

and Cai 1992; Voller and Harrison 1998; Hessburg et al. 1999; Dorner et al. 2002; Xi and Cho 2006). Indices such as patch density (PD), number of patches (NP), largest patch index (LPI), area-weighted mean shape index (SHAPE\_AM) and patch cohesion index (COHESION) were computed to discern the temporal dynamics in green spaces composition and landscape configuration (Table 1).

## Results

### Results of key informant interviews, focus group discussions and field surveys

Among the world's major cities, Greater Dhaka probably has the lowest number of playgrounds, parks, open spaces and swimming pools per capita (Hossain 2006). Since the environment of the city constitutes sharp physical and social divisions, provisions for preserving existing green spaces and/or the creation of new green areas have not been considered in any of the Master Plans devised earlier (Siddiqui et al. 2000). In recognizing the importance of green spaces to the environment, the Structure Plans of 1995–2015 strongly recommended the construction of new green areas, and also suggested that the present greeneries should be preserved (SDNPBD 2005). It is, however, surprising that there are no set rules/policies devised by the authority concerned that are intended to save the green spaces of Greater Dhaka in order to promote a sustainable urban environment. It is important to mention that according to the Chief Town Planner of DCC, the study area has only 8% tree coverage, while an ideal city needs at least 20% green spaces to attain a healthy urban environment (field study, personal communication, 2008). Currently, the Botanical Garden, Suhrawardy Udyan and Ramna Park are the three major green patches in the city. Apart from those, other noticeable green patches include the National Parliament Bhaban, Chandrima Park, Bahadur Shah Park, and the National Zoo. These green patches collectively represent a small proportion of the total study area, which is fairly inadequate in terms of the population:green space ratio. Field visits of these parks in the daytime confirmed that they are mostly occupied by homeless people and various types of hawkers, which has made them unsafe for city dwellers to use, as reported by the individual communities. In addition, local governments do not have good logistics to manage them effectively, as revealed by conversations with key informants. Hence, there is an urgent need to develop suitable policies and countermeasures for the management of existing green spaces. Involving local people in the management process and educating them on the importance of green spaces are deemed to be particularly important for the safe and sound

management of these expensive natural and cultural lands. Moreover, new green patches should be built to save the environment, as field work signifies that the percentage green space is too low for this highly populous megacity.

Field observations also revealed that the density of trees is very low across the green patches of Greater Dhaka (Fig. 3a, b). Only the vegetation patch located in Ramna Thana (Ramna Police Station) was found to have dense vegetation. Ramna Park, Suhrawardy Udyan and the Dhaka University campus, all established during the British periods, are also important green spaces with considerable tree density. An important initiative by the authority was its drive to increase greeneries by planting trees along roadsides, in existing parks, and in the suburbs (Fig. 3c, d). For instance, during 1993–2005, 95,000 trees were planted in Greater Dhaka (JICA 2005). From 1993 to 1995, DCC together with the Forest Department planted trees across an area of 75.5 km along roadsides, footpaths and on road dividers, and on 73.3 ha of open land in Greater Dhaka. According to the Project Director of the Infrastructure Development and Environmental Improvement Project of DCC, in 2002 the DCC targeted 45,000 tree plantations in the study area, but due to a scarcity of vacant lands, only 29,000 trees were planted. In 2003, DCC aimed to plant 6000 trees to replace those that were somehow destroyed, and a further 10,000 trees in whatever spaces were available in the Uttara and Mirpur areas, but there is no record of the number of trees that were actually planted.

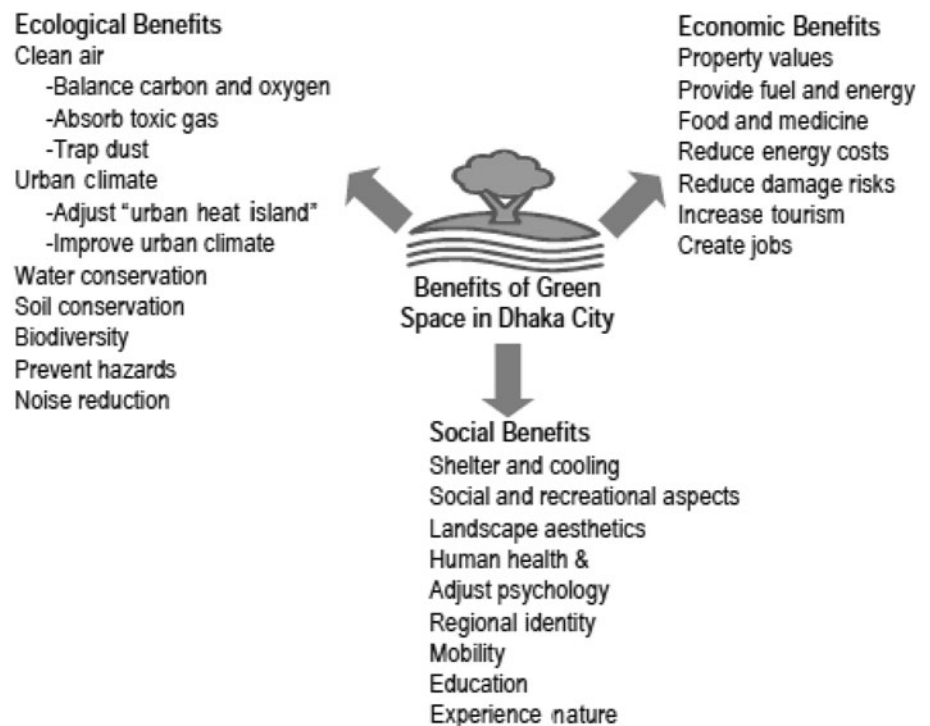
There are about 50 parks and open spaces in Dhaka, among which DCC owns 46. Some of the parks are already occupied by homeless people and hawkers, and some have been converted to temporary markets, bus stops, slums, etc. Of the total area, only 14.5% on average (17% in the north and central parts and 12% in the southern part) is open space, while 25% open space is believed to be required to support environmental sustainability in a city (UNEP 2006).

Miller (1996) categorized the functions of urban green spaces into three categories: architecture and aesthetics, climate, and engineering functions. During field visits and interviews, it was found that there has been a tendency to adopt this concept for sustainable development in Bangladesh, with particular emphasis placed on the aspects of ecology, society, and economy. This is perhaps a good indication. In consultation with various key informants and pertinent literature, the comprehensive benefits of urban green spaces for Greater Dhaka have been conceptualized and are shown in Fig. 4. This figure may be used to understand the types of benefits a city can receive from larger greeneries. For instance, green spaces in Greater Dhaka can provide a number of ecological benefits that are believed to be invaluable for human health as well as for the environment. Green patches are useful for cleaning the

**Fig. 3** Green spaces in Greater Dhaka (clockwise: **a** park near the National Parliament; **b** Ramna Park; **c** new trees planted along the roadside; **d** new trees in National Monument Park)



**Fig. 4** Conceptualization of the benefits of green spaces



air by balancing carbon and oxygen, absorbing toxic gas, trapping dust, regulating the urban climate, minimizing heat island effects, conserving water and soil, conserving biodiversity, preventing hazards, and reducing noise pollution. Economically, green spaces provide fuel and energy, sources of foods and medicine, and can be important for alleviating poverty. The green spaces of Dhaka also have important social benefits, as they provide

shelter and shade in workplaces in the summer, as well as social and recreational facilities, etc.

#### Green space dynamics

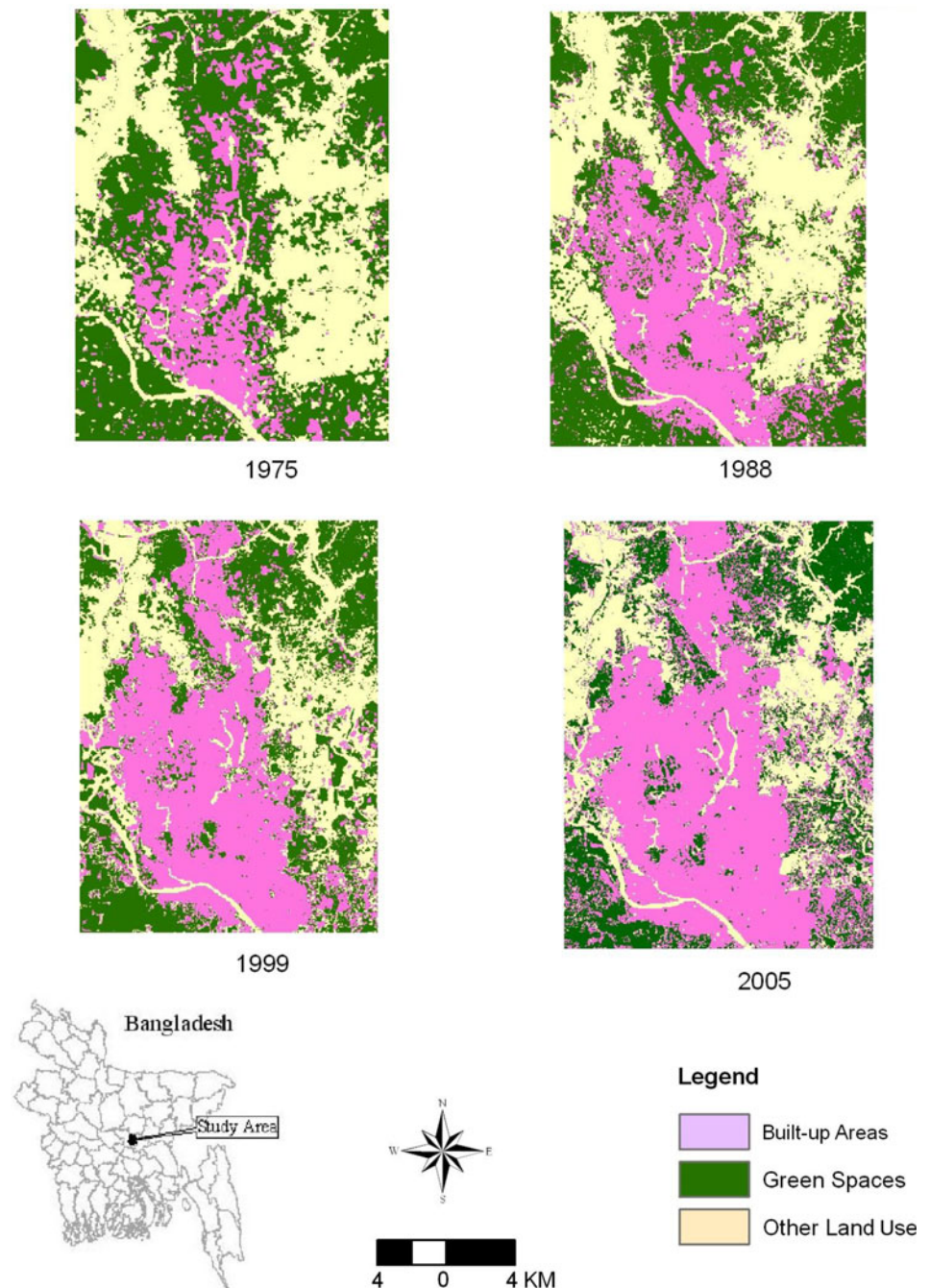
The extraction of green spaces along with other land-use classes from multi-temporal satellite data provided valuable information on the dynamics of green spaces in



Greater Dhaka during 1975–2005 (Fig. 5). This figure clearly depicts how green spaces are disappearing in the study area over the course of time. Post-classification change detection analysis showed a sizeable reduction in green spaces in the last 30 years. For example, it was found that there were 18,626 ha of green spaces in the study area in 1975, which had decreased to 14,818 ha by 1988 (Table 2). Thus, after 13 years (1975–1988), the amount of green space had decreased by 20.4%. By 1999, the area of green spaces had reduced still further, to 12,966 ha, indicating a 12.5% loss in 11 years. In 2005, the green space

amounted to about 10,009 ha, and the rate of change surpassed the previous record from 1999 (22.8%). In 1975, green spaces occupied 44.8% of the total study area, which dropped to 35.7%, 31.2% and 24.1% in 1988, 1999 and 2005, respectively. On the other hand, the built-up area expanded from 13.4% (5550 ha) to 49.4% (20,549 ha) from 1975 to 2005. In other words, the net increase in urban area was 14,999 ha over the study period (1975–2005), suggesting a huge growth in the human landscape and a subsequent reduction in the natural landscape, which obviously indicates the magnitude of the

**Fig. 5** Spatiotemporal changes in green spaces in Greater Dhaka



**Table 2** Land-use/cover conversion in the study area (1975–2005) (see text for explanation)

Land-use/cover type	1975		1988		1999		2005	
	Area	%	Area	%	Area	%	Area	%
Green spaces	18626.0	44.8	14818.7	35.7	12966.6	31.2	10009.7	24.1
Built-up	5550.5	13.4	11928.2	28.7	15913.4	38.3	20549.7	49.4
Other category	17387.5	41.8	14817.1	35.6	12684.0	30.5	11004.6	26.5
Total	41564.0	100.0	41564.0	100.0	41564.0	100.0	41564.0	100.0

Area in hectares

**Table 3** Summary of PA, UA and kappa statistics (%) for each land-use/cover category for 1975, 1988, 1999 and 2005 (see text for explanation)

Land-use/cover class	1975			1988			1999			2005		
	PA	UA	$K_{\text{hat}}$	PA	UA	$K_{\text{hat}}$	PA	UA	$K_{\text{hat}}$	PA	UA	$K_{\text{hat}}$
Green spaces	95.0	85.6	75.7	78.8	94.4	90.2	87.3	88.7	83.5	85.1	91.95	85.4
Built-up	61.7	87.9	84.2	77.6	65.5	79.5	88.5	89.6	82.9	90.1	87.5	75.9
Other category	90.3	84.4	75.7	98.4	85.9	79.6	96.6	93.4	90.7	100.0	78.9	77.3

Units are given in percent

PA producer's accuracy, UA user's accuracy,  $K_{\text{hat}}$  kappa statistics

anthropogenic activities that occurred during that period. Interestingly, green spaces also witnessed spectacular changes during 1988–1999, amounting to a net loss of 1852. To accommodate the 4636 ha of growth in built-up areas during this time, a great deal of vegetative cover was converted to urban land (Fig. 5). This analysis confirmed that urban green spaces are rapidly being converted in order to meet up the rising demands of urban built-up areas in Greater Dhaka. For example, a total of 8617 ha of green space were lost in response to the increase in urban built-up area and other categories from 1975 to 2005 (Table 2).

#### Accuracy of the land-use/cover maps

An assessment of the classification accuracy of the maps derived from satellite data was carried out using referenced data acquired from diverse sources. Error matrices were used to assess the classification accuracy, and these are summarized for all four years in Table 3. The producer's accuracy, the user's accuracy and the kappa statistics for each land-use class are presented in Table 3. The overall accuracies for 1975, 1988, 1999 and 2005 were 85.50, 86.50, 90.4, and 88.57%, and their corresponding kappa statistics were 77.36, 79.61, 85.65, and 79.95%. The producer's accuracy and the user's accuracy were also consistently high, ranging from 61 to 100% (Table 3).

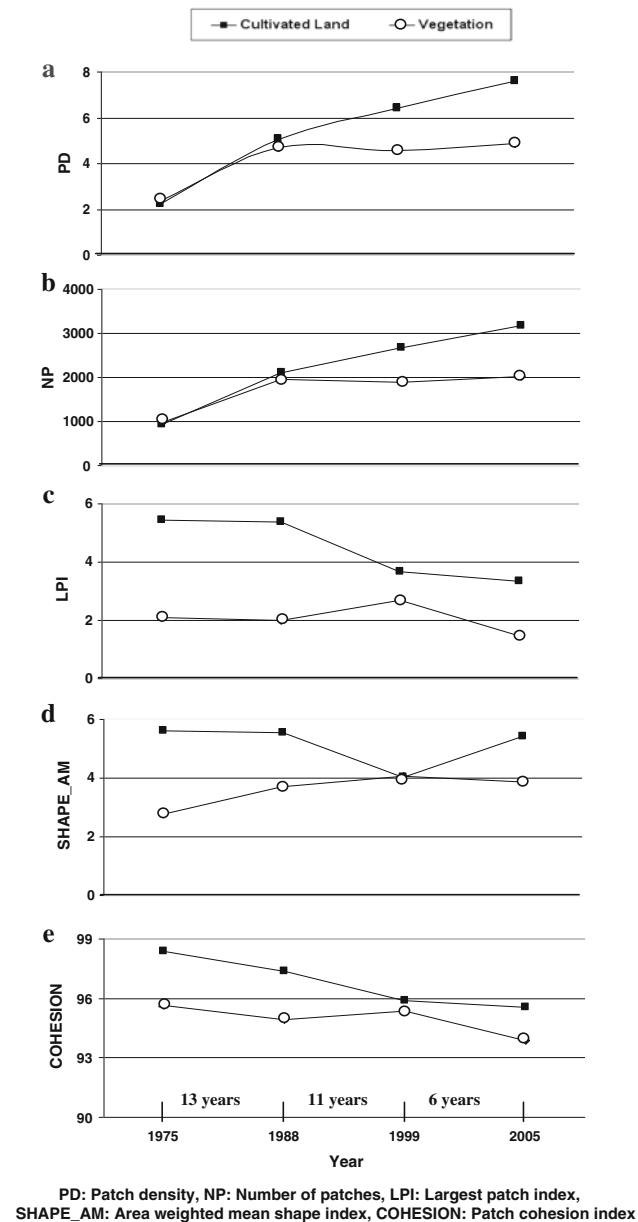
#### Configuration and composition of green spaces

The PD reflects the dominance of patch numbers of vegetation and cultivated land (Kong and Nakagoshi 2006),

and it is an important index for assessing landscape fragmentation (Luck and Wu 2002). The PD increased greatly for both vegetation and cultivated land (Fig. 6a), meaning that there were numerous unconnected small patches of vegetation and cultivated land, greater isolation, and a higher percentage of edge area in patches. Thus, the study resembles the findings of Kamusoko and Aniya (2007). They also reported that the increasing level of human activity was leading to landscape fragmentation in Zimbabwe.

NP indicates the total NP for a particular class level. The trend for increasing NP for cultivated land and vegetation indicates that the green spaces of the study area are already highly fragmented and are moving towards even more fragmentation. If this trend continues the patches of green areas in Greater Dhaka will be come less connected and more isolated (Fig. 6b). The increasing pace of urban development may have resulted in this large NP (Seto and Fragkias 2005).

LPI is a simple measure of dominance (McGarigal et al. 2002). The LPI for both vegetation and cultivated land is decreasing (Fig. 6c), meaning that there are fewer large patches of vegetation and cultivated land. For example, smaller LPI values in conjunction with the larger NP reveal that the landscape has become fragmented at the landscape level. In other words, it shows that the landscape tends to become finer grained as the pace of human activity in Greater Dhaka continues to accelerate. The SHAPE\_AM of the green spaces was somewhat surprising compared to the other indices. A number of studies suggest (e.g., Luck and Wu 2002; Gulinck and Wagendorp 2002) that intense



**Fig. 6** Temporal changes in spatial metrics in the green spaces of Greater Dhaka City

human disturbance could elevate the shape complexity of the landscape with the increasing dominance of one patch type (e.g., urban built-up). Though PD, NP and LPI indicate that the increase in built-up land leads to high fragmentation, the SHAPE\_AM result must be interpreted carefully. For instance, the SHAPE\_AM index increased for the vegetation class until 1999, while it constantly decreased for cultivated land cover from 1975 to 1999 (Fig. 6d). The decrease in the cultivated land category indicates that the shapes of the patches became more complex between 1975 and 1999. In contrast, the vegetation class showed an increasing trend from 1975 to 1999,

suggesting that this cover alone responded quite differently, due to the increase in the patch shape complexity of the cultivated land cover. However, an interesting trend can be observed after 1999 for SHAPE\_AM. For example, the index increased in 2005 for cultivated land while it slightly decreased for vegetation. This can be explained by the fact that the shape complexity of the vegetation cover became convoluted after 1999 (Thapa and Murayama 2009). Further research is required to understand the actual reason for the different behaviors of these two categories when analyzed individually. The physical connectivity of the green spaces decreased over the course of time, as indicated by the COHESION index (Fig. 6e). This revealed that the cohesion values for cultivated land and vegetation consistently dropped, indicating that the patches of the land types are becoming physically less connected (Herold et al. 2003). At the same time, subdivision among patch types increased, as identified by the low cohesion values for both categories.

## Discussion and conclusions

Based on spatiotemporal green space dynamics, it was found that the green spaces of Greater Dhaka are rapidly decreasing. Estimates of green spaces using satellite images from 1975 to 2005 revealed that the rate of change in green spaces was consistently high, and in the last 30 years a total loss of 8617 ha was observed in comparison to the base year of 1975. At present, Dhaka's urban infrastructure is highly stressed due to overpopulation (15 million people), and the population is increasing by several hundreds of thousands every year as migrants move into the city seeking work and better jobs. As a result, green spaces are infringed and transformed into buildings and other infrastructures, resulting in more urban lands. Luck and Wu (2002) recognized that urbanization is one of the most important driving forces behind land-use and land-cover changes in Jinan City (China). Kong and Nakagoshi (2006) reported that the driving forces are the policies that affect the development and management of urban green spaces. The causes of these changes in green spaces in the study area were identified. Among them, rapid population growth driven by rural–urban migration, economic development, and a lack of awareness among policymakers and city dwellers are contributing factors. In addition, the use of political power to influence the illegal conversion and leasing of parks, a lack of appropriate rules and regulations to protect urban green spaces, a limited budget for the management of urban green spaces, and the introduction of alien species are also factors that contribute to the reduction of green patches in Greater Dhaka.

The total population of Dhaka increased from 1.98 to 9.91 million between 1974 and 2001, an increase of 400% over this period (BBS 1997, 2001). In 2000, it was the 11th most populous city in the world, but it is forecast to be the world's fourth largest megacity by population by 2015 (Lizin 2002). In 1991, the population density of Dhaka was 15,333 persons per km<sup>2</sup>; in 2001 it was an estimated 18,055 persons per km<sup>2</sup> (BBS 2001). In 1975, there were 5550 ha of built-up areas, and in 2005 this figure shot up to 20,549 ha. This obviously indicates the rate of natural land transformation in the study area.

The economy of Bangladesh is controlled by its capital. It attracts a large number of rural migrants. Records show that the GDP of Dhaka was \$52 billion in 2005, with an annual growth rate of 6.1%. The estimated GDP in 2020 is \$126 billion. The annual per capita income of Dhaka is estimated to be \$550, although a large segment of the population live below the line of poverty, with many surviving on less than \$3 a day (Lawson 2002). At present, Greater Dhaka is enjoying strong growth in the finance, banking, manufacturing, telecommunications and service sectors. This development will have a tremendous impact on future land-use patterns; it is believed that this growth will create enormous pressure on the existing green spaces. The reduction of green spaces is also producing poor-quality landscape with irregular patches and an uneven distribution, and the drastic changes in the green spaces in the study area are primarily responsible for the decline in ecoservice quality.

As mentioned above, the presence of green spaces in the study area is beneficial not only from an ecological point of view but also from the perspective of maintaining the quality of life of urban residents. Green spaces may also benefit an urban ecosystem by reducing the costs of heating and cooling buildings. The extent and quality of the urban green space can have important effects on the provision of ecosystem services (e.g., climate regulation), ecosystem resilience, and biodiversity. Since Dhaka is expanding very rapidly, the importance of green spaces should not be ignored; proper planning should be devised immediately. This study confirmed that green space management in urban Dhaka is mostly negligible. However, to ensure quality of life and to enable the region to adapt to climate change, more emphasis should be placed on creating new greeneries and preserving existing green patches. During field visits, we noticed substantial mismanagement of green spaces in the study area. In order to support the proper functioning of the ecosystem and to maintain the ecological balance of Dhaka, a comprehensive green space management strategy needs to be formulated in which existing green spaces (e.g., Chandrimala Udyan, Bahadur Shah Park, the National Zoo, Suhrawardy Udyan, Ramna Park) should be included, in order to ensure their effective management.

In addition, awareness should be raised by educating people about the role and importance of green spaces in a healthy environment. It is worth noting that immediately planning such strategies for green space management would greatly contribute to the sustainability and livability of the community, and enhancing green areas has the potential to mitigate the adverse effects of urbanization.

An accuracy assessment of land-use/cover data revealed that Landsat MSS yielded the lowest overall accuracy (85.5%) among the datasets. It should be noted that the MSS imagery is too coarse to study the land cover of an urban environment, so the accuracy drops due to mixed pixels (Haack 1987). However, the examination of land-cover data accuracy revealed that all of the datasets met the minimum USGS total accuracy target set by Anderson et al. (1976), so the application of the rule-based post-classification refinement was found to be effective. It is important to mention here that all of the images used in this study were obtained during winter, so data from other seasons should also be considered in order to determine seasonal spectral properties as well as the land-use/cover change characteristics of a highly dynamic urban environment. Moreover, the study could not employ high-resolution images (e.g., IKONOS), which are believed to be effective for studying the urban environment. Since the provision of aerial photographs to the public is strictly prohibited in Bangladesh by the SOB, high-resolution images could be a good alternative for extending the study.

Spatial metrics analysis indicated sharp changes in the composition and configuration of green spaces, as manifested by the increases in PD and NP and the decrease in LPI. The LPI of cultivated land and vegetation was higher in 1975 than in 2005. This supports the results for land-use changes obtained from multi-temporal satellite data, and implies that the continuous disturbances that are occurring on this surface are making the green areas highly fragmented. From 1975 to 2005, COHESION decreased to 84.81% for cultivated land and to 71.82% for vegetation, suggesting a decreasing trend in physical connectivity for urban green spaces.

In conclusion, green space dynamics and spatial metrics analyses are imperative for understanding the landscape ecological conditions of urban green spaces. This study revealed that the green spaces of Greater Dhaka are decreasing over the course of time, and are also becoming highly fragmented due to the increasing pace of human activity in this region. This activity is not only causing the destruction of landscape ecological processes and services, but is also eroding the biodiversity in urban areas. Moreover, consistent landscape fragmentation can result in a poor quality of life in the urban environment. Therefore, a comprehensive green space management strategy should be implemented for Greater Dhaka that could support

proper functioning of the ecosystem. As reliable and updated data are greatly lacking in Bangladesh, the green space maps produced in this study can contribute to the development of sustainable urban land-use planning decisions that target a sound and healthy urban environment.

**Acknowledgments** We greatly acknowledge the support in the form of a research grant from the International Foundation for Science (IFS), Sweden, in which the third author leads a project as PI (Project Ref: W4656-1). We are grateful to the GELs programme of IDEC, Hiroshima University, for inviting us to their summer seminar (5–21 August 2009), which encouraged us to develop this paper. Our special thanks go out to the Government of Bangladesh and the Bangladesh Public Administration Training Centre for allowing us to use their logistics support. We are also grateful to Prof. Jhonamie Mabuhay for her constructive suggestions and English corrections. This research was one of the Asian City Projects of Hiroshima University. This research was partially funded by the Twenty-First Century Center of Excellence (COE) Program for Social Capacity Development for Environmental Management and International Cooperation at the Graduate School for International Development and Cooperation, Hiroshima University, Japan. Finally, constructive suggestions from three anonymous referees are gratefully acknowledged, as they helped us to substantially improve this manuscript.

## References

- Alphan H (2003) Land use change and urbanization in Adana, Turkey. *Land Degrad Dev* 14(6):575–586
- Amin SMN, Dewan AM, Kabir MH (2008) Urban development and environmental degradation: the case of Dhaka metropolitan, Bangladesh. In: Annual Meeting of the Association of American Geographers, Boston, MA, USA, 15–19 April 2008
- Anderson R, Hardy EE, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data (USGS Professional Paper 964). USGS, Sioux Falls
- Apan AA, Raine SR, Paterson MS (2002) Mapping and analysis of changes in the riparian landscape structure of the Lockyer Valley catchment, Queensland, Australia. *Landscape Urban Plan* 59:43–57
- Azad AK, Kitada T (1998) Characteristics of the air pollution in the city of Dhaka, Bangladesh in winter. *Atmos Environ* 32(11):1991–2005
- Baker WL, Cai Y (1992) The rule programs for multi-scale analysis of landscape structure using the GRASS geographical information system. *Landscape Ecol* 7:291–302
- BBS (1991) Bangladesh population census 1991, Zila: Dhaka. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka
- BBS (1997) Bangladesh population census 1991. Urban Area Report, Dhaka: Statistics Division. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka
- BBS (2001) National population census 2001: preliminary report. Bangladesh Bureau of Statistics, Ministry of Planning, Dhaka
- BCAS (2006) Dhaka City State of Environment. Bangladesh Centre for Advanced Studies, Dhaka
- Bolstad PV, Lillesand TD (1991) Rapid maximum likelihood classification. *Photogramm Eng Remote Sens* 57:67–74
- Center for Urban Studies (CUS) (1975) Generalized land use map of Dhaka City. CUS, Dhaka
- Center for Urban Studies (CUS) (2005) National Institute of Population, Research and Training (NIPORT) and MEASURE evaluation: slums in urban Bangladesh; mapping and census, 2006. CUS, Dhaka
- Chowdhury AM, Faruqui S (1989) Physical growth of Dhaka City. In: Ahmed SU (ed) Dhaka: past, present and future. The Asiatic Society of Bangladesh, Dhaka, pp 43–61
- Congalton RG (1991) A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sens Environ* 37:35–46
- Coppin P, Jonckheere I, Nackaerts K, Muys B, Lambin E (2004) Digital change detection methods in ecosystem monitoring: a review. *Int J Remote Sens* 25(9):1565–1596
- Davis RG, Barbosa O, Fuller RA, Tratalos J, Burke N, Lewis D, Warren PH, Gaston KJ (2008) City-wide relationships between green spaces, urban land use and topography. *Urban Ecosyst* 11:269–287
- DCC (2008) History of Dhaka City Corporation. DCC, Dhaka
- Dewan AM, Yamaguchi Y (2008) Effect of land cover change on flooding: example from Greater Dhaka, Bangladesh. *Int J Geoinform* 4(1):11–20
- Dewan AM, Islam MM, Kumamoto T, Nishigaki M (2007) Evaluating flood hazard for land-use planning in Greater Dhaka of Bangladesh using remote sensing and GIS techniques. *Water Resour Manag* 21(9):1601–1612
- Dorner B, Lertzman K, Fall J (2002) Landscape pattern in topographically complex landscapes: issues and techniques for analysis. *Landscape Ecol* 17:729–743
- EGIS/WARPO (1996) Datum and map projections for GIS and GPS applications in Bangladesh (Technical Note 10). Water Resources Planning Organization, Government of Bangladesh, Dhaka
- Environmental System Research Institute (ESRI) (2005) Using ArcGIS. ESRI, Redlands
- Flood Action Plan (FAP) 8A (1991) Master plan study for Greater Dhaka protection project. Japan International Cooperation Agency, Dhaka
- Gardner RH, O'Neill RV (1991) Pattern, process, and predictability: the use of neutral models for landscape analysis. In: Turner MG, Gardner RH (eds) Quantitative methods in landscape ecology. Springer, New York, pp 289–307
- Gulick H, Wagendorp T (2002) References for fragmentation analysis of the rural matrix in cultural landscapes. *Landscape Urban Plan* 58:137–146
- Haack B (1987) An assessment of Landsat MSS and TM for urban and near-urban digital classification. *Remote Sens Environ* 21(2):201–213
- Harris PM, Ventura SJ (1995) The integration of geographic data with remotely sensed imagery to improve classification in an urban area. *Photogramm Eng Remote Sens* 61(8):993–998
- Hasan S, Mulamootil G (1994) Environmental problems of Dhaka City. *Cities* 11(3):195–200
- Herold M, Goldstein NC, Clarke KC (2003) The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sens Environ* 86:286–302
- Hessburg PF, Smith BG, Salter RB (1999) Detecting change in forest spatial patterns from reference conditions. *Ecol Appl* 9:1232–1252
- Hossain S (2006) Social characteristics of a megacity: a case of Dhaka City, Bangladesh. In: Proc TASA 2006 Conf, Perth, Australia, 4–7 Dec 2006
- Huang G, Chen Y (2002) *Ecocity: theory and design approach*. Science Press, Beijing (in Chinese)
- Irvine KN, Richard AF, Patrick D-W, Jamie T, Sarah RP, Philip HW, Kevin JL, Kevin JG (2010) Ecological and psychological value of urban green space. In: Jenks M, Jones C (eds) Dimensions of the sustainable city. Springer, Berlin
- Islam N (1996) Dhaka: from city to megacity: perspectives on people, places, planning and development issues. Urban Studies Program, Dhaka

- Islam N (2005) Dhaka now: contemporary development. The Bangladesh Geographical Society, Dhaka
- Japan International Cooperation Agency (JICA) (1991) Master plan for Greater Dhaka food protection project FAP 8A (Main Report and Supporting Report II). Flood Plan Coordination Organization (recently WARPO), Dhaka
- Japan International Cooperation Agency (JICA) (2005) The study on solid waste management in Dhaka City (Clean Master Plan, Final Report). JICA, Dhaka
- Jensen JR (1996) Introductory digital image processing: a remote sensing perspective. Prentice Hall, Upper Saddle River
- Jensen JR (2000) Remote sensing of the environment: an earth resource perspective. Prentice Hall, Upper Saddle River
- Jim CY, Chen WY (2006) Perception and attitude of residents toward urban green spaces in Guangzhou (China). *Environ Manag* 38(3):338–349
- Kamusoko C, Aniya M (2007) Land use/cover change and landscape fragmentation analysis in the Bindura District, Zimbabwe. *Land Degrad Dev* 18:221–233
- Khalequzzaman M, Kamijima M, Sakai K, Chowdhury NA, Hamajima N, Nakajima T (2007) Indoor air pollution and its impact on children under five years old in Bangladesh. *Indoor Air* 17(4):1–8
- Khan NA, Choudhury JK, Huda KS (2004) Forestry sector review report. Bangladesh Forest Department, Ministry of Environment and Forest, Dhaka
- Kong F, Nakagoshi N (2006) Spatial-temporal gradient analysis of urban green spaces in Jinan, China. *Landscape Urban Plan* 78:147–164
- Lawson A (2002) Good times for bourgeois Bangladeshis. [http://news.bbc.co.uk/2/hi/south\\_asia/2018535.stm](http://news.bbc.co.uk/2/hi/south_asia/2018535.stm), accessed 15 July 2009
- Leica Geosystems (2006) ERDAS IMAGINE tour guides. Leica Geosystems Geospatial Imaging, Norcross
- Lillesand TM, Kiefer RW (1999) Remote sensing and image interpretation. Wiley, New York
- Lizin AM (2002) City-to-city networking to fight poverty. In: UNDP (ed) Choices magazine. UNDP, New York
- Lu Q, Weng D (2005) Urban classification using full spectral information of Landsat ETM+ imagery in Marion County, Indiana. *Photogramm Eng Remote Sens* 71(11):1275–1284
- Luck M, Wu J (2002) A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecol* 17:327–339
- Mabuhay J, Isagi Y, Nakagoshi N (2005) Ecological indicators of biodiversity in tropical urban green spaces. *WSEAS Trans Environ Dev* 1:85–91
- McGarigal K, Marks BJ (1995) FRAGSTATS: spatial pattern analysis program for quantifying landscape structure (Gen Tech Rep PNW-GTR-351). Pacific Northwest Research Station, USDA Forest Service, Portland
- McGarigal K, Cushman SA, Neel MC, Ene E (2002) FRAGSTATS: spatial pattern analysis program for categorical maps. *Comp software prog Univ Mass. Amherst*. <http://www.umass.edu/landeco/research/fragstats/fragstats.html>
- Miller WR (1996) Urban forestry: planning and managing urban green spaces. Prentice Hall, Upper Saddle River
- Mundia CN, Aniya M (2006) Dynamics of land use/cover changes and degradation of Nairobi City, Kenya. *Land Degrad Dev* 17(1):97–108
- Nakagoshi N, Watanabe S, Kim JE (2006) Recovery of green resources in Hiroshima City after World War II. *Landscape Ecol* 2:111–118
- Phan DU, Nakagoshi N (2007) Analyzing urban green space pattern and eco-network in Hanoi, Vietnam. *Landscape Ecol* 3:143–157
- Quadir DA (2010) Climate change and disease burden in Bangladesh. In: Dengue Symp, Dhaka, Bangladesh, 22–25 May 2010
- Rosenfield GH, Fitzpatrick-Lins K (1986) A coefficient of agreement as a measure of thematic classification accuracy. *Photogramm Eng Remote Sens* 52(2):223–227
- SDNPBD (2005) Green cities plan for the planet. Bangladesh Department of Environment, Dhaka
- Seto KC, Fragkias M (2005) Quantifying spatiotemporal patterns of urban land use change in four cities of China with time series landscape metrics. *Landscape Ecol* 20:871–888
- Shalaby A, Tateishi R (2007) Remote sensing and GIS for mapping and monitoring land cover and land use changes in the Northwestern coastal zone of Egypt. *Appl Geogr* 27(1):28–41
- Shi S (2002) Research on the urban spatial structure guided by the urban green space system. Central China University, Wuhan (in Chinese)
- Siddiqui K, Ahmed J, Awal A, Ahmed M (2000) Overcoming the governance crisis in Dhaka City. University Press, Dhaka
- Singh A (1989) Digital change detection techniques using remotely sensed data. *Int J Remote Sens* 10(6):989–1003
- Swanwick C, Dunnett N, Woolley H (2003) Nature, role and value of green spaces in towns and cities: an overview. *Built Environ* 29(2):94–106
- Thapa RB, Murayama Y (2009) Examining spatiotemporal urbanization patterns in Kathmandu Valley, Nepal: remote sensing and spatial metrics approach. *Remote Sens* 1:534–556
- Turner BL II (1989) The human causes of global environmental change. In: DeFries RS, Malone T (eds) Global change and our common future: papers from a forum. National Academy Press, Washington, DC, pp 90–99
- UNEP (2006) Dhaka City State of Environment: 2005. UNEP, Dhaka
- Voller J, Harrison S (1998) Conservation biology principles for forested landscapes. UBC, Vancouver
- Xi JY, Cho NN (2006) Spatial and temporal dynamics of urban sprawl along two urban-rural transects: a case study of Guangzhou, China. *Landscape Urban Plan* 79:96–109
- Yuan F, Sawaya KE, Loefelholz BC, Bauer ME (2005) Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multi-temporal Landsat remote sensing. *Remote Sens Environ* 98(2–3):317–328