Journal of the Indian Society of Remote Sensing (April 2021) 49(4):773–792
https://doi.org/10.1007/s12524-020-01201-9

RESEARCH ARTICLE

Spatiotemporal Change of Urban Water Bodies in Bangladesh: A Case Study of Chittagong Metropolitan City Using Remote Sensing (RS) and GIS Analytic Techniques, 1989–2015

Morshed Hossan Molla[1] · Mohammad Abu Taiyeb Chowdhury[1] · A. Z. Md. Zahedul Islam[2]

Received: 25 March 2020 / Accepted: 5 October 2020 / Published online: 16 November 2020

Abstract

This is an empirical study that attempts to explore the spatiotemporal changes of Urban Water Bodies (UWBs) in the Chittagong Metropolitan City from 1989 to 2015, using Remote Sensing and Geographic Information Systems analytic techniques. More precisely, Ground Truthing, along with Landsat^{TM} data and/^{OLI} satellite images was collected for the years 1989, 2001, 2010 and 2015, respectively; Checklist Survey, Key Informant Interviews and observation (overt) methods were also used for conducting the study. Narrative Analysis along with statistical tools, especially SPSS (version-20), was applied as well. The study reveals that nearly 1249 types of water bodies were detected by the checklist survey and '*Ground Truthing Method*', beside 1352 types of water bodies were identified through interpretation of series satellite images in the Metropolitan area. The total number of water bodies in Chittagong City was found declining gradually, because nearly 1605, 1526, 1400 and 1352 types of water bodies were detected in 1989, 2001, 2010 and 2015 years, respectively. Although the regression analysis curve prescribed the changing pattern or decreasing rate of UWBs was $\sim$ 10% which represented per year interval. Besides, the emerged and filled nature of UWBs was confused conditions. Some water bodies were emerged or excavated at southern and western edges of the coast due to soil collection for road construction and commercial fishing purposes. Besides that, many water bodies filled at every place in city area due to unplanned urbanization and industrialization, new settlement and housing, land pricing and fragmentation, unlawful encroachment and violence of Real Estate Corporation and so on. Therefore, strengthening of laws and policies and proper coordination among urban autonomous agencies will be significant to stop illegally filled of water bodies and to protect water bodies in a Chittagong Metropolitan city in Bangladesh.

Keywords Urban water bodies · Landsat imagery · Spatiotemporal analysis · Environmental sustainability · Chittagong city

Introduction

Landscape alteration has a multiplying effect on biodiversity, water quality, and carbon emissions with many other negative impacts on aquatic and terrestrial ecosystems (Rojas et al. 2013; Jianchu et al. 2005). In recent decades, rapid urbanization has been accelerating land cover change in such a way that has an enormous impact on the radioactive, thermodynamic, and hydrological processes that can lead to a change in the local climate in terms of temperature, precipitation, and cloudiness (McCarthy et al. 2010; Kaufmann et al. 2007). For instance, Urban Water Bodies (UWBs) are a micro-morphological unit of urban physical environment, most often refers to small accumulations of water, such as

✉ Morshed Hossan Molla
morshedgeo@yahoo.com

Mohammad Abu Taiyeb Chowdhury
mat_chowdhury@yahoo.com

A. Z. Md. Zahedul Islam
azmd_zahed@yahoo.com

[1] Department of Geography and Environmental Studies, Faculty of Biological Science, University of Chittagong, Chittagong 4331, Bangladesh

[2] Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Agargaon, Sher-e-Banglanagar, Dhaka 1207, Bangladesh

pond, *dighi*, *doba*, *khal*, river, canal, lake, reservoirs and humid fallow land in urban areas. As a micro-morphological unit, UWBs have a multidimensional significant. Especially, urban flood water retention, erosion and sedimentation, control demystification and micro-climate, provision of habitat for organism and support of aquatic life, along with alternate water sources for household purposes, like bathing, cleaning and other requirements. In contemporary towns and cities, waterfronts have remained the focus for many economic and recreational activities (Francis 2012). Besides, fire distinguisher, underground water recharge with sources of money, such as fishing or aquaculture, urban agriculture, beautification and aesthetic views. However, these have been subjected to gradual disappearance recently as well as significant degradation of their water quality. In this context, Remote Sensing (RS) and Geographical Information System (GIS) techniques are being widely used to assess natural resources and monitor environmental changes. Also, it is possible to analyze land use change dynamics using time series of remotely sensed data. The incorporation of GIS and RS can help analyze this kind of research in a variety of ways like land cover mapping, detecting over the time (Lambin 2001). With the advancement of technology, availability of historic spatiotemporal data and high satellite images, GIS and RS techniques are now very useful for conducting research like land cover change detection analysis (Mundia and Aniya 2005).

Bangladesh is one of the densely populated countries in the world. In recent times, this country has witnessed rapid, unplanned urban expansion accompanied by serious environmental degradation. Owing to the accelerated urban growth, the area has experienced serious environmental degradation and a number of ecological problems (Rana 2011; Hasan et al. 2013; Banu 1995). Nearly 56% of the land cover had undergone changes, mainly because of the expansion of built-up areas and other human activities over 36 years along with the city expanded by 618%, with an average annual rate of increase of 17.5% (Hassan and Nazem 2015). The Chittagong Metropolitan city is the second largest city in Bangladesh based on population size and land area (Rahman 2012). Besides, it is also the Divisional headquarter of Chittagong Division. According to the World Urbanization Prospective Report (2009 revision) Chittagong is 56th urban agglomeration and 10th fast growing city in the world. The busiest sea port of the country makes the city as one of the main international business hub, as well as the commercial capital of the country. The Chittagong Metropolitan area has the population of 3.83 million (BBS 2008) in 770 square kilometers of land area (CDA 2008, Ch. P.1). The rapid growth of population, urbanization and industrialization have created a tremendous pressure on land and changes in the city. At present, UWBs are in severe threats, like disappearing, changing in size, depth and shape rapidly due to natural and man-made activities. Attitudes toward UWBs are changing. These are no longer viewed as degraded systems of little value, but as more productive ecosystems with intrinsic values in their own right (Tyler 2006; Francis 2014; Hassall 2014). The role of UWBs in providing important regulating and cultural ecosystem services is also increasingly recognized (Voelker and Kistemann 2013). Hence, the paper attempts to explore the spatiotemporal changes of Urban Water Bodies (UWBs) in the Chittagong Metropolitan City (CMC) from 1989 to 2015, using Remote Sensing (RS) and Geographic Information Systems (GIS) analytic techniques.

Methods and Materials

Selection of the Study Area

The study area is located between 22° 15 and 22° 25 north latitudes and between 91° 45 and 91° 55 east longitudes along the southeast coast of Bangladesh, bounded by the Karnaphuli River and its tributary the Halda River to the south and east, by the Bay of Bengal to the west and by a range of hills to the north (Fig. 1). The metropolitan area is greatly influenced by the seasonal monsoon climate, for example the mean annual rainfall is 2687 mm and mean annual temperature is 26.24 °C (Ahmed and Alam 2008). Besides, the area accommodates about 5 million inhabitants within the urbanized territory (BBS 2011).

Data Acquisition and Preparation

A series of comprehensive geospatial datasets, Landsat images and field survey method were used to explore the spatiotemporal changes of UWBs in Chittagong Metropolitan City (Fig. 2). These geospatial data were collected from various sources, including the Chittagong Development Authority (CDA) 1995, 2001, 2006 and 2008; Survey of Bangladesh (SOB), 1955, 1960, 1984 and 2008, Google Earth, 2015, and Space Research and Remote Sensing Organization (SPARRSO) at 2013 (Table 1). For detecting Urban Water Bodies (UWBs), the study analyzed to nine types of maps from different sources. These maps helped to detect the existing Urban Water Bodies (UWBs) in the Chittagong Metropolitan City. Besides, the '*Ground Truthing Method*'[1] has helped to detect emerging and filled-up water bodies from 1979 to present in the Chittagong Metropolitan city. Moreover, to calculate the number of

[1] Ground Truthing is a term used to refer the absolute truth of something. Ground Truth = Estimated Accuracy (Go to 100 sites, right 90 times, 90% accuracy). Ground truth is an integral part of the use of remotely sensed data for land use change prediction.

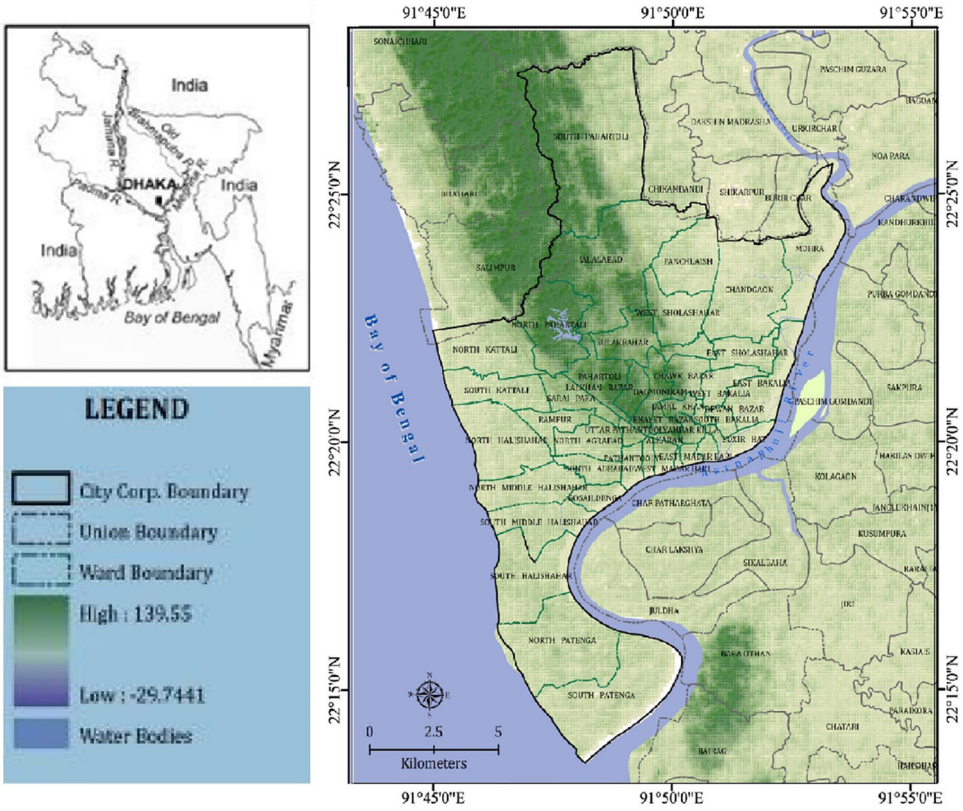


Fig. 1 Location map and digital elevation of the study area

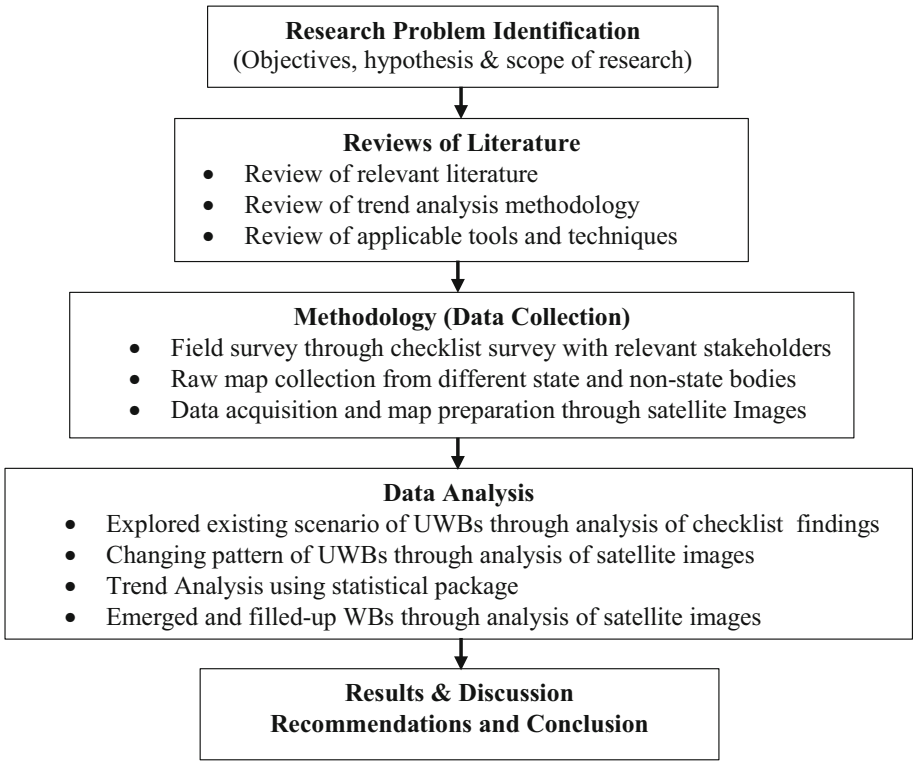


Fig. 2 Research flowchart

Table 1 Data types and sources used in this study. *Source*: Chittagong Development Authority (CDA) 2001, 2006, Survey of Bangladesh (SOB), 2008, 1984: SPARRSO, 1989, 2001, 2010 and 2015: Google Earth, 2015

Types of data	Resolution/scale	Year	Source
Base Map	1:250,000	2001, 2006	CDA
Topographic Map	1:250,000	1955, 1960	SOB
Google Earth Image		2015	Google Earth
Chittagong City Guide map	1:16,600	2008	SOB
Chittagong City Generalized Land Use Map	1: 50,000	1984	SOB
Landsat TM and OLI 1989, 2000, 2010 and 2015	30 M spatial resolution	1989, 2000, 2010, 2015	SPARRSO
Chittagong Metropolitan Master Plan and Detail Area Plan		2008	CDA
Chittagong City Corporation Administrative Map	1:50,000		CDA
Aerial Photography	1:50,000	1995	CDA

TM, Thematic Mapper; OLI, Operational Land Imager

water bodies, checklist survey has been done. As well as different types of maps were collected, including base map, topographic map, Google earth image, guide map, land use map, master plan and detail area plan, administrative map and aerial photography. To explore the spatiotemporal changes of UWBs, a time series of Landsat data, including imagery from 1989, 2001, 2010 and 2015 (30 m spatial resolution) were collected from Space Research and Remote Sensing Organization (SPARRSO). These images were analyzed to investigate the changing patterns of UWBs from 1989, 2001, 2010 and 2015 years and compared their emerged and filled between 1989 to 2001, 2001 to 2000 and 2000 to 2015 in Chittagong Metropolitan city.

To explore the changing patterns of UWBs, the study was carried out using integrated technology of Remote Sensing and Geographic Information System (GIS). Standard procedures of geo-referencing, image interpretation and on-screen digitization to generate water body data layers were carried out using ERDAS Imagine software. GIS analyses were carried out using ArcGIS software to reveal the changing scenario of water body in the study area. Basically, two types of data were used for exploring the spatiotemporal changes of WBs such as raster satellite data and vector data. The raster data were acquired from Landsat TM images (Figs. 3, 4 and Table 2).

Figure 4 shows the flow chart used for raster data processing, water body vector data layer generation and vector data analysis.

Geometric correction of the image; the satellite image of 1989 was provided by SPARRSO as a geometrically corrected image. This image was used as the reference image for geometric correction of the satellite images of 2001, 2010 and 2015. Projection used for the images was Transverse Mercator. The correction procedure involves generation of ground control points (GCP), calculation of transformation metrics using the GCPs and re-sampling of the image to be geometrically corrected using the transformation metrics. The GCPs has been generated from the reference image (1989), using the ERDAS Imagine software. Nearest neighbor method was used for re-sampling of the image. After geometric correction of the full image (185 km * 185 km), the image of the study area was extracted from it using the subset tool of ERDAS Imagine software. *Visual interpretation of images* was used to identify the surface features of the study area on the images, the images were interpreted visually. Based on the visual interpretation, the water bodies in the study area were generated. Visual interpretation of images of various years was carried out based on standard technique of color and texture analysis using the false color composite (R-4, G-3, B-2 for Lansdsat TM and R-5, G-3, B-2 for Landsat OLI) of the image. *Generation of thematic data layers* was based on the visual interpretation of the images, thematic data layer of the water body was generated from the images using on-screen digitization technique. The thematic data layers were generated in vector format. ERDAS imagine software was used for generation of thematic data layers. Management of thematic data layers and change of the UWBs detection were used for GIS technique through the vector data layers managing following steps;

- Building the topology of each data layer.
- Assignment of identification of each data layer.

Overlay of the water body data layers of all the study year was carried out to form a composite data layer. The composite data layer contained identification of water bodies of each year which were used for addressing it in order to generate change classes of water bodies over the study period. Logical operations were carried out on the

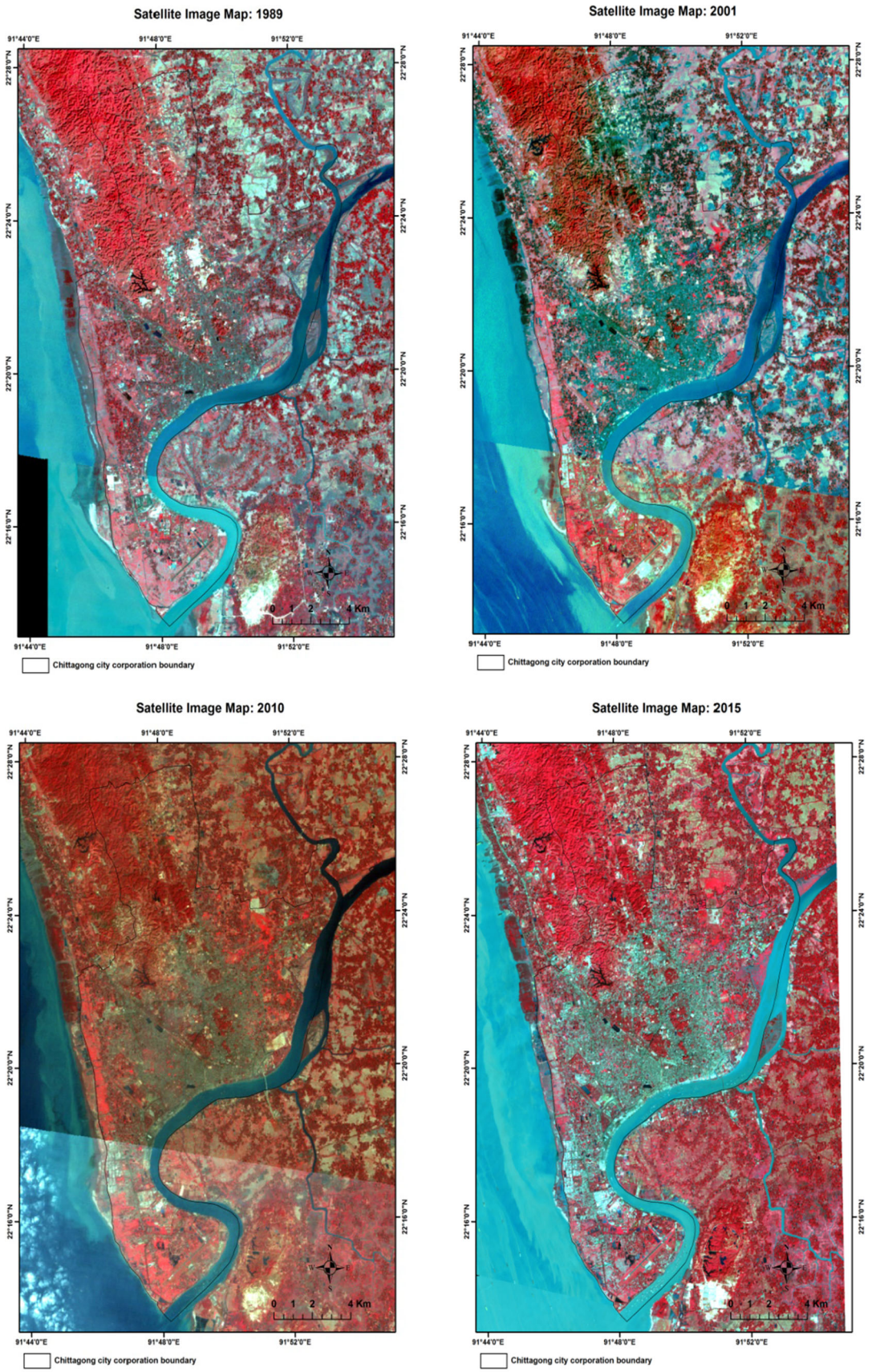


Fig. 3 Landsat TM images used for the study

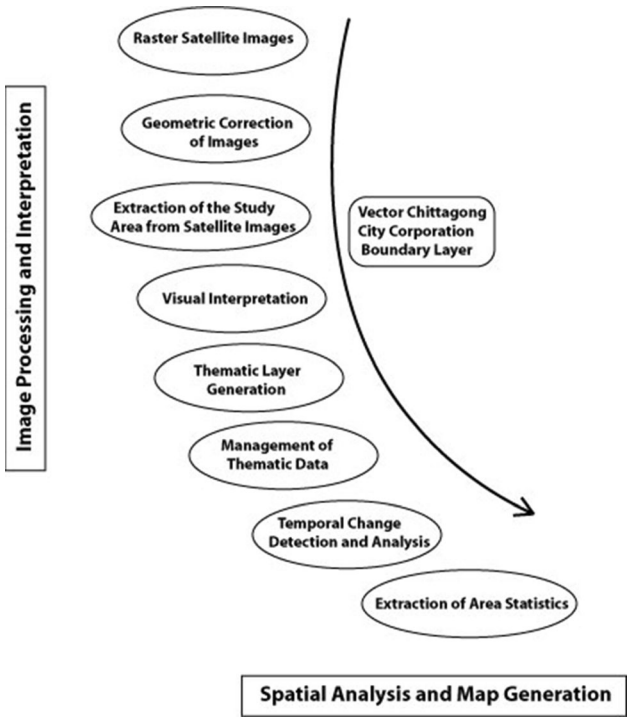


Fig. 4 Raster data processing and analysis stages followed during the study

composite data layer to generate the multi-temporal change classes. Statistical information on the area of water bodies in each year and on the change classes was derived from the attribute table of the composite data layer. Arc GIS software was used for data management and change detection analysis. Meaningful data were analyzed the different type of software's such as ArcGIS 9.3, ERDAS IMAGINE 2011, Statistical Package for the Social Science (SPSS) software version: 20 and narrative analysis techniques. In addition, Regression Analysis technique was applied to an estimated changing scenario of WBs along with trends of UWBs in Chittagong Metropolitan City.

Results and Discussion

Existing Urban Water Bodies (UWBs) Scenarios in the CMC

The Chittagong Metropolitan City is situated on the bank of coast which is influenced by tidal fluctuation, unique topographic phenomena and humid climate along with hotspot of biodiversity. It is also located at the intersection of many bio-geographic divisions (Islam 2009). The study explored nearly 1249 types of water bodies identified through the checklist survey and '*Ground Truthing Method*' along with 1352 types of water bodies were detected through interpreted series satellite images in a whole Metropolitan area including 41 Metropolitan wards (Table 3).

In Chittagong City, water bodies could be found in every ward. However, maximum water bodies were detected on the western side or along with seaside areas, particularly North Halishahar, South Middle Halishahar and North Middle Halishahar.

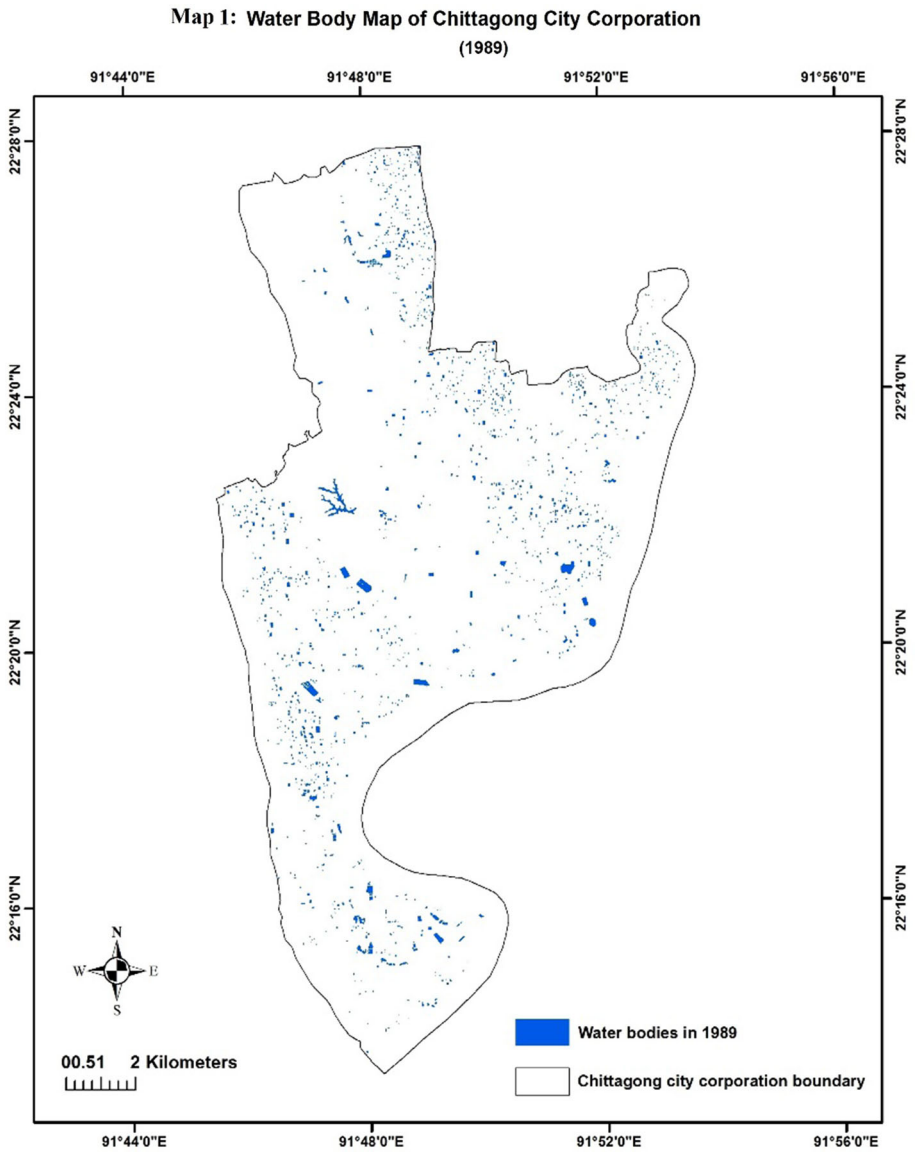
Changing Patterns of Urban Water Bodies from 1989 to 2015 in Chittagong Metropolitan City

To detect the Urban Water Bodies since 1989 to 2015, the study was used to series satellite images, including 1989, 2001, 2010 and 2015, respectively. These images identified that the number of water bodies was gradually decreased in CMC. For instance, in 1989 total water bodies were 1605, but in the year of 2001 were detected 1526. In 2010, the total WBs were 1400 and in 2015 total WBs were 1352 (Fig. 5). Besides, checklist survey reveals that unplanned urbanization, industrialization and infrastructural development, urban land pricing, new residential and commercial area expansion and sometimes illegal constructions of slums and squatters for urban poor and climate displacement peoples have accelerated the rate of decrease of UWBs in CMC.

Table 2 Data characteristics. *Source*: SPARRSO, 1989, 2001, 2010 and 2015

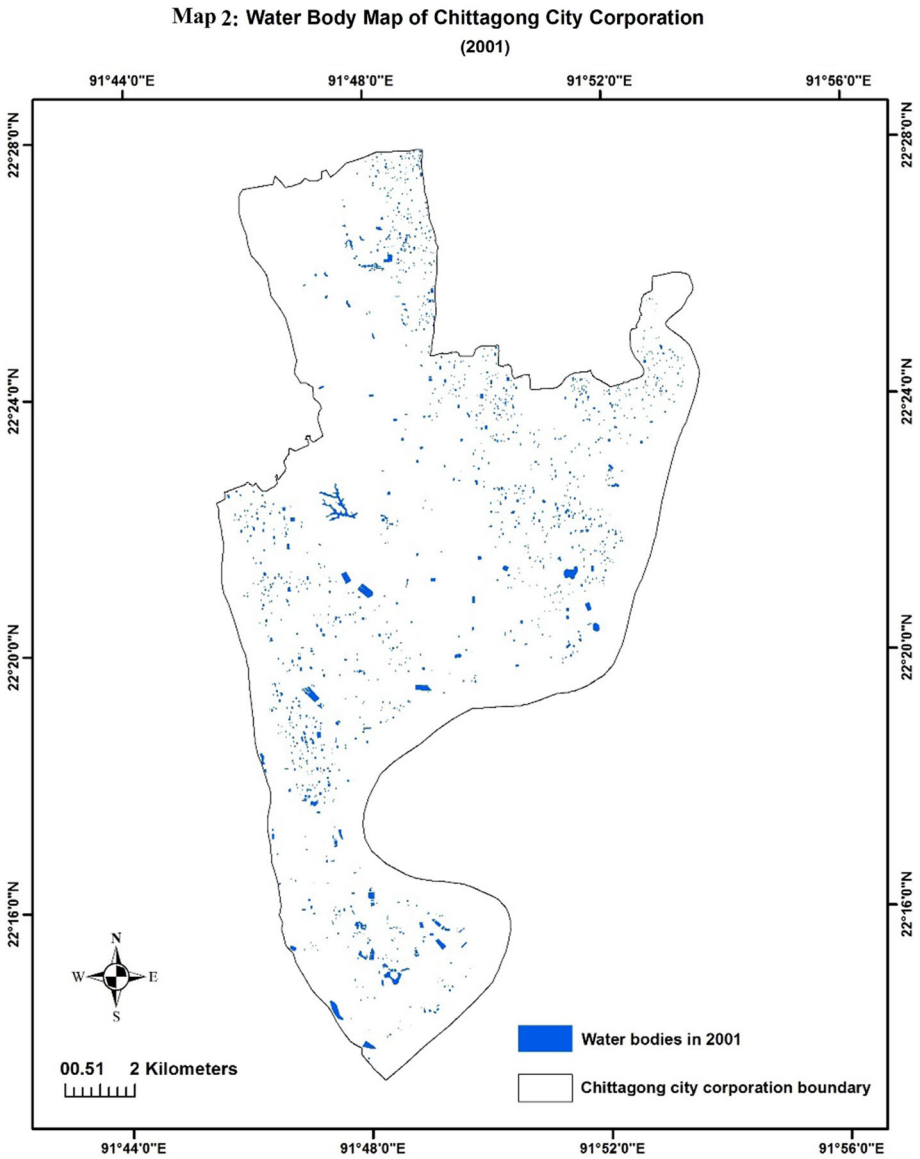
S. no	Satellite (sensor)	Bands	Resolution/scale	Date of acquisition	Year	Source
1	Landsat TM	1, 2, 3, 4, 5	30 m	05-01-1989	1989	Earth explorer (SPARRSO)
2	Landsat TM	1, 2, 3, 4, 5	30 m	07-02-2001	2001	
3	Landsat TM	1, 2, 3, 4, 5	30 m	08-02-2010	2010	
4	Landsat OLI	2, 3, 4, 5, 6	30 m	22-02-2015	2015	

TM, Thematic Mapper; OLI, Operational Land Imager



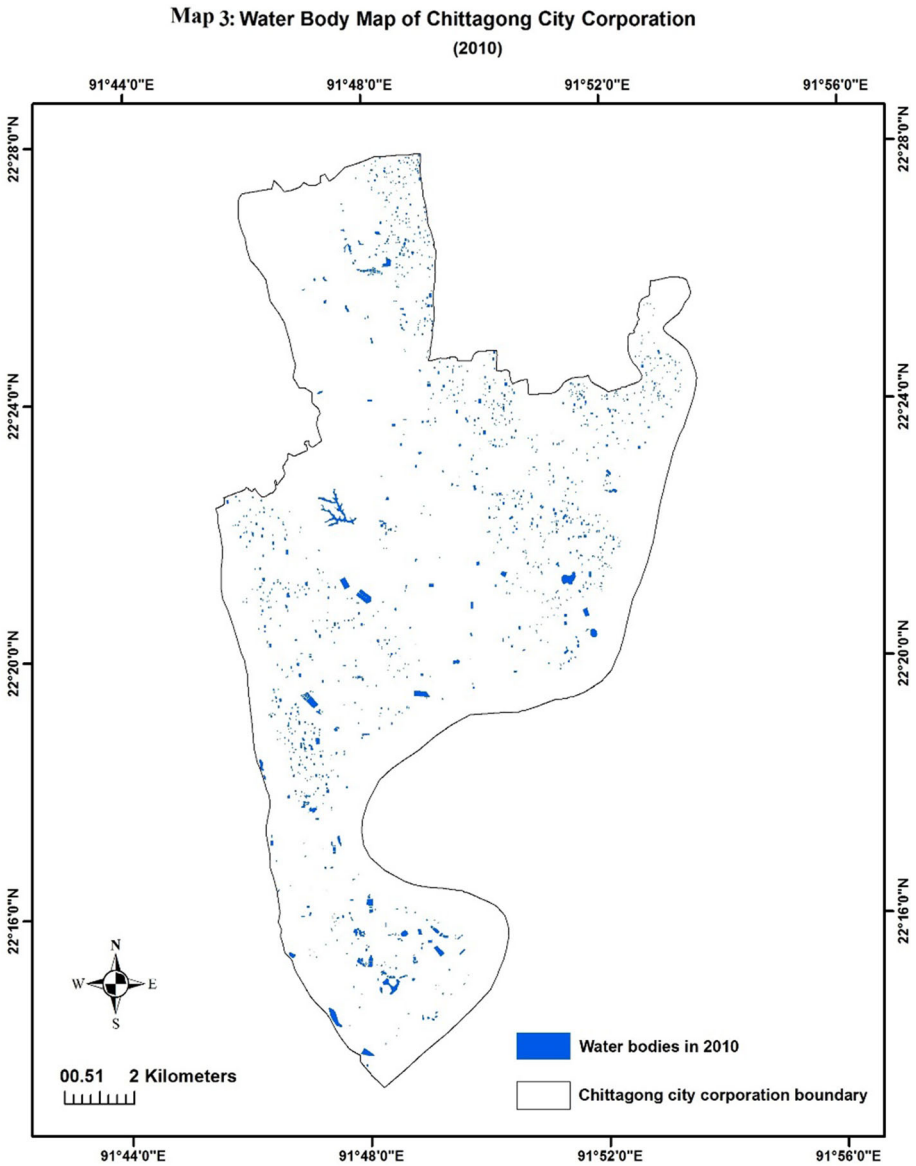
Source: Based on Satellite Image collected from SPARRSO, 2014

Nearly 1605 types of water bodies were detected during the identification of Map in 1989 from a supplied satellite image of the Chittagong Metropolitan city (Map 1). Water bodies were concentrated western side and northeastern side while the central area is hilly and undulating area. In Western and eastern sides exist a lot of humid or fallow land of Chittagong city existed. Alternatively, urban water bodies were tremendously filled-up alongside of the Karnofully river because of the functional activities, especially the establishment of the small and middle scale industries near the bank of the river. As a result, fallow lands and water bodies were filled-up gradually.



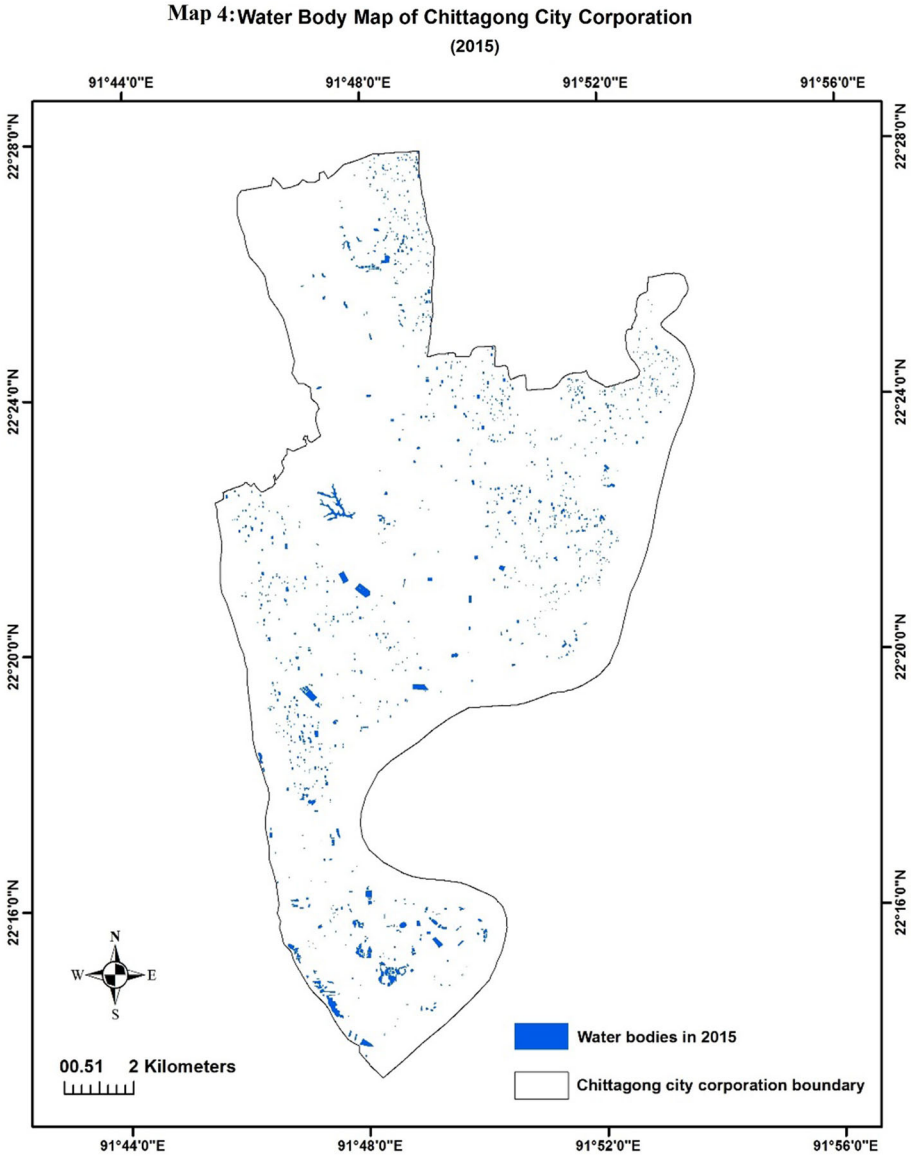
Source: Based on Satellite Image collected from SPARRSO, 2014

Almost 1526 types of water bodies were detected during the identification of UWBs of Map in 2001 supplied satellite image in the Chittagong Metropolitan city (Map 2). Water bodies were concentrated in western and northeastern side. Although the central area was hilly, huge humid or fallow lands were existed in the western and eastern side of the Chittagong city.



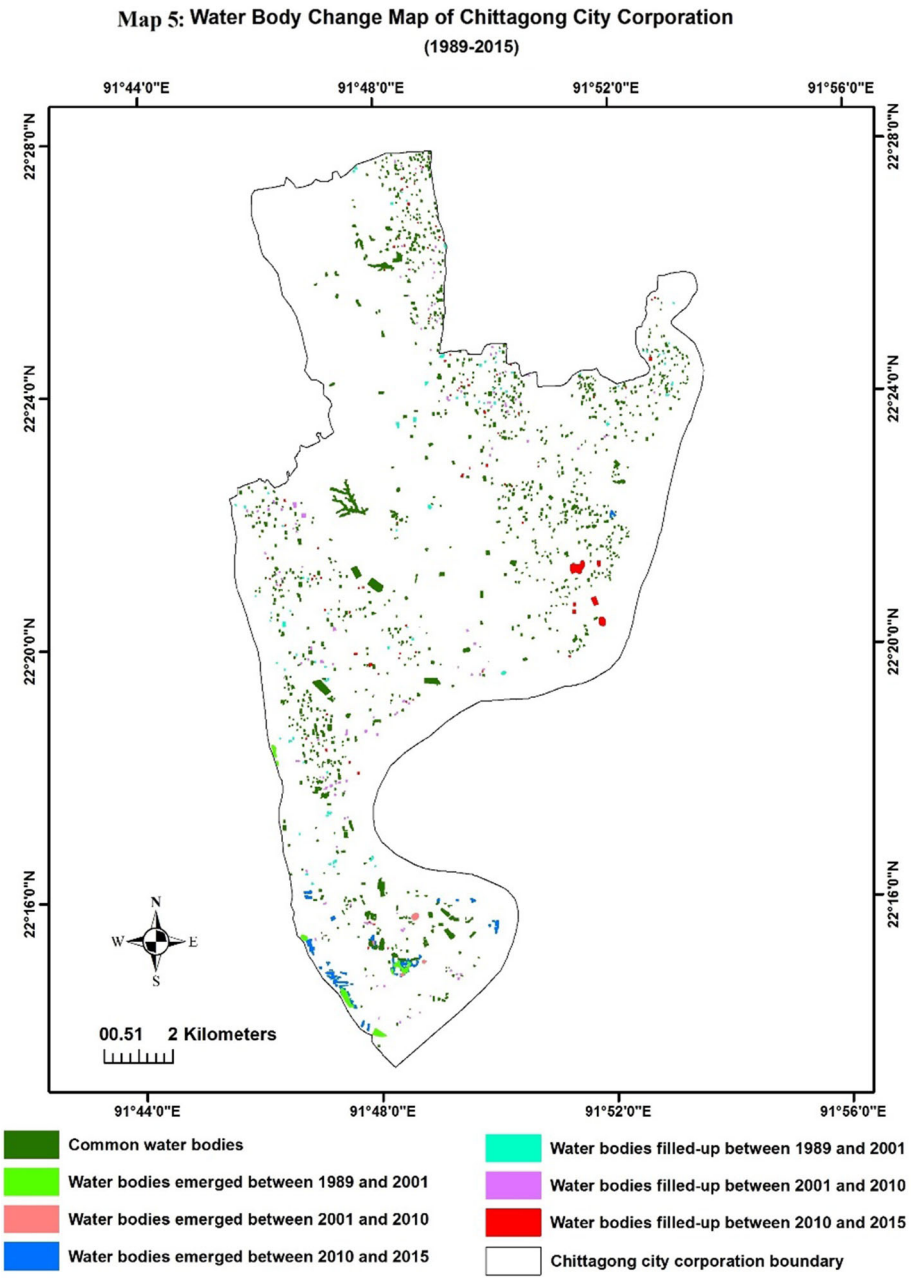
Source: Based on Satellite Image collected from SPARRSO, 2014

Nearly 1400 types of water bodies were detected during the identification UWBs of Map in 2010 supplied satellite image in the Chittagong Metropolitan city (Map 3). Identified water bodies were concentrated in western and northeastern side. Although, the central area was hilly, huge humid or fallow lands were existed in the western and eastern side of the Chittagong city.



Source: Based on Satellite Image collected from SPARRSO, 2014

Total 1352 types of water bodies were detected during the identification of UWBs of Map in 2015 supplied satellite image in the Chittagong Metropolitan city (Map 4). Identified water bodies were concentrated in the western and northeastern side. Although the central area was hilly and huge humid or fallow lands were existed in the western and eastern side of the Chittagong city. In addition, map 5 illustrates the changing patterns of urban water bodies in the Chittagong Metropolitan city. Total seven types of color shading were used for representing common water bodies, emerged water bodies from 1989 to 2001, 2001 to 2010 and 2010 to 2015 and filled-up water bodies from 1989 to 2001, 2001 to 2010 and 2010 to 2015, respectively.



Source: Based on Satellite Image collected from SPARRSO, 2014

Trend Analysis of UWBs in Chittagong Metropolitan City

For trend analysis, linear regression model has successfully applied to measure the relationship between years and measuring issues, like temperature and sea level (Uddin et al. 2015; Radzi and Ismail 2013). Table 4 and Fig. 6 has been exploring the projection of the changing pattern of urban water bodies addressing the satellite images as well as past and future scale for the trend, impact and projection of water bodies in the Chittagong Metropolitan City.

Here the fixed linear regression model was $y = -10.007 \times +21{,}522$ and $R^2 = 0.9738$.

Where y = Year (Satellite images); x, outcome variable = Number of water bodies; independent variable (Fig. 7).

Here, the intercept term 21,522 means that every year the constant maximum Area (Hectare) was 21,522 in Chittagong Metropolitan area. The regression coefficient was -10.007 means that, the Area (Hectare) was increased -10.007 times every year or 12% more from its previous counterpart (Fig. 7).

Table 3 Total number of Urban Water Bodies (UWBs) in the CMC. *Source*: Checklist Survey, December, 2014 to March, 2015

Ward no	Ward name	Ward to ward survey of water bodies	Satellite image digitizing
1	South Pahartali	95	
2	Jalalabad	51	
3	Panchlaish	54	
4	Chandgaon	85	
5	Mohra	46	
6	East Sholashahar	17	
7	West Sholashahar	12	
8	Sulakbahar	17	
9	North Pahartali	9	
10	North Kattali	82	
11	South Kattali	40	
12	Saraipara	28	
13	Pahartali	11	
14	Lal Khan Bazar	2	
15	Bagmoniram	17	
16	Chawk Bazar	16	
17	West Bakalia	19	
18	East Bakalia	52	
19	South Bakalia	14	
20	Dewan Bazar	4	
21	Jamal Khan	3	
22	Enayet Bazar	2	
23	North Pathantooli	8	
24	North Agrabad	34	
25	Rampur	9	
26	North Halishahar	141	
27	South Agrabad	15	
28	Pathantooli	5	
29	West Madarbari	2	
30	East Madarbari	4	
31	Alkaran	3	
32	Anderkilla	2	
33	Firingee Bazar	6	
34	Patharghata	6	
35	Boxir Hat	20	
36	Gosaildanga	12	
37	North Middle Halishahar	57	
38	South Middle Halishahar	115	
39	South Halishahar	44	
40	North Pothenga	44	
41	South Pothenga	46	
Total		1249	1352

Note:

$= -10.007 \times$ means $(-10.007 \times$ total years)
$= -10.007 \times (2015–1989)$
$= -10.007 \times 26$
$= -260.18$ (Downward trends)

To validate satellite images counting, time series data analysis method has been used. The water bodies disappeared rate of last 26 years (2015–1989) is (–) 260.16. The key findings of the analysis show that the disappearing number of water bodies increases the rate of (–) 260 per 26 years which is shown in Fig. 8. Similarly, the

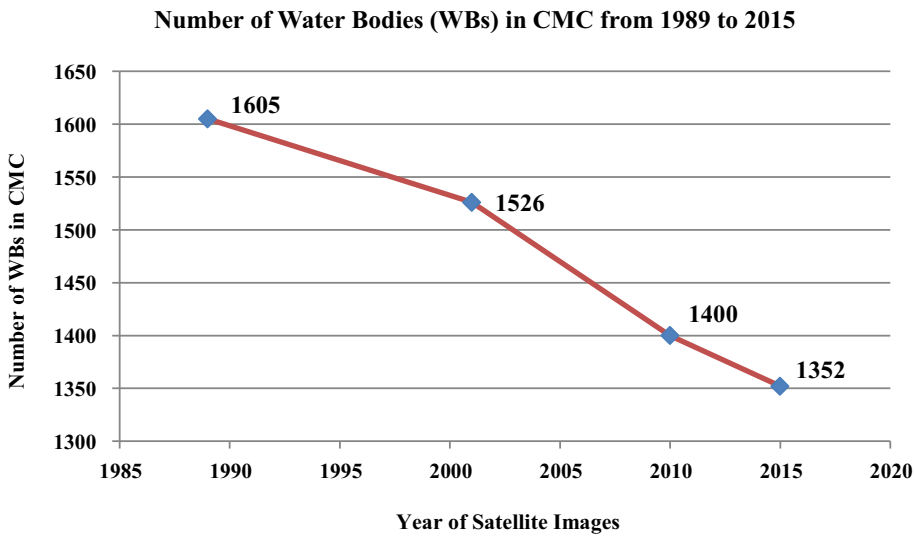


Fig. 5 Detecting of Urban Water Bodies Since 1989 to 2015 in CMC

Table 4 Projected change of number of urban water bodies in CMC

Year	Number of urban water bodies
2010	1400
2020	1300
2030	1200
2040	1100
2060	900
2100	700

disappearing number of water bodies increases the rate of (–) 10 per years.

Emerged and Filled-Up of Urban Water Bodies in CMC Since 1989 to 2015

Emerged and filled-up urban water bodies were frazzling conditions in the Chittagong Metropolitan City (Table 5).

Historical documents, critical literature reviews, Key Informant Interviews (KIIs), checklist survey and observation (overt) methods explored that the few water bodies were in excavated in the south Patenga area for aquaculture purposes, especially for commercial fishing of telapia, shrimp and crab during the 1990 decade. Alternatively, last 1990 decade to 21st decade a number of water bodies were excavating for soil collection to build the Port Connecting Road and some were for commercial fishing purposes alongside of the west coast and south Patenga ward in the Chittagong Metropolitan city. Following maps 6, 7 and 8 show the emergence of urban water bodies and their absolute locations in the Chittagong Metropolitan City. However, it indirectly shows that the water body emerging rate was positive, but filled-up rate was rapid. For uneven fluctuation of the number of emerging water bodies in CMC, it creates problems for further statistical interpretation. In some special cases, urban water bodies were emerged in the Chittagong Metropolitan City but the actual feature was different. The filled-up rate of UWBs has visualized the real scenario of water bodies in the Chittagong Metropolitan City. These rates were slow and emerging places of water bodies were agglomerated. If the emerge of water bodies were dispersedly distributed, then it can be clearly said that the emergence of the water bodies were positive.

Urban water bodies in and around the city of Chittagong have been being filled-up from the last couple of years.

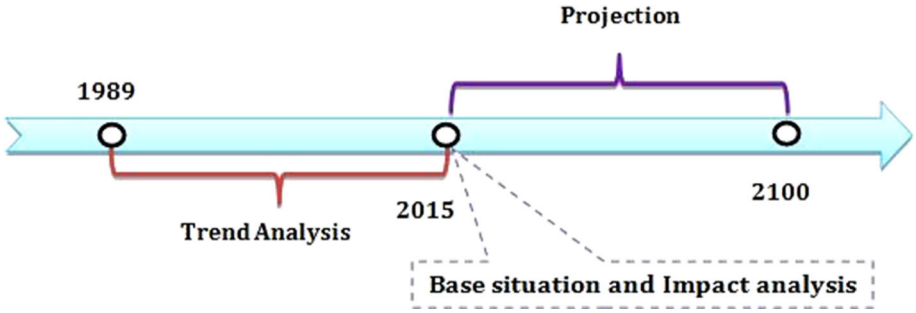


Fig. 6 Past and future time scale for the trend, impact and projection of water bodies

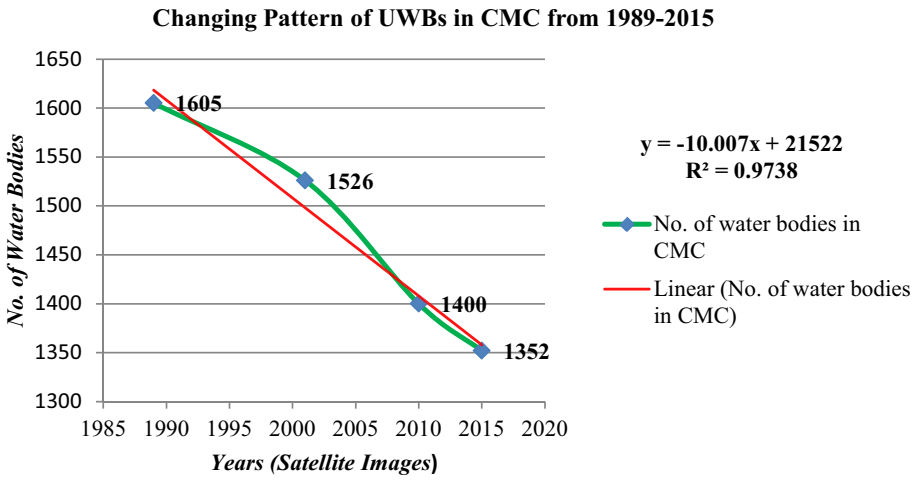


Fig. 7 Changing pattern of UWBs in CMC from 1989 to 2015

Fallow Landfills for building new settlements in South Halishaher

Pond filled-up for expansion of land in Muhammadpur area south Shaloshar

Concrete fills on pond for building new homes in Bakolia area

Bamboo wall built or capturing of pond area in the south Patenga area

Fully filled-up pond for building new settlements

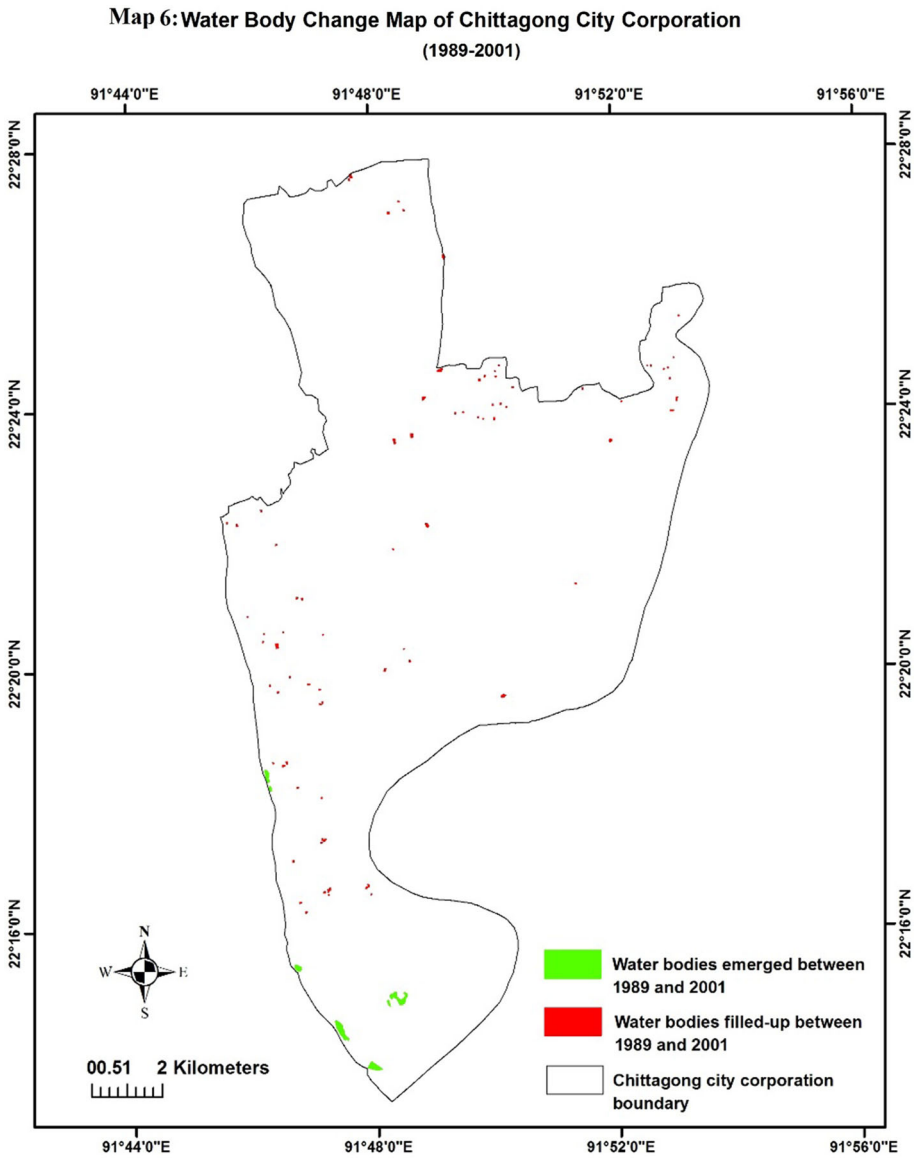
Naturally filled-up of siltrated surface loose materials from long time

Fig. 8 Filled-up water bodies in Chittagong Metropolitan City

Table 5 Emerged and filled-up of Urban Water Bodies in CMC since 1989 to 2015. *Source*: Prepared by authors, 2019–2020. Source: Analysis of satellite images 1989, 2001, 2010 and 2015; Landsat TM & OLI (Thematic Mapper and Operational Land Imager)

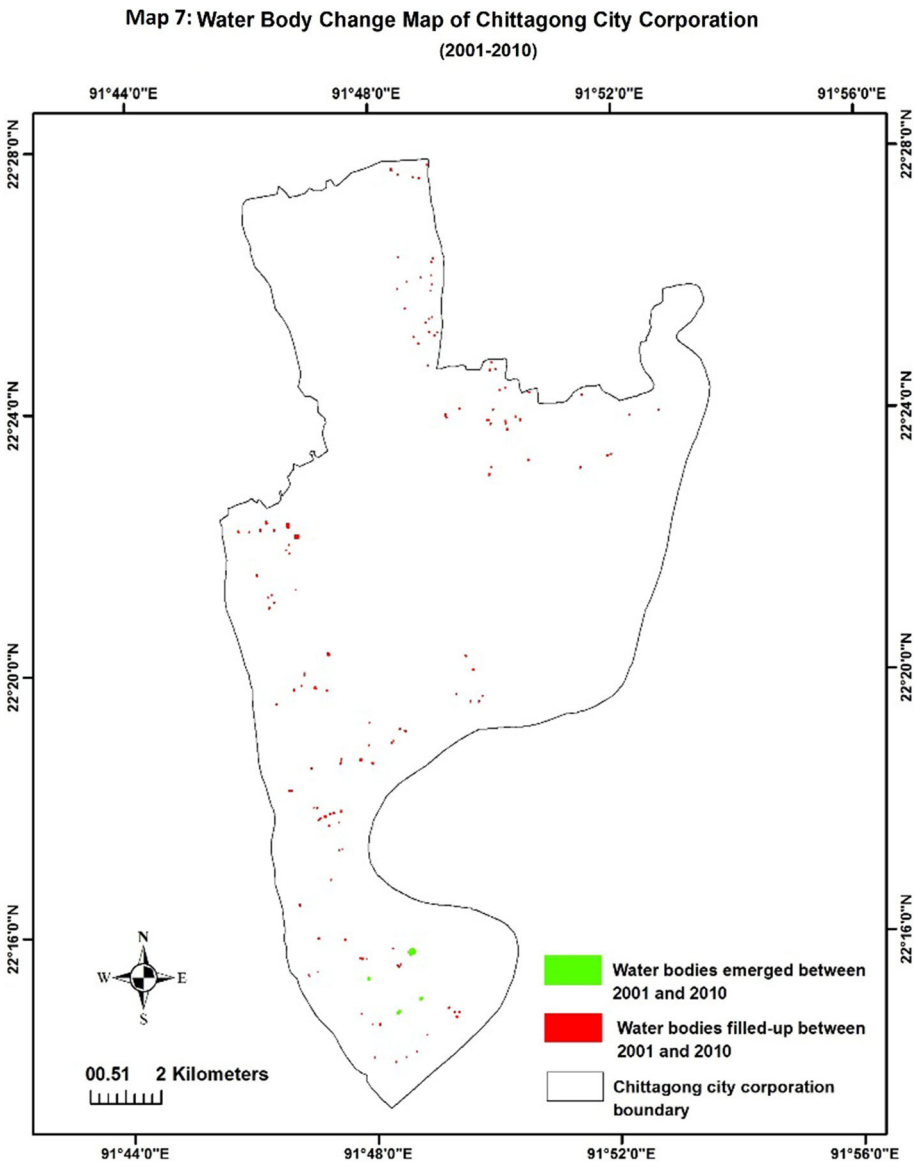
Sl. no.	Change class	Area (ha)	No
Emerged Water Bodies in Chittagong Metropolitan City			
1.	Water bodies emerged between 1989 and 2001	23.57	10
2.	Water bodies emerged between 2001 and 2010	4.78	5
3.	Water bodies emerged between 2010 and 2015	37.45	47
Filled-up Water Bodies in Chittagong Metropolitan City			
1.	Water bodies filled-up between 1989 and 2001	16.12	86
2.	Water bodies filled-up between 2001 and 2010	19.37	129
3.	Water bodies filled-up between 2010 and 2015	29.97	90

Almost 100 years old ponds in the city were also being filled-up by hill cutting soil (Alam et al. 2005). The current study reveals that the filling of urban water bodies in the Chittagong Metropolitan city was accelerated by different types of reasons. Two of the main reasons are natural causes and anthropogenic or man-made causes. Natural causes were less important than the man-made causes for the filled-up water bodies in this city. Natural causes, especially excessive precipitation and the shortage of impervious topography have been spread of surface runoff of rainwater. This runoff was washing the surface loose topographical materials and these materials were moving with surface runoff. In this way, the water was discharged at adjoining water bodies, low-lying and fallow land areas. These loose materials deposited on the water bodies, low-lying and fallow land areas. As a result, water bodies, low-lying and fallow land areas were filled-up naturally. On the other hand, man-made causes were the main causes for filling urban water bodies in the Chittagong Metropolitan city. This cause was comprised of different categories such as unplanned urbanization, rapid industrialization, new settlement and housing building, land pricing, fragmentation of inherited lands, unlawful encroachment and violence of Real Estate Corporation. The Chittagong Metropolitan city is an industrial hub, business capital, district headquarter and port city in Bangladesh. For this reason, a huge agglomeration of people occurs in this city for various purposes, especially for job opportunity, service purposes and better quality education and lifestyle. Disaster internally displaced people for natural disaster were also coming from adjacent districts for dwelling here. As a result, the urban population has been gradually increasing and that growth rate hampers urban governance in Chittagong city. Besides that infrastructural development activities were done in unplanned ways. As a result, dishonest people filled-up water bodies, low-lying topography and fallow land to prepare land for industrial development and housing purposes. These activities have been increasing the land price in this city. Poor and middle class land owner filled-up their land for selling or building new settlements for high rent purposes. The city dwellers also argued that, after 1995 to 2005, significant appearance of the violence of 'Real Estate Company' directly or indirectly involved filling up urban water bodies for building new apartment or housing in this city. They target land owner of extended family and economically poor land ownerships. They are easy to convince the family member and to giving high price of land or build the apartment. Although the land filling is prohibited by the existing laws, these laws should be strictly implemented by the authority of the Department of Environment (DoE). Negation of working authority and personnel of 'Real Estate Company' results in unlawful initiatives occurring in this city. Moreover, Metropolitan dwellers believed that the fragmented inherited land is another prime cause for filling water bodies in this city. A father divided his land to his children and children use his/her land for their own needs. Commonly, poor land owners usually fill their low-lying areas for building new settlement purposes. Sometimes, the water bodies were intentionally filled-up for the shortage of homestead and acquire land for new settlement purposes. This filling process has been being done very slowly. At first households' wastages, building or construction wastes and unused household furniture were continuously dumping into water bodies. A few days later, these water bodies lose their aesthetic views and water gets degraded. Sometimes land owners fill the edge of ponds by creating a bamboo wall. This process has been being continued for filling the water bodies. This process is carefully done because they are only afraid of movement of DoE. City dwellers expressed that the initiatives of DoE were appeared for saving of urban water bodies in the Metropolitan area. We also got the information from the dwellers that sometimes the authority gives a financial punishment to the landowners for filling their own land.



Source: Based on Satellite Image collected from SPARRSO, 2014

During 1989 to 2001, total 86 numbers of water bodies were filled-up in the Metropolitan Area. Maximum water bodies were filled-up in western and southern areas situated along side of the coast and southeastern areas of this city. In the central and south portion of the city, less filling activities were occurring. Although central and south portions of the city were covered by high land, in these area water bodies were filled-up by siltration processes because of excessive hill cutting. In map analysis (Satellite images) it is visualized that, maximum water bodies were filled-up in the wards 02 (Jalalabad), 05 (Mohra), 11 (South Kattali), 12 (Saraipara), 13 (Pahartali), 24 (North Agrabad), 26 (North Halishahar), 37 (North Middle Halishahar), 38 (South Middle Halishahar), 39 (South Halishahar) and 40 (North Pothenga), respectively. There were four reasons that accelerated the filling of water bodies of these wards: industrial, residential, commercial and functionalities of Chittagong port. Water bodies were filled in wards no 02 (Jalalabad), 05 (Mohra), 11 (South Kattali), 12 (Saraipara) and 13 (Pahartali) for installation of new industries and settlements or residential area purposes. In ward no 24 (North Agrabad), water bodies were filled-up for the installation of a new commercial center and residential purposes. In wards no 26 (North Halishahar) and 37 (North Middle Halishahar), water bodies were filled-up for residential purposes (housing or apartment). In wards no 38 (South Middle Halishahar), 39 (South Halishahar) and 40 (North Potenga), water bodies were filled-up for commercial, residential and functionalities of Chittagong port purposes. However, out of these wards, water bodies filled-up during this time for the above mentioned reasons in the whole Metropolitan area.

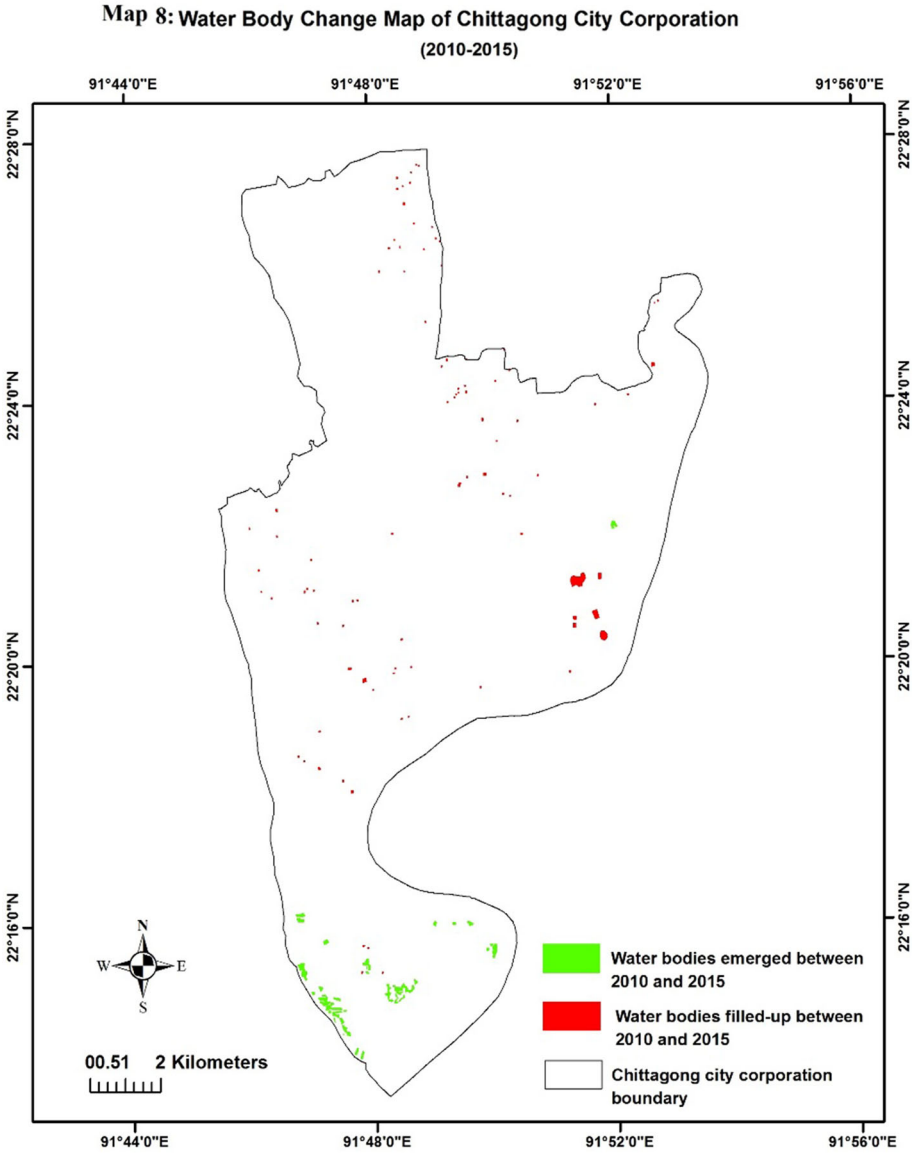


Source: Satellite Image collected from SPARRSO, 2014

During 2001 to 2010, total 129 water bodies were filled-up in the Metropolitan Area. Maximum water bodies were filled-up in western and northern areas which were situated along side of the coast and Chittagong port areas and southeastern areas of this city. In the central and south portion were of the city such activities less. Although central and south portions of the city are covered by high land, in map analysis (Satellite images), it has been visualized that the maximum water bodies were filled-up in the wards 01 (South Pahartali) 02 Jalalabad 03 (Panchlaish) 04 (Chandgaon) 05 (Mohra) 10 (North Kattali) 12 (Saraipara) 22 (Enayet Bazar) 26 (North Halishahar) 30 (East Madarbari) 31 (Alkaran) 32 (Anderkilla) 37 (North Middle Halishahar) 38 (South Middle Halishahar) 39 (South Halishahar) 40 (North Pothenga) 41 (South Pothenga), respectively.

To build a new residential (housing block) or residential apartment purposes, water bodies were filled-up on these wards such as 01 (South Pahartali), 02 Jalalabad, 03 (Panchlaish) 04 (Chandgaon), 22 (Enayet Bazar), 26 (North Halishahar), 30 (East Madarbari) 31 (Alkaran) and 37 (North Middle Halishahar), respectively. Besides, to build a new residential area and installment of new industries, water bodies were filled-up in the wards no 02 Jalalabad, 05 (Mohra), 12 (Saraipara) and 41 (South Pothenga). Moreover, to build a new residential and commercial apartments, water bodies were filled-up in the wards no 32 (Anderkilla), 38 (South Middle Halishahar) and 39 (South Halishahar). Wards no 38 and 39 were not directly affected by the functionality of Chittagong port. In addition, to build create a new industry or industry cum building, water

bodies were filled-up in the wards no 05 (Mohra), 10 (North Kattali) and 40 (North Pothenga). Ward no 5 was influenced by Kalurghat industrial activities, ward no 10 onward was influenced by Faujdarhat industrial activities and ward no 40 was influenced by the Patenga industrial area, respectively.



Source: Based on Satellite Image collected from SPARRSO, 2014

During 2010 to 2015, total 90 numbers of water bodies were filled-up in the Metropolitan Area. Maximum water bodies were filled-up the middle portion of the western, southern and eastern areas. Water bodies filled-up in whole city areas, but filling activities were more noticeable in West Bakalia, East Bakalia and South Bakalia areas. In map analysis, (Satellite images) it is visualized that, maximum water bodies were filled-up in the wards 01 (South Pahartali), 02 (Jalalabad), 03 (Panchlaish), 04 (Chandgaon), 05 (Mohra), 06 (East Sholashahar), 07 (West Sholashahar), 08 (Sulakbahar), 10 (North Kattali), 11 (South Kattali), 12 (Saraipara), 17 (West Bakalia), 18 (East Bakalia), 19 (South Bakalia), 23 (North Pathantooli), 24 (North Agrabad), 25 (Rampur), 27 (South Agrabad), 30 (East Madarbari), 37 (North Middle Halishahar), 38 (South Middle Halishahar) and 41 (South Pothenga), respectively.

In Chittagong city, most of the hilly areas are found in the Thanas of Chandgaon, Double Mooring, Pahartali, Khulshi and Bayezid Bostami along with hills around the Foy's Lake area are the most famous hilly area within the city. Besides, Tiger Pass hill, Batali hill, CRB hill, Moti

Jharna Hill, Court hill, DC hill etc. are widely known as the hilly areas of the city. In these areas, water bodies were disappearing before due to surface seat wash erosions of hilly land, although few numbers of water bodies still exist. During 2010 to 2015, urban water bodies were filled-up for building new settlements, expansion of business center (shops) and shopping centers. During this period, the filled-up water bodies were medium and small size of water bodies. City dwellers argued that after 2000, Department of Environment (DoE) had increased their monitoring of urban water bodies for management aspects. Among 41 wards of the Chittagong Metropolitan city, 22 wards were identified for filling of water bodies. In special cases, a lot of water bodies were filled in the wards no 17, 18 and 19 namely West Bakalia, East Bakalia and South Bakalia, respectively. City folks opined that the wards no 17, 18 and 19 was a low-lying topographical and lower income generating settlers were settled in the Chittagong Metropolitan city. In these criteria, maximum area was covered by urban fallow land and household water sources. These fallow lands were used for household water source purposes for poor urban dwellers and somewhat used for fishing and alternative water sources for household level. Commonly, these lands were filled for building new apartments for renting purposes and installed new retail shops and garages.

Conclusion

In spite of their fundamental importance to humans, UWBs have been severely affected by a multitude of anthropogenic disturbances, which have led to serious negative effects on the structure and function of existing ecosystem. Whereas, Urbanization is an economic indicator and directly correlated to the country's development in developing countries like Bangladesh. However, unplanned urbanization has led to different types of economic, social and environmental problems in urban areas. Chittagong has unclassified, the irregular and heterogeneous character of its landuse. It is very difficult to identify the zoning in a particular area. As a result, city dwellers experience chaotic development activities here, such as lay-lying topography, spaces of urban water bodies and open land have been converted to new residential, industrial and commercial hubs. Consequently, city dwellers face urban flooding, scorching temperature due to changing urban micro-climate along with frequent fire hazard and extreme water crisis. Because UWBs have considered the alternate water sources for city dwellers and so on. In this situation, proper coordination of urban autonomous bodies, citizen awareness, community movement and inclusion of urban management related laws, rules and regulations and strong legislation would be necessary to reduce the negative impacts of unplanned urbanization in urban areas, particularly to save the urban environmental ecology through conserving or protecting the UWBs.

Acknowledgements This work received financial support from the Social Science Research Council, Planning Division, Ministry of Planning, the government of the People's Republic of Bangladesh (Ref.: 20.00.0000.309.02.815.12-116; Date: 19/01/2014). The author, Morshed Hossan Molla, acknowledged the Social Science Research Council, Planning Division, Ministry of Planning, the government of the People's Republic of Bangladesh, M.Phil fellowship program for supporting his M.Phil research.

References

Ahmed, S. S., & Alam, M. S. (2008). Rainfall in Chittagong City and aspects of drainage congestion: A spatio-temporal perspective. *Jahangirnagar University Journal of Science, 34*(1), 31–45.

Alam, M. E., Chowdhury, M. A. T., & Akbar, M. T. (2005). Aspect of socio-environmental problems resulting from hill cutting in the City of Chittagong Bangladesh: Local people's perspectives. *Pakistan Journal of Social Sciences, 3*(8), 1048–1052.

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

BBS. (2008). Statistical yearbook of Bangladesh 2011, Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. www.bbs.gov.bd.

BBS. (2011). Statistical yearbook of Bangladesh 2011, Bangladesh Bureau of Statistics, Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh. www.bbs.gov.bd.

CDA. (2008). *Chittagong development authority (physical feature survey in Chittagong Metropolitan City during 2006–2007)*. Andarkilla: Department of Geographical Information System.

Francis, R. (2012). Positioning urban rivers within urban ecology. *Urban Ecosystems, 15,* 285–291.

Francis, R. (2014). Urban rivers: Novel ecosystems, new challenges. *WIREs Water, 1,* 19–29.

Hassall, C. (2014). The ecology and biodiversity of urban ponds. *Wiley Interdisciplinary Reviews: Water, 1,* 187–206.

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

Hassan, M. M., & Nazem, M. N. I. (2015). *Examination of land use/land cover changes, urban growth dynamics, and environmental sustainability in Chittagong city*. Dhaka: Environment Development and Sustainability.

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

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

Kaufmann, R. K., Seto, K. C., Schneider, A., Liu, Z., Zhou, L., & Wang, W. (2007). Climate response to rapid urban growth:

Evidence of a human-induced precipitation deficit. *Journal of Climate, 20*(10), 2299–2306.

Lambin, E. F. (2001). Remote sensing and GIS analysis. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences*. Oxford: Pergamon.

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

Mundia, C. N., & Aniya, M. (2005). Analysis of land use/cover changes and urban expansion of Nairobi city using remote sensing and GIS. *International Journal of Remote Sensing, 26,* 2831–2849.

Radzi, A. B. A., & Ismail, H. B. (2013). Trend analysis of sea level rise for Kukup (Johor), West Coast of Peninsular Malaysia. In *International Conference on Emerging Trends in Engineering and Technology (ICETET'2013)* December 7–8, 2013 Patong Beach, Phuket (Thailand).

Rahman, M. S. (2012). Quantifying urban form-compactness versus sprawl: An analysis of Chittagong and Sylhet Metropolitan Cities. *Jahangirnagar University Planning Review, 10,* 39–50.

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

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

Tyler, S. (2006). *Natural resource co-management: Local learning for poverty reduction*. Ottawa: IDRC.

Uddin, M. J., Rahim, M. A., Rahman, M. S., & Satter, M. A. (2015). Community perception on climate change and adaptation scenarios in Southern part of Bangladesh. *Journal of Health and Environmental Research, 1*(2), 12–18.

Voelker, S., & Kistemann, T. (2013). Reprint of: "I'm always entirely happy when I'm here!" Urban blue enhancing human health and well-being in Cologne and Dusseldorf, Germany. *Social Science & Medicine, 91,* 141–152.