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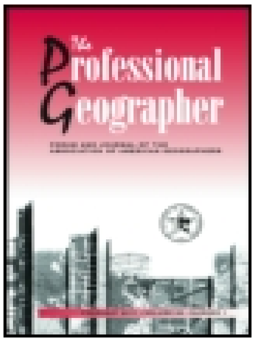

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Rapid change in land use and land cover (LULC) and unplanned urban expansion in Dhaka City, Bangladesh, receives continuous attention from local policymakers and the international community. This study employed a supervised classification procedure and postclassification change detection technique to estimate major changes between different LULC classes. The study revealed that built-up area increased significantly from 1989 to 2014. The total urban growth of 81.54 percent resulted in a substantial decrease in natural vegetation cover and agricultural land. In addition, water bodies have declined consistently over the last twenty-five years. The overall accuracy of LULC change maps produced from Landsat data ranged from 89.72 percent to 92.97 percent. The results should contribute to ongoing LULC information updates while forecasting possible future LULC change and sustainable development under greater population density. **Key Words: change detection, Dhaka City, LULC, sustainable development, urban expansion.**

在孟加拉达卡市，土地使用与土地覆盖（LULC）的快速变迁与未经规划的城市扩张，持续受到地方政策制定者与国际社会的关注。本研究运用受监督的分类过程以及分类后的变迁侦测技术，评估不同的 LULC 分类间的重大变迁。本研究显示，1989 年至 2014 年间, 建成环境面积有显着的增加。百分之八十一点五四的总体城市成长, 导致植被覆盖和农业用地的大幅减少。此外，过去二十五年来水体持续降低。陆地卫星数据所生产的 LULC 变迁地图的总体正确率从百分之八十九点七二至百分之九十二点九七不等。研究结果应可对持续进行的LULC信息更新作出贡献，同时预测在更大人口密度下 LULC 可能的未来变迁与可持续发展。 **关键词: 变迁侦测, 达卡市, LULC, 可持续发展, 城市扩张。**

El rápido cambio en uso del suelo y cobertura de la tierra (LULC), y la expansión urbana sin planificación de Ciudad Dhaka, Bangladesh, reciben continua atención de los legisladores locales y de la comunidad internacional. Este estudio utilizó un procedimiento de clasificación supervisado y una técnica de detección de cambio posterior a la clasificación para estimar los cambios importantes entre diferentes clases de LULC. El estudio reveló que el área construida se incrementó significativamente de 1989 a 2014. El crecimiento urbano total del 81.54 por ciento resultó en una sustancial reducción de la cubierta de vegetación natural y de la tierra agrícola. Además de esto, los cuerpos de agua han declinado consistentemente durante los pasados veinticinco años. La exactitud general de los mapas de cambio de LULC producidos a partir de datos de Landsat oscilaron del 89.72 por ciento al 92.97 por ciento. Los resultados deben contribuir a las actualizaciones en curso de la información sobre los LULC, al tiempo que se pronostica el posible cambio de los LULC a futuro y un desarrollo sustentable bajo densidades más altas de la población. **Palabras clave: detección de cambio, Ciudad Dhaka, LULC, desarrollo sustentable, expansión urbana.**

For the first time in humankind's history in 2008, half of the world's population resided in urban areas (Jha, Bloch, and Lamond 2012). In addition, a significant portion of urban population growth occurred in developing countries (United Nations [UN] 2010; Tewolde and Cabral 2011), which continues today. The fastest rates of urbanization can be found in cities located in low-income economies. A classic example is the city of Dhaka, Bangladesh. Urbanization in developing countries, however, is a recent phenomenon. Since the second half of the twentieth century, rural-to-urban migration has increased substantially in many developing countries because of growing opportunities in urban settings resulting from disproportionate economic systems and degraded landscapes (Meyerson, Merino, and Durand 2007; Grimm et al. 2008). The UN (2014) projected that the world's cities would house an additional 2.5

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billion people by 2050, and nearly 90 percent of the increase would be on the two continents (Asia and Africa) containing the most developing countries. One of the inevitable consequences of urbanization is land use and land cover (LULC) change. Changes in LULC associated with urban expansion and the factors driving this change are of concern in many developing countries.

Within the last several decades, researchers have examined urbanization and its impact on LULC change in developing countries (Imagawa, Fukuhara, and Watanabe 1997; Stow and Chen 2002; Dewan and Yamaguchi 2009b). Adverse effects associated with urbanization include biodiversity loss, land degradation, food insecurity, exhaustion and contamination of water resources, as well as changes in global climate (Yorke and Margai 2007). To curb these adverse effects, urban planners and policymakers in many developing countries have advocated for the collection of timely and reliable data to update existing land use maps and to evaluate patterns and rates of change (Yorke and Margai 2007; Dewan and Yamaguchi 2009a).

Fortunately, the integration of remote sensing technologies with geographic information systems (GIS) has proven to be effective in monitoring urbanization and land use change (Muller and Zeller 2002; Kamh et al. 2010). The integration of GIS and remote sensing technologies for monitoring urbanization and its effects on LULC change is particularly effective in four major areas: (1) analyzing the rate and magnitude at which changes are occurring, (2) examining changes over a significant time span and foreseeing future changes, (3) documenting spatial patterns of change and identifying risk locations, and (4) pinpointing socioeconomic characteristics and biophysical factors causing these changes (Yorke and Margai 2007). It is against this background that this study intended to evaluate spatial and temporal patterns of LULC change in Dhaka by integrating remote sensing and GIS techniques. Results from this research can provide policymakers and nongovernmental organizations with information to help ensure environmentally friendly and sustainable urban expansion of Dhaka in the future. Furthermore, the methodological approach of the study can serve as an example that can be used by urban planners of Dhaka City to monitor the ever-increasing urbanization of the city as well as to update existing maps on LULC.

Until the end of the sixteenth century, Dhaka was a small rural settlement on relatively high and flat land surrounded by wetlands that was subject to flooding. The city had several rulers who possessed different perspectives on city development and expansion (Kabir and Parolin 2012). Since the 1950s, Dhaka has been subjected to several different development plans but none of the plans has been able to guide sound expansion of the city. The first Master Plan for Dhaka, The Dacca Master Plan, was prepared by the Dacca Improvement Trust (DIT) in 1959 (Ahmed, Nahiduzzaman, and Bramley 2014) and emphasized spatial planning. According to the plan, all new development should follow the principle of isolated and discrete land use planning while considering the provision of utilities and services (Zaman and Lau 2000). The Dacca Master Plan gave priority to the Dhaka-Tongi axis (northern region of the city) as the primary site of future development because of its higher elevation and relative safety from flood events. Development in the Dhaka-Tongi axis did not accelerate until after the liberation war, however. In 1971, tremendous growth began in the Dhaka-Tongi axis when Dhaka was selected as the capital of independent Bangladesh (S. Hasan and Mulamoottil 1994). The city experienced an extraordinary shift in both physical and socioeconomic aspect after the historical change. The historical change in the city's status rendered the Dacca Master Plan outdated because of rural–urban migration that resulted from the change in the city's status.

In 1981, the first strategic plan for urban development was proposed. The Dhaka Metropolitan Area Integrated Urban Development Project (DMAIUDP), unlike the master plan of 1959, did consider population growth from migration. Both plans strategically focused on urban expansion in the higher elevated flood-free area in the northern portion of the city to minimize development pressure on areas near the urban core (Ahmed, Nahiduzzaman, and Bramley 2014). Unfortunately, the DMAIUDP did not materialize due to the lack of commitment and the need for reorganization (Zaman and Lau 2000).

In 1992, the Dhaka Metropolitan Development Plan (DMDP) 1995–2015 was proposed to facilitate the role of Rajdhani Unnayan Kartripakkha (RAJUK), the local capital development authority, in planning matters and to initiate an integrated development plan at the metropolitan scale (Ahmed, Nahiduzzaman, and Bramley 2014). The increasing urban expansion of Dhaka was regulated by the DMDP for twenty years, through its Structure Plan, Urban Area Plan, and Detailed Area Plan (DAP). The DAP acted as a reference document and provided detailed analysis of twenty-six strategic planning zones (RAJUK 1997). The DMDP prescribed urban expansion in the peripheral areas of the city as opposed to the 1959 and 1981 plans. It also predicted the growth in the eastern edge of the mostly flood-prone areas. Unfortunately, DMDP failed to meet expectations due to Bangladesh's government inability to enforce laws concerning the urbanization of the city.

Over the last four decades, however, Dhaka has become the primary city of Bangladesh because of a significant expansion in public and private establishments; rapid development of housing; new openings of national and international businesses; and growth of trade, industry, and overall infrastructure (Alam and Rabbani 2007). Dhaka is recognized as a megacity due to substantial population growth as well as urban growth (Hossain 2008). Megacities are another type of humankind's settlement developed in distinctive physical areas of diverse nations with various growth rates, socioeconomic status, and cultural backgrounds (Shams, Shohel, and Ahsan 2014). The modern areal expansion of Dhaka is also attributed to the configuration of the physical landscape in and around the city. In particular, the river system and the elevation of land in relation to flood levels guide urban growth (Chowdhury and Faruqui 1989).

The expansion of Dhaka, like many cities in developing countries, cannot be explained by a single urbanization theory but by a combination of theories. Within urban studies literature, it is argued that urbanization is due largely to rural–urban migration (McCatty 2004; Sridhar, Reddy, and Srinath 2013). Rural to urban movement is often explained by various theories such as modernization, dependency, and urban bias (UN 2013). Unfortunately, the type of urbanization occurring in Dhaka and many cities within developing countries is the result of both rural–urban migration and a natural increase in population, which makes it difficult to explain Dhaka's growth through one urbanization theory.

Despite the diverse reasons behind rapid urbanization, most of the growing urban areas in developing countries face similar challenges: adjusting quickly to the growth and developing solutions to increase housing and to meet demands in service and transportation (UN-Habitat and UNESCAP 2015). Dhaka is no exception to these problems. As indicated earlier, LULC is an inevitable effect of urbanization. The importance of LULC analysis for natural resource management and environmental science in rapidly urbanizing areas is beyond a shadow of a doubt (Yorke 2006; Yadav, Kapoor, and Sarma 2012) particularly within cities located in developing countries. Despite the fact that Dhaka is Bangladesh's primary city and a world megacity, little research has examined LULC change associated with the urban expansion of the city. It is therefore imperative that patterns and rates of LULC change within Dhaka be analyzed using remote sensing technologies coupled with GIS to help policymakers and nongovernmental organizations ensure environmentally friendly and sustainable urban development for the city.

In terms of relative location, Dhaka is within the Dhaka district of Bangladesh. The total area of Dhaka is approximately 307 km^2 (118.53 mi^2). One third of the urban population of Bangladesh lives in Dhaka, which is approximately 16.98 million (UN-Habitat and UNESCAP 2015). Dhaka is the eleventh densest city on earth. A concern has emerged about whether the city can support a 3.6 percent annual growth in population (UN 2014). Its presence as the largest city in Bangladesh has been steady over a period of about 400 years (Rahman et al. 2011).

The area under investigation in this study is surrounded by four stream networks: the Buriganga, Turag, Tangi, and Balu (Figure 1). The city has a subtropical-monsoon season with humid climatic conditions (Dewan, Kumamoto, and Nishigaki 2006). During the summer months the monsoon season lasts from June until September. The tropical storm season occurs from April until June during the summer months and then again from September until December. The area experiences an annual average temperature of 27.5°C. The physiography of Dhaka's peripheral region is most viable for agricultural practices, but rapid urbanization is consuming agricultural land for residential, industrial, and commercial uses. The combination of urban expansion and increasing population growth is responsible for the physical and environmental instability of the area due to land transformation as well as rapid urbanization (Rahman et al. 2011). Urban LULC change information is important for updating land use maps and for the management of natural resources. LULC changes, particularly urban area expansion, have significant effects on the environment in general. To monitor the consequences of rapid urbanization, the collection and analysis of reliable and current urban land cover data obtained from Landsat satellites is important.

Data and Method

Data Sources

Three 30 m × 30 m spatial resolution satellite images (i.e., one Landsat Thematic Mapper [TM], one ETM+ [Enhanced Thematic Mapper Plus] and one OLI [Operational Land Imager]) were acquired for the years 1989, 2002, 2014, respectively, from the U.S. Geological Survey (USGS 2014). Both Landsat 7 ETM+ and Landsat 8 OLI satellites images have a 15 m panchromatic band, which were used to generate pan-sharpened images. Topographic maps of the year 1991 (scale 1:50,000; Sheet No. 79 I/5 and 79 I/6) and Dhaka surrounding map of 2004 (scale 1:5,000; Sheet No, 174) were collected from Survey of Bangladesh (SOB). Other data used for this study were obtained from the Geo Daten Information (2014) Web site, including the Dhaka boundary, water bodies, and transportation networks shapefiles.

Materials and Methods

Three different images were initially subjected to image preprocessing (including georeferencing and image enhancement) to enhance their visual appearance and to examine their spatial extent. Following the image preprocessing procedure, a supervised classification method employing the maximum likelihood classifier algorithm was performed on each of those images. First, five categories of training sites, each for different land use types, were created over the study

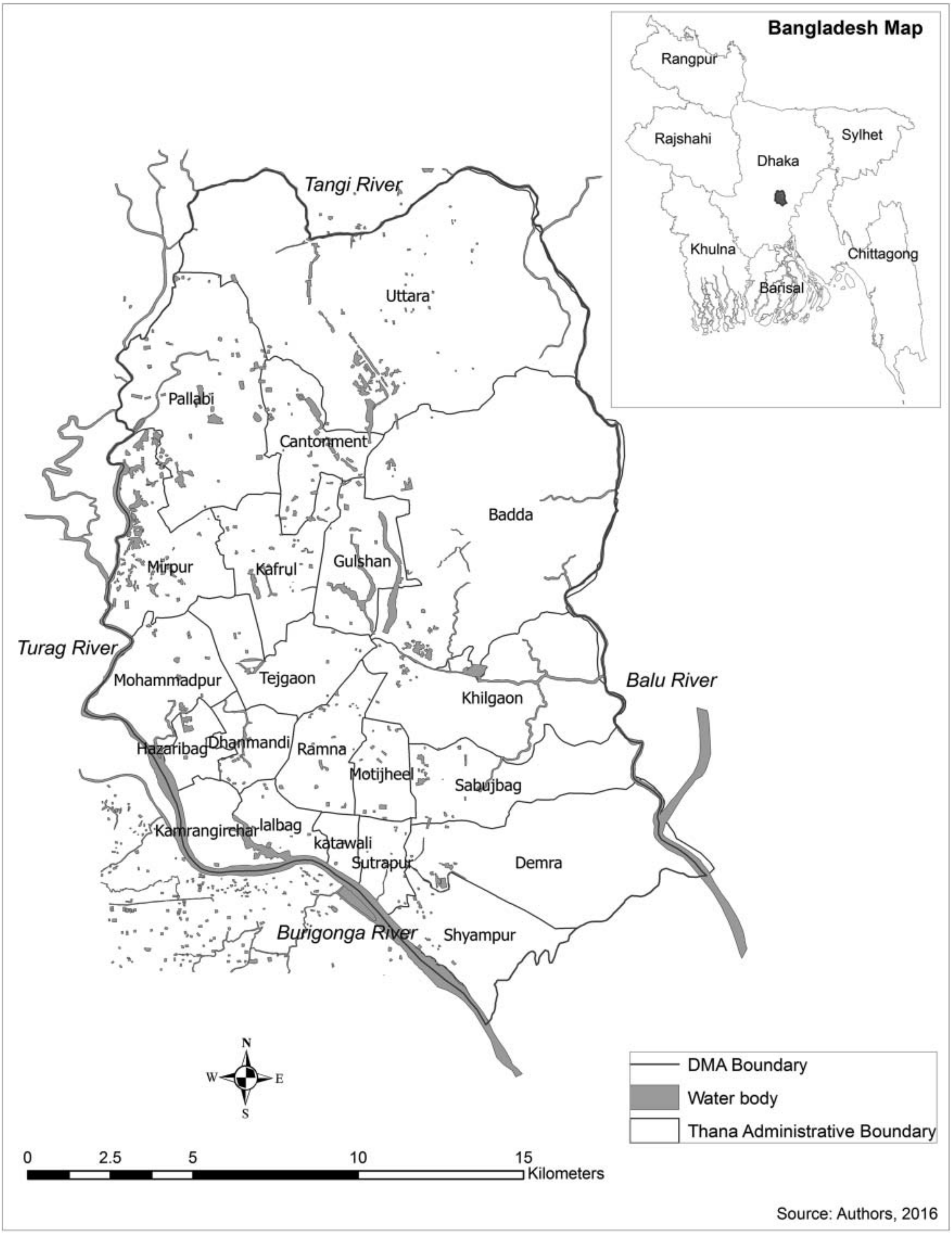

Figure 1 *Location of study area, Bangladesh. DMA = Dhaka Metropolitan Area.*

region using existing topographical maps, the Dhaka surrounding map, and land use maps (ESRI 2014). The five LULC categories include water, built-up land, vegetation, agricultural land, and barren land. The built-up land category can be defined as the areas characterized by (greater or equal to 50% in cover) nonvegetation, buildings, systematic road networks, concrete, industrial facilities, and runways (Potere et al. 2009; Liu et al. 2014). Second, using the training site samples together with the maximum likelihood classifier algorithm, the images were classified into the five LULC classes. Areas of individual LULC category were calculated following image classification for 1989, 2002, and 2014. Finally, percentage changes in LULC between the three time periods were calculated by employing postclassification change detection techniques.

Postclassification comparison involves an analysis of the difference between two independently categorized products (Singh 1989), and it is the most commonly used and widely accepted method of change detection (Yuan et al. 2005; Dewan and Yamaguchi 2009b; Kamh et al. 2010). This method holds promise because data from two dates are separately classified, thereby minimizing the problem of normalizing for atmospheric and sensor differences between two dates and also providing a complex matrix of change information (Jensen 2005). The results include the amount, location information, and nature of change (Howarth and Wickware 1981; Dewan and Yamaguchi 2009a). In addition, a base year map can also be produced from this method for record-keeping and future use (Jensen 2005). This method has some disadvantages as well, however. The postclassification technique is time consuming and also dependent on the accuracy of individual date classifications (Lu et al. 2004) and subject to error propagation (Zhang et al. 2002; Yuan et al. 2005; Dewan and Yamaguchi 2009b).

Three different statistical analyses were performed to evaluate the accuracy of the classifications and significant differences of land uses between the three study time periods. First, accuracy assessment reports were generated. Before generating the report, the equalized random distribution parameters were used to select points randomly throughout the study area (Olofsson et al. 2014; Castilla 2016). For the 1989 LULC image, 256 random points were selected. For the 2002 LULC image, 253 random points were selected, and 244 random points were selected for the 2014 LULC image. After the point selections, the classified land use category was added to each point's attribute. In addition, using the existing land use map, Dhaka surrounding map, and topographic maps as well as the original satellite images, a reference land use category was added to each point's attributes. Afterward, the accuracy assessment algorithm in Erdas Imagine was used to generate accuracy reports. Second, using the error matrix data obtained from the generation of the accuracy reports, the kappa coefficient was computed for the years 1989, 2002, and 2014. The kappa coefficient is a statistic that measures interrater agreement for categorical items. The purpose of calculating the kappa coefficient was to test for a significant difference between the classified LULC categories and the referenced LULC categories. Third, using the data from the error matrix, a test of marginal homogeneity was performed to examine whether there were significant changes in LULC classes between the selected study periods. The test of marginal homogeneity is used to detect whether the marginal row proportions and marginal column proportions are equal. It is a variation of the familiar chi-square test of contingency tables. A significant difference in the marginal row and column proportions indicates a significant change in the outcome categories (Sun and Yang 2008). The test of marginal homogeneity has a test statistic and when the null hypothesis is true it follows a chi-square distribution with $k - 1$ degrees of freedom. The null hypothesis tests whether the marginal probabilities in row totals and column totals are the same; that is, no significant changes in LULC classes between the selected study periods. Rejection of the null hypothesis indicates that there were significant changes in LULC classes in Dhaka.

Results and Discussion

Land Use Classification Results for 1989, 2002, and 2014

The classified image (Figure 2) shows that Dhaka was surrounded by water bodies. Built-up areas were agglomerated at the lower left and in the middle, as well as the upper middle areas in the north. Vegetated areas were dispersed across the study area but mostly concentrated in the northeastern and northwestern areas. Water bodies, like ponds, lakes, and small and medium-size reservoirs, were evident throughout the image, especially in the south and western parts of Dhaka. Vegetation cover constituted the largest LULC category, covering about 11,641.32 ha (37.8 percent) of the study area (Table 1). The second and third largest LULC categories were built-up and agricultural lands, which totaled around 9,806.40 ha (31.8 percent) and 5,029.65 ha (16.3 percent), respectively. Water bodies constituted the fourth largest LULC category, covering about 3,509.46 ha (11.4 percent) of the study area. The LULC category with the least coverage area in 1989 was barren land covering 2.7 percent of the study area.

The LULC pattern in the study area in 2002 (Figure 3) was similar to that of 1989 with some exceptions (i.e., vegetation and agricultural lands). In 2002, built-up constituted the largest LULC category, covering about 42.5 percent of the study area (Table 1). The second and third largest LULC categories were vegetation (39.6 percent) and water (7.6 percent), respectively. Agricultural lands constituted the fourth largest LULC category, covering about 5.7 percent of the study area. The LULC category with the least

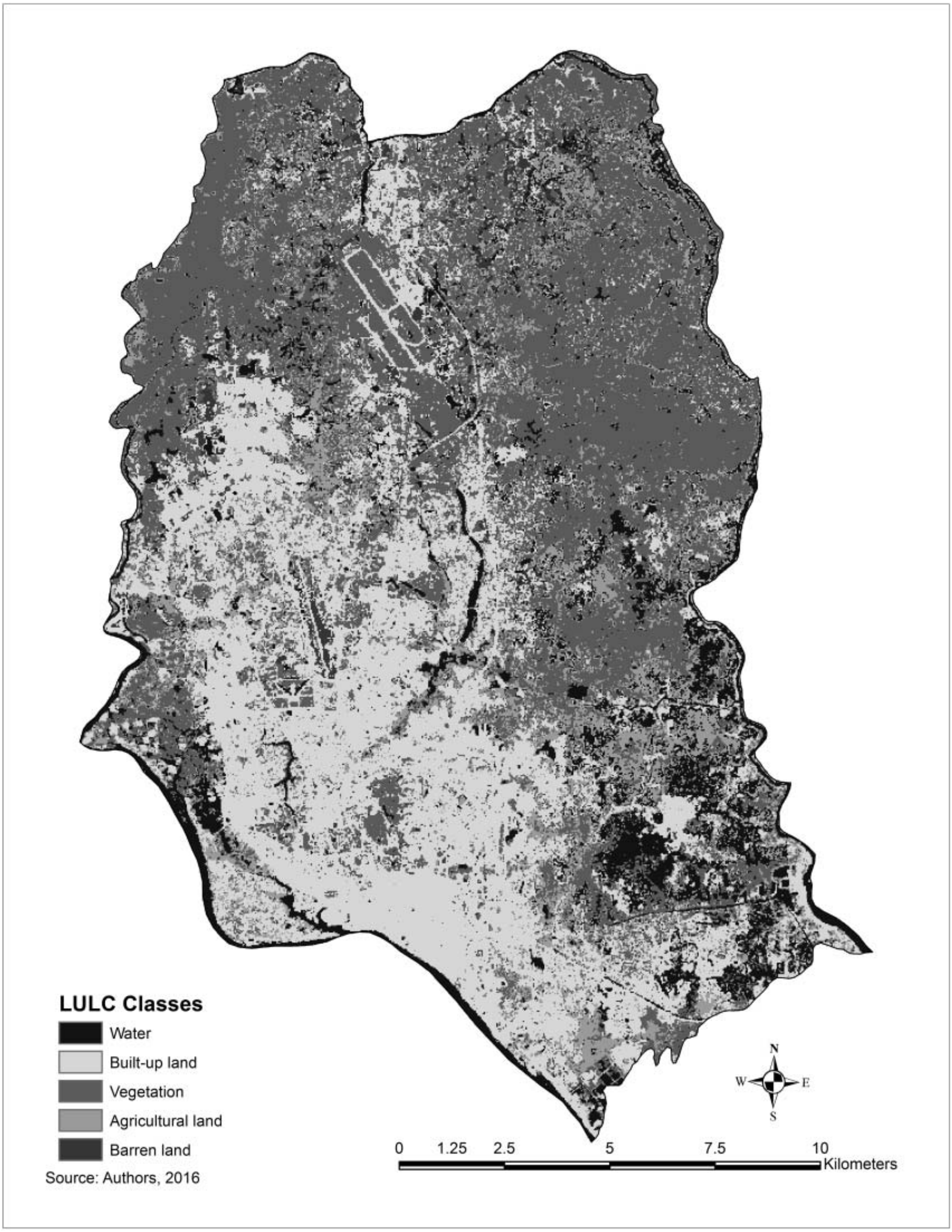

Figure 2 *Land use and land cover classification results, 1989. LULC = land use and land cover.*

coverage area in 2002 was barren land, covering 4.5 percent of the study area.

Figure 4 shows the LULC patterns observed for the 2014. It can be seen from Table 1 that built-up constituted the largest LULC category, covering about 57.9 percent of the study area in 2014. The second and third largest LULC categories were vegetation (29.2 percent) and water (5.9 percent),

Table 1 *Land use and land cover coverage of the 1989, 2002, and 2014 classification results and their percentage change*

	1989		2002		2014		Percentage change	
LULC class	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**1989–2002**	**2002 – 2014**
Water	3,509.46	11.4	2,356.02	7.6	1,828.58	5.9	−32.87	−22.39
Built-up land	9,806.40	31.8	13,108.68	42.5	17,802.63	57.9	33.68	35.81
Vegetation	11,641.32	37.8	12,201.57	39.6	8,994.38	29.2	4.81	−26.29
Agricultural land	5,029.65	16.3	1,771.38	5.7	615.13	2.0	−64.78	−65.27
Barren land	830.07	2.7	1,379.25	4.5	1,512.97	4.9	66.16	9.70

Note: LULC = land use and land cover.

respectively. Barren lands constituted the fourth largest LULC category, covering about 4.9 percent of the study area. The LULC category with the least coverage area in 2014 was agricultural lands, covering 2.0 percent of the study area.

Estimation of Land Conversion in Dhaka

Like other cities of developing countries, mixed land use practice is very common inside Dhaka. From Table 1, it can be seen that water bodies decreased by 32.87 percent in the first half of the study period (1989–2002), and in the second half of the study period (2002–2014) it decreased another 22.39 percent. Most of the decrease in water bodies can be attributed to reclamation of these waterlogged areas for residential use and other purposes. It can also be seen from Table 1 that built-up area increased by 33.68 percent in the first half of the study period (1989–2002), and in the second half of the study period (2002–2014) it increased another 35.81 percent. The increase in built-up area could be attributed to the rapid population increase of the city caused by rural–urban migration as well as a natural increase in population. This result is consistent with LULC change associated with urbanization found in most developing countries. Although vegetated area increased by 4.81 percent during the first time period, it decreased during the second time period (i.e., −26.29%). The increase in vegetation cover during the first period might be attributed to misclassification because the government made no effort to increase vegetation cover in the area. In addition, it is difficult to see vegetation cover increase when the process of urbanization is at work. It must be noted that the overall decrease in vegetation is consistent with results obtained by Corner, Dewan, and Chakma (2014). Agricultural land decreased by about 64.78 percent during the first time period between 1989 and 2002 and decreased further (approximately 65.27 percent) during the second period. The decrease in agricultural land is mainly attributed to the rapid urbanization of Dhaka. There were consistent increases in barren land throughout the study period, which is similar to earlier research by Dewan and Yamaguchi (2009a, 2009b). Most barren land areas are potential sites for future built-up land.

Postclassification Comparison for Built-Up Land

Table 2 provides an overview of individual classes that were converted from water, vegetation, agricultural, and barren lands to built-up land, highlighting urban area growth. As discussed earlier, this study was mainly concerned with urban expansion in Dhaka. Vegetated land contributed the highest amount to built-up areas (2,647.44 ha), followed by agricultural land (1,841.76 ha), water (805.41 ha), and barren land (419.76 ha) from the year 1989 to 2002 (Figure 5). Figure 6 shows the final change pattern of LULC classes to built-up land during the period of from 2002 to 2014. Urban expansion was clearly discernible throughout the study area. There was very little agricultural land left in 2014. It is apparent that 4,557.40 ha of vegetation cover was altered to built-up land during the study period. Water and barren land contributed 922.59 ha and 955.69 ha to built-up land, respectively, during the period from 2002 to 2014. In addition, 718.52 ha of agricultural land was converted to built-up land.

In terms of patterns of change, three different observations were made. First, there was significant change in LULC from other categories to built-up. Second, there was no particular direction of urban expansion identifiable for the period from 1989 to 2002. Expanded areas were dispersed across the study site. Between 2002 and 2014, the directions of urban built-up area increased from west to east. This result could be attributed to the fact that those areas were the only available areas for the city to expand during that period.

Changes in Built-Up Areas between 1989 and 2014

Although changes of LULC were observed from 1989 to 2002 and from 2002 to 2014, the study also considered overall change from 1989 to 2014 (Figure 7). There is a significant gain and loss in different LULC classes. It is apparent that vegetated land cover contributed significantly to newly formed built-up land, followed by agricultural land and water bodies, respectively, over the last twenty-five years.

Figure 7 shows that some clusters of vegetation cover were cleared for built-up land in the eastern part of the study area. Analysis of the data demonstrated how Dhaka expanded in size, especially through

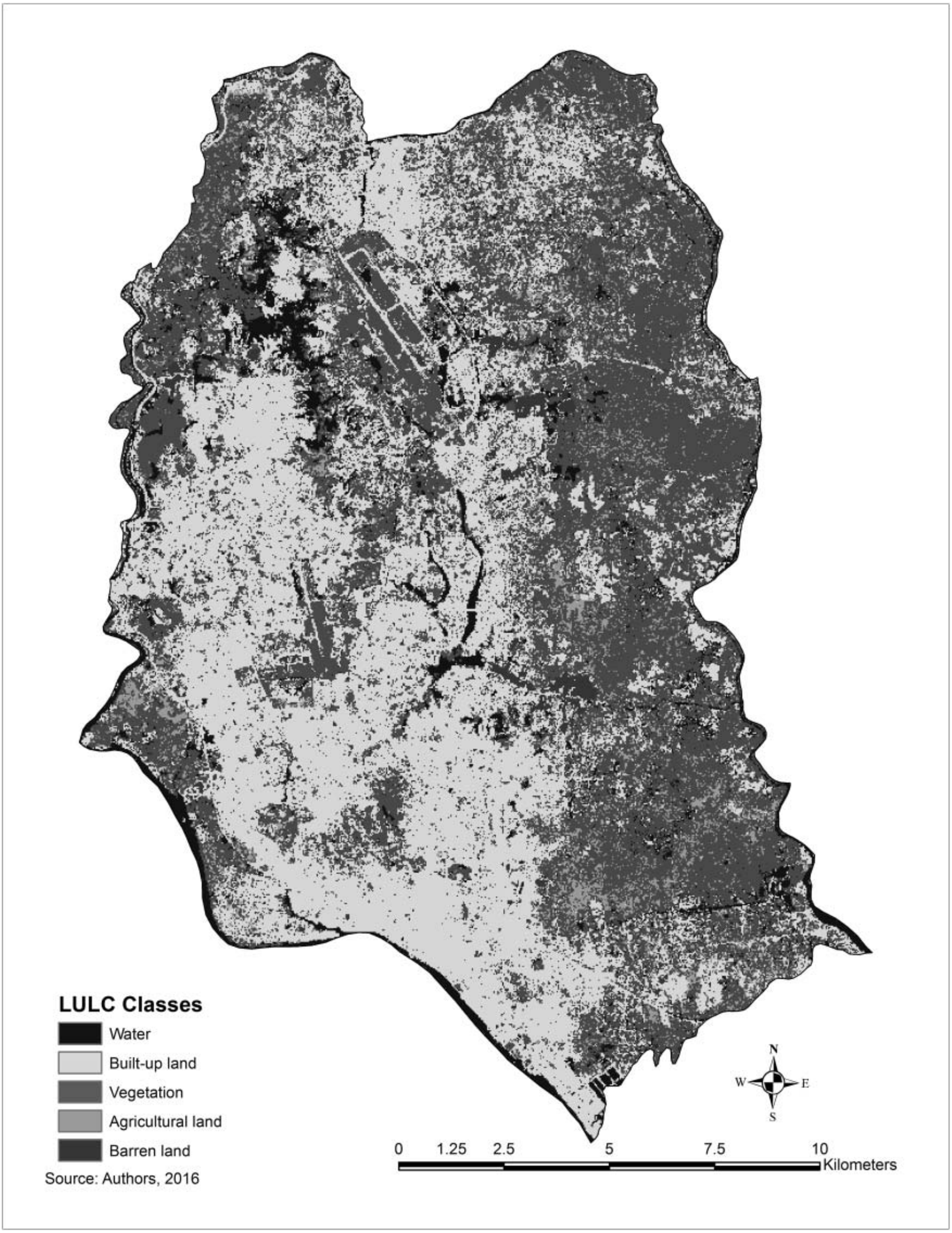

Figure 3 *Land use and land cover classification result, 2002. LULC = land use and land cover.*

suburban development. This expansion consumed significant areas of agricultural land and vegetation cover. A growing number of people from all over the country are moving to Dhaka, which has contributed to its status as a rapidly growing city. Table 3 shows the comparative study of the built-up areas with population densities. Rural–urban migration and natural increase in population are the two main reasons causing this rapid urban population growth. The increasing population exerts immense pressure on limited

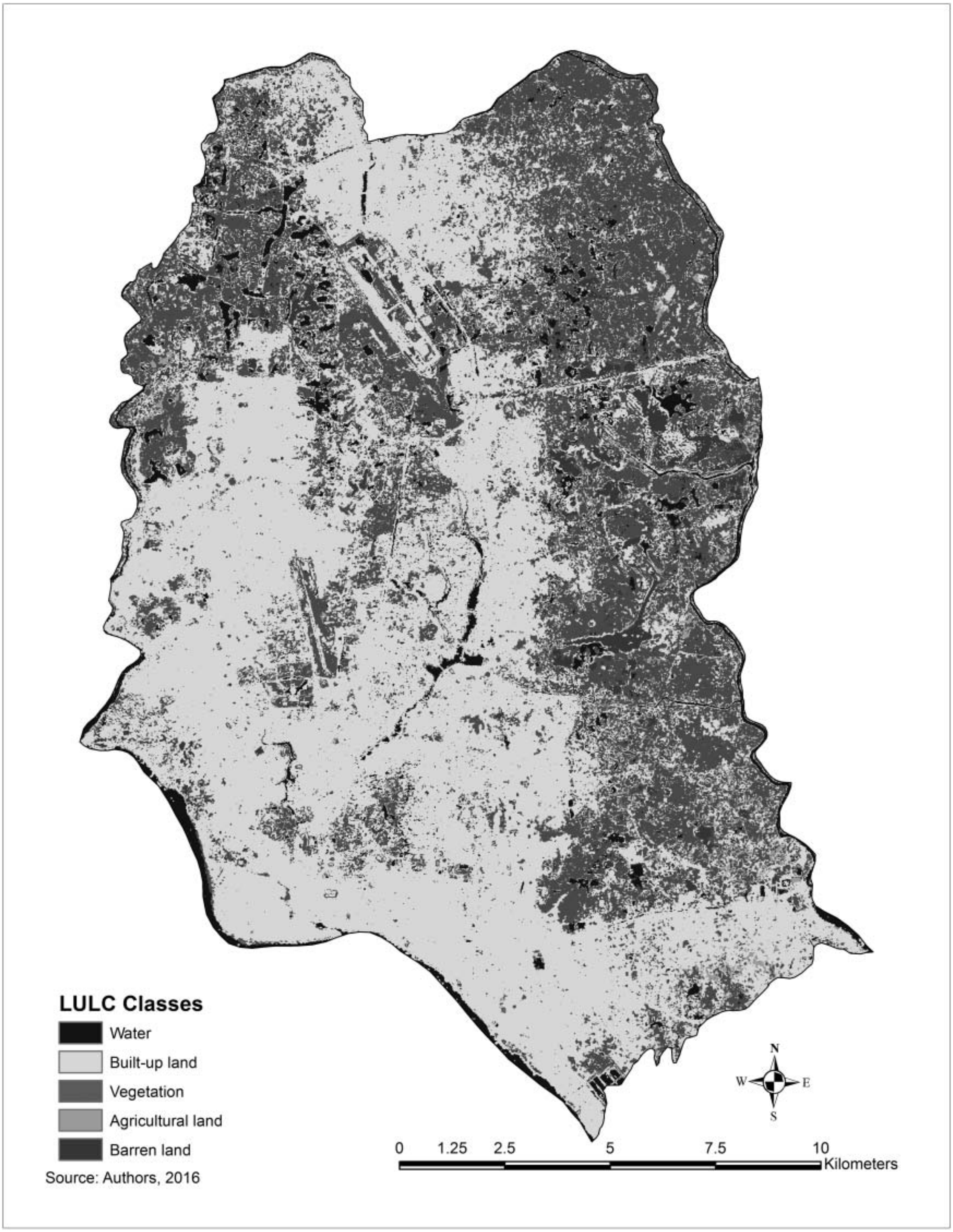

Figure 4 *Land use and land cover classification result, 2014. LULC = land use and land cover.*

resources that ultimately leads to the expansion of built-up areas. Built-up land has increased with the increase of population. In 1989, built-up land covered only 98.06 km^2 and the total population density of the Dhaka metropolitan area was 21,051 per km^2. By the year 2014, total built-up land increased 81.54 percent, and population density (47,192 per km^2) more than doubled. Each year, a number of unemployed rural people move to the city looking for jobs and many end up residing in unplanned settlements (slums) located

Table 2 *Amount of land changed to built-up land for the 1989 to 2002 and 2002 to 2014 period*

Land use change	Change 1989–2002 (ha)	Change 2002–2014 (ha)
Water to built-up land	805.41	922.59
Built-up land, no change	7,394.31	10,632.35
Vegetation to built-up land	2,647.44	4,557.40
Agricultural land to built-up land	1,841.76	718.52
Barren land to built-up land	419.76	955.69

in the inner part of the city (Zaman and Lau 2000), along the flood protection embankment or the rail line (World Bank 2007).

Accuracy Assessment

The accuracy reports indicated different overall classification accuracy for the three different images. The overall accuracy of LULC change maps produced from the Landsat data was 92.97, 89.72, and 91.39 percent for 1989, 2002, and 2014 images, respectively. As indicated earlier, the kappa coefficient measures the agreement between the reference values and classified classes. Therefore, it is important to describe the error assessment with a confidence interval (Castilla 2016) on the agreement of the remote sensing-derived information (Jensen 2005). Table 4 shows the confidence interval for 1989, 2002, and 2014 classifications. Although the kappa coefficient was greatest in 1989 and lowest in 2002, all of the confidence intervals overlapped one another. Generally, when the values for the confidence interval are greater than 80 percent, the hypothesis demonstrates a strong agreement between the remotely sensed data classification and the reference data (Congalton and Green 2009). Table 5 shows the results of the test of marginal homogeneity. The test evaluated whether the percentages of the five different LULC classes remained the same or were different during each respective period. The test statistics and their associated p values indicated a rejection of the null hypothesis of marginal homogeneity between 1989 and 2002, 2002 and 2014, and 1989 and 2014 land use ($p < 0.0001$; Table 5). The distribution of the LULC differs significantly from the year 1989 to 2002, from 2002 to 2014, and from 1989 to 2014. The test statistics for the year 1989 to 2014 LULC provided a high chi-square value and associated lower p value that ultimately means a significant change in LULC for the twenty-five-year time span.

It is essential to note that the outcomes presented for this study offer just the initial assessment of LULC change associated with the growth of the city. These results are yet to be authenticated by ground truthing; however, the study made use of preexisting maps for confirmation purposes. The lack of verifiable ground truthing does not necessarily restrict the importance of findings derived from remote sensing and GIS studies (Yorke and Margai 2007). According to Burl et al. (1994), lack of verifiable ground truthing of the study can be mitigated by using meticulous systematic procedures to ensure data integrity and by recognizing the level of uncertainty associated with the initial results.

Concluding Remarks and Policy Implications

This study demonstrated the practicability and potential of using multitemporal images to explore changes in LULC, including the patterns and rates of the built-up category. The postclassification comparison change detection method was employed following the maximum likelihood supervised classification of each image. The results revealed significant changes over the twenty-five-year period where most LULC classes decreased substantially in areal extent whereas built-up LULC category expanded substantially. The results revealed that built-up land increased by 33.67 percent (3,302.28 ha) between 1989 and 2002 and by 38.81 percent (4,693.95 ha) from 2002 to 2014. The overall expansion of built-up land was 81.54 percent at an average rate of 2.41 percent a year. Vegetation cover is imperative for a healthy environment and the beautification of a city. Unfortunately, the study revealed that a significant amount of agricultural and vegetated land covers were converted to built-up land. The rapid growth of built-up land consequently consumed most of the lands that were being used for agricultural activities and for maintaining green vegetation across the city.

Like other studies, this research encountered some limitations. First, anniversary data were required to perform change detection accurately. Yet, there were no cloud-free (less than 10 percent) anniversary data available from the USGS Earth Explorer Web site for the proposed study area as well as the study period. Second, although there was a panchromatic band (0.52–0.90 μm) for Landsat ETM+, it was not as beneficial because of the unusual spectral resolution of the band. In addition, the resolutions of the imagery were too coarse, which in turn reduced the accuracy of the classification. Further, ground truthing could not be performed for this preliminary study. Topographic maps together with the original satellite images were used to identify features for accuracy assessment, however. The use of topographic maps and other forms of land use maps to confirm classification results, although not a substitute for ground truthing, is an acceptable form of validating the accuracy assessment (Olofsson et al. 2014; Castilla 2016). Regardless of the limitations, this study used

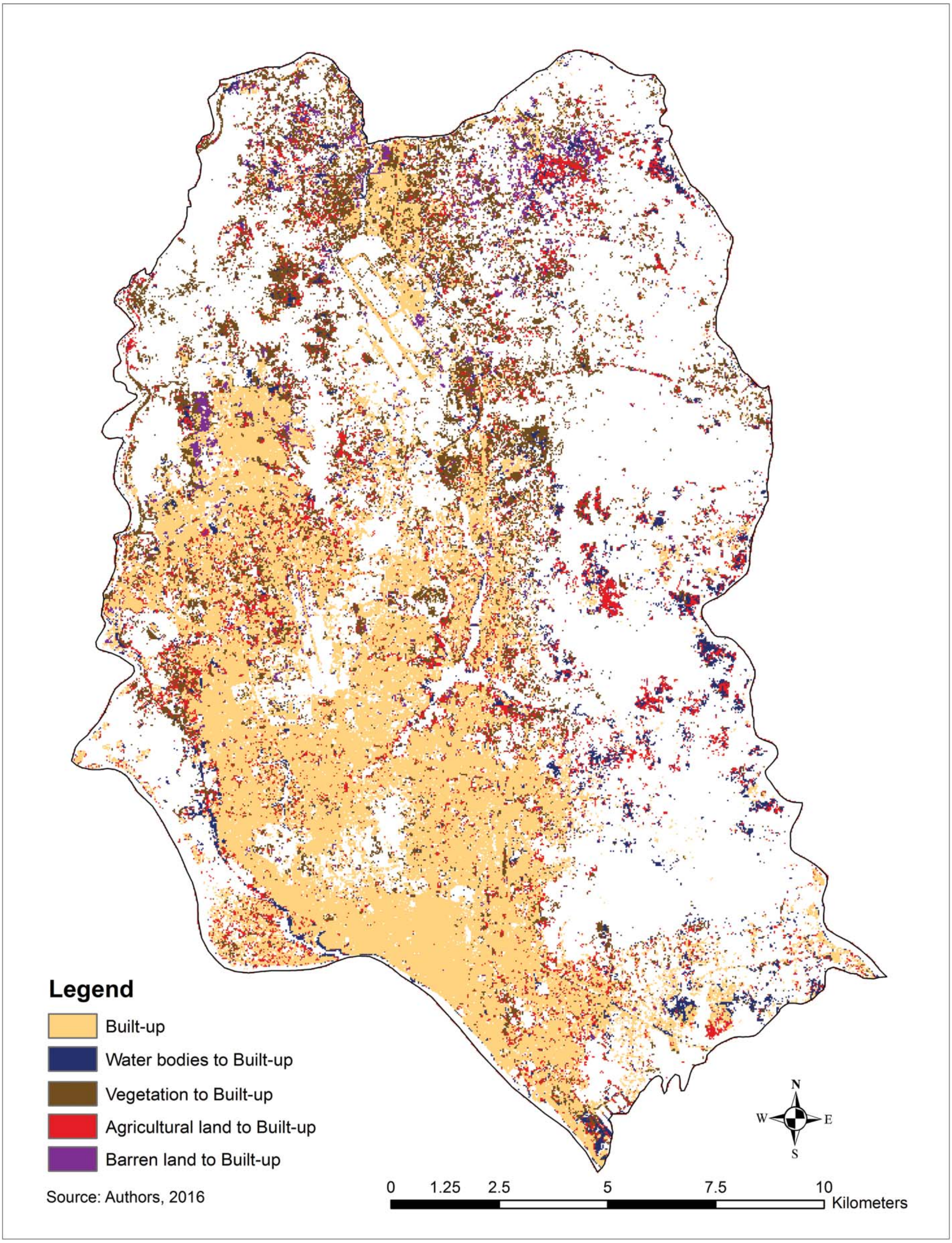

Figure 5 *Area of significant change in built-up land in Dhaka city from 1989 to 2002. (Color figure available online.)*

supervised classifications and employed a postclassification change detection method to assess LULC change.

Dhaka controls a large portion of Bangladesh's economic, political, administration, and social sectors. It is a dynamic city that has enticed considerable industrial investment, especially in the ready-made garment industry. The garment industry employs around 1.5 million people (K. M. F. Hasan et al. 2016), most of them located in Dhaka, which

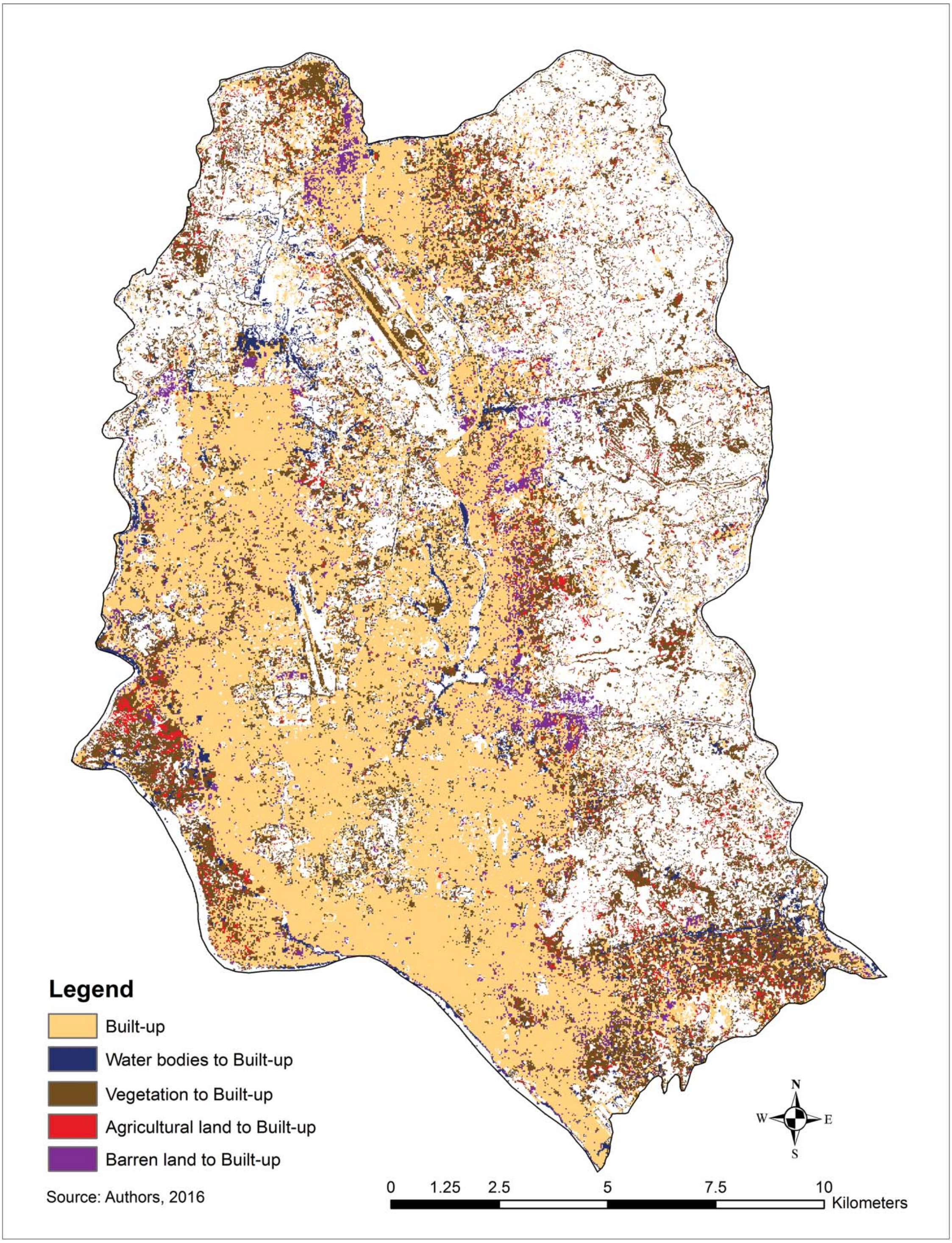

Figure 6 *Area of significant change in built-up land in Dhaka city from 2002 to 2014. (Color figure available online.)*

accounts for more than 80 percent of all exports (Islam and Sayef 2012; K. M. F. Hasan et al. 2016). The presence of good economic and social conditions in Dhaka coupled with poor economic conditions (particularly landlessness) and the lack of nonagricultural jobs in the poor rural areas of Bangladesh has pushed and continues to push the rural population to the city for better employment opportunities. In addition, frequent and severe natural disasters such as floods and river bank erosion

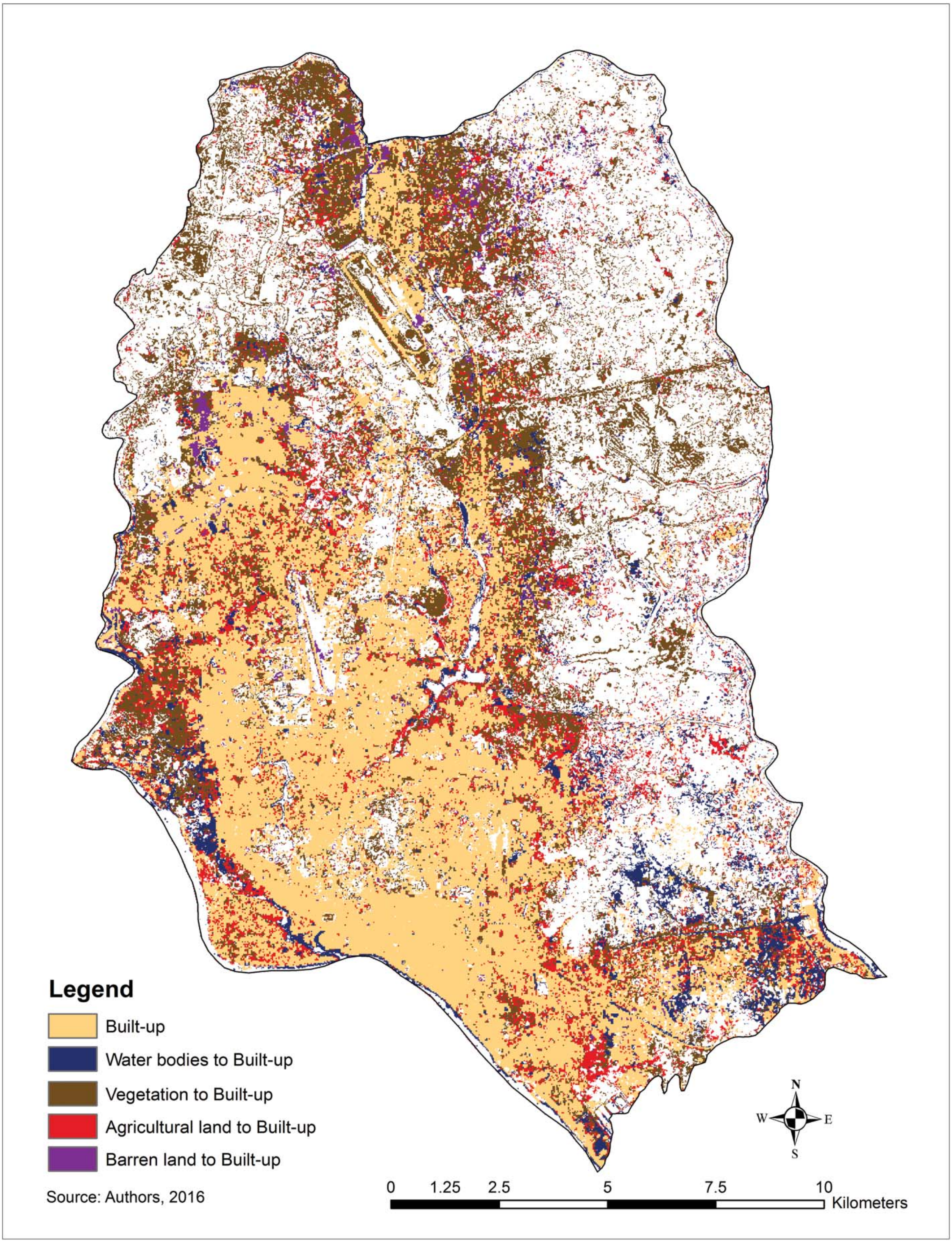

Figure 7 *Area of significant change in built-up land in Dhaka city from 1989 to 2014. (Color figure available online.)*

encourage rural–urban migration to the city. People flock from around the country to the city of Dhaka because of inadequate education, health, and employment opportunities at home. Bangladesh is a developing country and still has a high birth rate. The natural increase in population of Dhaka coupled with the rural–urban migration means that more and more other LULC categories must be converted to residential purposes. To make matters worse, the government of Bangladesh, like that in

Table 3 *Comparisons of the total population and built-up areas in Dhaka City*

Year	Total population	Total built-up land (km^2)	Population density (pop/km^2)
1989	6,487,459	98.06	21,051
2002	9,672,763	131.08	31,387
2014	14,543,124	178.02	47,192

Table 4 *Confidence intervals for 1989, 2002, and 2014 classification*

Year	Kappa score	*SE*	Kappa at 95 percent confidence intervals
1989	0.9121	0.0199	0.8729–0.9513
2002	0.8715	0.0239	0.8247–0.9183
2014	0.8921	0.0225	0.8480–0.9362

Table 5 *Marginal homogeneity test results*

Study period	Chi-square value	Degrees of freedom	*p* value ($\alpha = 0.05$)
1989–2002	2,866.951	4	<0.0001
2002–2014	2,806.084	4	<0.0001
1989–2014	7,608.466	4	<0.0001

many developing countries, has failed to develop and implement policies that can curb the urban growth of Dhaka. Furthermore, the government of Bangladesh has failed to enforce existing laws that seek to protect other LULC categories surrounding urban areas. For example, private real estate companies and influential people within Bangladesh are able to legally acquire lands that are supposed to be used for green areas of Dhaka as well as wetlands and convert it to housing projects (Khan 1998; Zaman and Lau 2000). Regrettably, converting agricultural lands and vegetation cover to built-up areas comes with severe consequences. For example, water quantity could be affected by newly formed urban settlements. Biological life associated with stream channel dynamics might also be affected substantially by unprecedented growth of built-up land. As a result, constant monitoring of LULC change is important, and this study exemplifies how monitoring of LULC change can be achieved using GIS and remote sensing technologies.

Conclusively, it can be said that documentation of LULC change is essential for tracking and mitigating the consequences of urbanization, particularly for a rapidly growing urban area like Dhaka. Regular updates of LULC change information, particularly for a rapidly growing urban area like Dhaka, can play an important role in terms of future prediction of change and monitoring of natural resources, such as biological life (including vegetation) and water bodies for sustainable development. Therefore, to ensure sustainable growth of built-up areas that exists in harmony with other LULC categories, the government of Bangladesh, the Dhaka North City Corporation (DNCC), and the Dhaka South City Corporation (DSCC) should adopt a comprehensive plan for LULC in Dhaka.

The comprehensive plan should include existing LULC and zones identified for particular land uses in the study area. This zoning regulation should include policies for preserving current land as well as sustainable development of future land uses. Policies might consider minimizing disparity between Dhaka and other major cities in Bangladesh, as well as the rural–urban economy. To ensure long-term sustainability and environmental consideration, policymakers can incorporate polycentric urban hubs in the strategic plan. Policymakers should also pay significant attention to the development of transportation infrastructure. A congested city like Dhaka should consider including a mass transit provision in its strategic plan. Improvement in the mass transit system in and around the city will encourage people to commute from nearby places to Dhaka, which will alleviate the current pressure on utilities and services.

Considering the dynamic change in LULC in Dhaka, the city needs to concentrate on developing a framework that incorporates more institutional governance and innovation in policymaking. Different authorities have shared an obligation over the years for the development, planning, administration, law and order, and utilities and services of Dhaka. Despite the fact that RAJUK is the primary organization for planning and urban development control, they need to coordinate with DNCC and DSCC and other government offices for planning on basic service administration. ■

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