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Does building development in Dhaka comply with land use zoning? An analysis using nighttime light and digital building heights

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Abstract

Zoning is an important tool to regulate the use of land, characterize built form over land, and thus facilitate urban sustainability. Availability of reliable data is crucial for monitoring land use zoning, which contributes directly to the success of Sustainable Development Goals (SDGs) in general and SDG Goal 11 for sustainable cities and communities in particular. However, obtaining this valuable information using traditional survey methods is both costly and time-consuming. Remote sensing technology overcomes these challenges and supports urban policymaking and planning processes. This study unveils a novel approach to developing a cost-effective method for identifying building types using Sentinel-2A, Visible Infrared Imaging Radiometer Suite (VIIRS)–based nighttime light (NTL) data, and TanDEM-X–based Digital Surface Model (DSM) data. The newly developed Normalized Difference Steel Structure Index (NDSSI) is useful for rapidly mapping industrial buildings with steel structures. The implementation status of Dhaka's existing land use plan was evaluated by analyzing the spatial distribution of different types of building uses. This study classifies residential, commercial, and industrial buildings within Dhaka using building height, and nighttime light emission. The experimental results reveal that about 67% of commercial and 51% of industrial buildings within the Dhaka Metropolitan Area (DMA) do not comply with the land use zoning by the Detailed Area Plan (DAP). It also reveals that approximately 10% of commercial buildings, 9% of industrial buildings, and 6% of residential buildings have encroached upon conservation zones (such as open space, flood prone zone, water bodies and proposed areas for future road extension). A major constraint in the study was the low spatial resolution of the nighttime lights dataset, which made it difficult to distinguish individual sources of light. Still, the methodological approaches proposed in this study are expected to promote reduced costs and efficacious decision-making in urban transformation and to help achieving SDG 11, especially in developing countries.

Keywords: Urban sensing; Sustainable development; Building use; Urban planning; Remote sensing applications.

Introduction

Asian countries are experiencing significant vertical and horizontal urban expansion due to rapid population growth. Spatial planning helps guide urban development in an orderly manner. However, while deviation from approved landuse plan is inappropriate and illegal, it is a very common practice, especially in developing countries. Prevalence of this practice is often attributed to the lack of capabilities, monitoring tools, and relevant data among urban local government bodies (Avtar, et al., 2020). Obtaining information about physical features and structures has been foundational for urban planning practices (Clark, 1969). Thus, the extraction of building information such as land use function and building height play a decisive role in city planning, development, and management (Scholten & Stillwell, 2013). These types of quantitative building information can be successfully employed in land use zoning (Fischel, 2000; Pissourios, 2019), disaster mitigation planning (Okada & Takai, 2000), energy consumption modeling (Heiple & Sailor, 2008), urban expansion monitoring (Artmann et al., 2019; Ahmad et al., 2016), land use change modeling (DasGupta et al., 2019; Elmqvist et al., 2018), heat mitigation strategies (Shih et al., 2020), disaster mitigation (Hiroi et al., 2015; Okada & Takai, 2000) , provision of shelter (Ahmad, 2015), formulation of environmental pollution reduction policies (Kuzmichev & Loboyko, 2016; Mustafizur et al., 2019), monitoring of urban emissions (Adhary Arbain et al., 2019), urban morphology study (Milojevic-Dupont et al., 2020) and ecosystem services (Inostroza & Barrera, 2019; Spyra et al., 2019; Gadda & Gasparatos, 2009). Multiple and complex trade-offs caused by urban land use changes can positively or negatively influence an urban area's contribution toward Sustainable Development Goals (Avtar, Aggarwal, et al., 2020; Dolley et al., 2020).

In most developing countries, data on building typology including building type, use, height, and materials, is still collected by traditional survey methods (Wilkinson & Kibblewhite, 2004). Ground-based surveys are labor-intensive, time-consuming, and expensive. Advanced remote sensing techniques are gaining popularity for spatial and non-spatial data acquisition by using spectral and spatial information of satellite imagery. Xiao & Zhan (2009) applied remote sensing data in urban planning and development studies in the city of Beijing. By applying Cartosat-1 digital surface models and multispectral Landsat ETM + imagery, the Central Business District (CBD) was delineated in the megacities of London, Paris, and Istanbul (Taubenböck et al., 2013). Another study extracted urban features such as building type, connectivity, green areas, and water bodies using aerial photography (Banzhaf & Hofer, 2008). However, the use of conventional optical satellite data cannot provide building topology information with high accuracy (Malpica & Alonso, 2012). Therefore, Digital Surface Model (DSM) has been employed to classify building types into land use categories such as industrial, residential, and semi-detached house/terrace house/building blocks using fuzzy classification

(Wurm et al., 2011). In another study, Airborne Laser Scanning (ALS) was used to detect both residential and industrial buildings using domain ontology and machine-learning techniques (Belgiu et al., 2014). Terrestrial Laser Scanning (TLS) is also used to enhance the performance of three-dimensional (3D) urban modeling and building information collection (Haala et al., 2008; Mill et al., 2013). Furthermore, researchers have used aerial photography (Zhou & Zhou, 2014) and high-resolution optical images (Sun et al., 2018; Tian et al., 2018) to extract building extent in urban areas.

However, previous studies have mostly underestimated the challenges and practical applications of advanced remote sensing techniques in developing counties, likely due to limited resources and financial constraints. For example, LiDAR (Light Detection and Ranging) is widely used to acquire 3D building structures with high accuracy. However, the use of LiDAR data in developing countries is very limited due to difficulty in acquisition and high processing costs (Geiß et al., 2015). Also, ALS- and TLS-based building information extraction techniques rely on ground-based surveys and require more resources (Liang et al., 2016). In addition, other previous studies have used optical data to extract urban features via digital segmentation or a support vector machine (SVM) learning process. Improvement in data collection tools and techniques is gradually maturing to deliver exponential gains toward urban sustainability.

However, those previous studies are not sufficient for building topology extraction (Jin & Davis, 2005). For example, Sritarapipat & Takeuchi (2017) reported that commercial buildings are taller and emit higher amounts of NTL. However, while industrial buildings are tall, they actually emit low NTL, and residential building height varies, but they also emit low NTL (Wicht & Kuffer, 2019). Sritarapipat & Takeuchi (2017) developed an approach to classify building types in Yangon city of Myanmar using NTL, Landsat-OLI, and GeoEye-DSM data. The use of these methods has been considerably less explored in the field of urban planning in developing countries. Therefore, this study explores a cost-effective method to classify the building types of DMA in Bangladesh. The objective of this study is to classify residential, commercial, and industrial buildings using TanDEM-X DSM, VIIRS based NTL, and Sentinel-2A data. By overlaying the extracted buildings type on existing landuse zoning by government organization, will provide useful insights to developing a strategy regarding zoning violations, development and management, monitoring building occupancy, and installation of utility services in a cost-effective way. The methodology developed in this study will help sustainable cities and communities achieve SDG 11. According to Dolley et al. (2020), "Recognizing the most obvious trade-offs, a land use planning decision on urban expansion may consider the need for more housing (SDG 11.1) alongside the economic and employment benefits of new industrial zones (SDG 8) and the environmental health benefits for urban citizens of relocating polluting industries (SDG 3) against the need to preserve agricultural land for the sake of food security (SDG 2)."

Study area

The study area of the DMA comprises of a core part of Bangladesh's capital, Dhaka city, which is located at 23.71°N latitude and 90.41°E longitude (Figure 1). In a Detailed Area Plan (DAP, 2010–2015), residential areas are proposed to be about 42% of the total land use areas considered, followed by mixed-use (8%), commercial (4%), and industrial use (2%) for DMA (RAJUK, 2015). Due to the increasing demands of business activities, ease of accessibility, and lack of proper land use zoning, commercial buildings are developing alongside major road networks and Central Business Districts (CBDs) (Mohsin, 1989). After the liberation of Bangladesh in 1971, it became necessary to increase commercial facilities to keep pace with the rise of economic activities. At that time, the heights of commercial buildings were mostly one to two stories, but during the early 20th century, the development of high-rise shopping complexes increased due to investments by private developers and new access to bank loans (I. Islam & Adnan, 2011). The industrial sector also contributes significantly to the national Gross Domestic Product (GDP) including a sizable contribution from the garment sector industries (Abdin, 2019). The literature suggests that most of the industrial buildings are about one to two stories tall, and steel-fabricated structures are gaining popularity currently due to their higher resale value, except for large-scale industries (Saha Shumon, 2013). Generally, large-scale industries (e.g., garments, pharmacy, leather, and ceramic factories) operate in high-rise buildings, but small- or medium-scale industries (e.g., bakery, chemical, printing and packaging, and furniture factories) operate in low-rise buildings. These characteristics make Dhaka a good example of human activities associated with variations in economic activities.

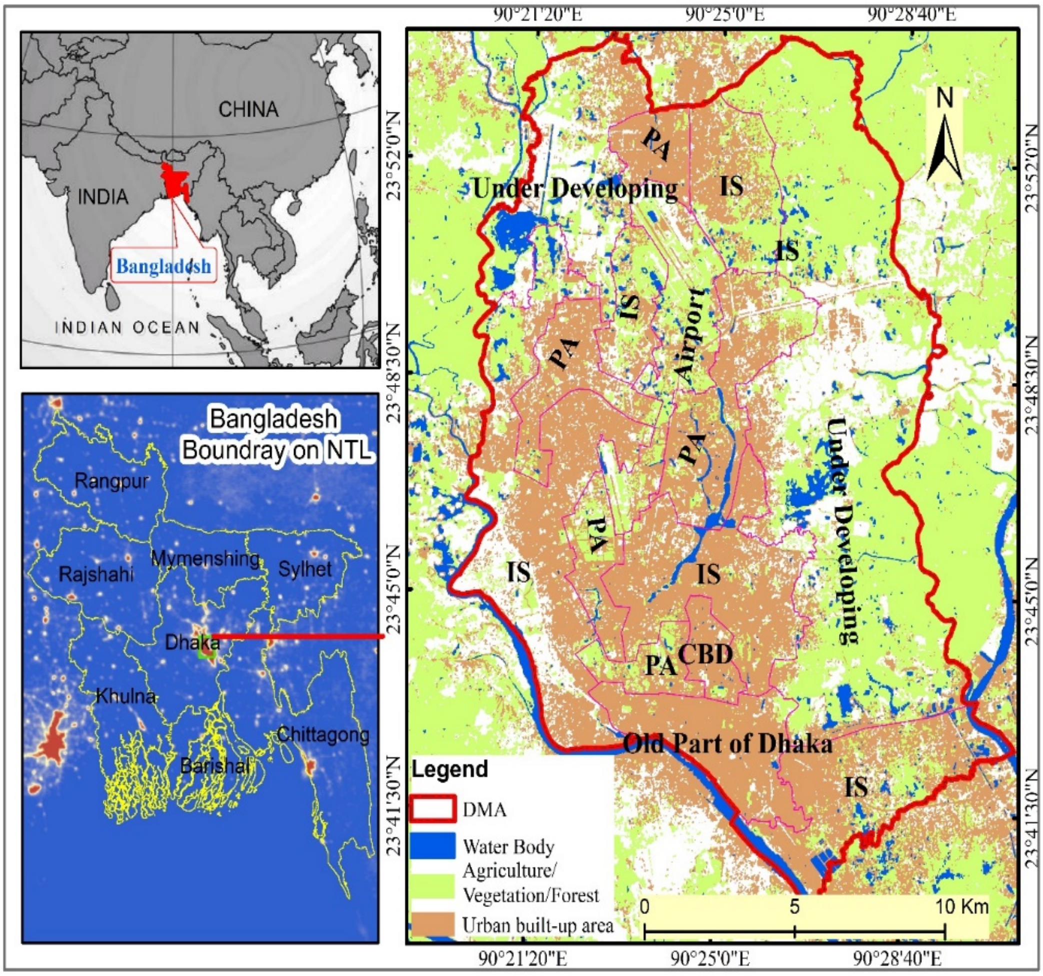

Figure 1. Map showing the location of Bangladesh and nighttime light (NTL). A land cover map of the DMA boundary and its planned area (PA), informal settlement (IS), and CBDs are shown.

Information about building height, type, land use, and a building's spatial distribution is indispensable for urban planning and management. Figure 2 illustrates the different types of urban settlements in the DMA area. There are three distinctive urban settlements in the DMA area: (1) IS (informal settlement) in the old part of Dhaka, characterized by a high-density mixed land use pattern, typically ceding the outer layer to commercial uses and retaining the inner part for residential and manufacturing uses; (2) planned settlement, which shows grided development characterized by residential, commercial, institutional, and industrial land use; and (3) IS, characterized by spontaneous development without any formal urban planning (Ahmed et al., 2014). Private landowners have developed ISs characterized by narrow streets that have a serpentine character and irregular, inconsistent, and asymmetric plot shapes and sizes (Bahauddin et al., 2014).

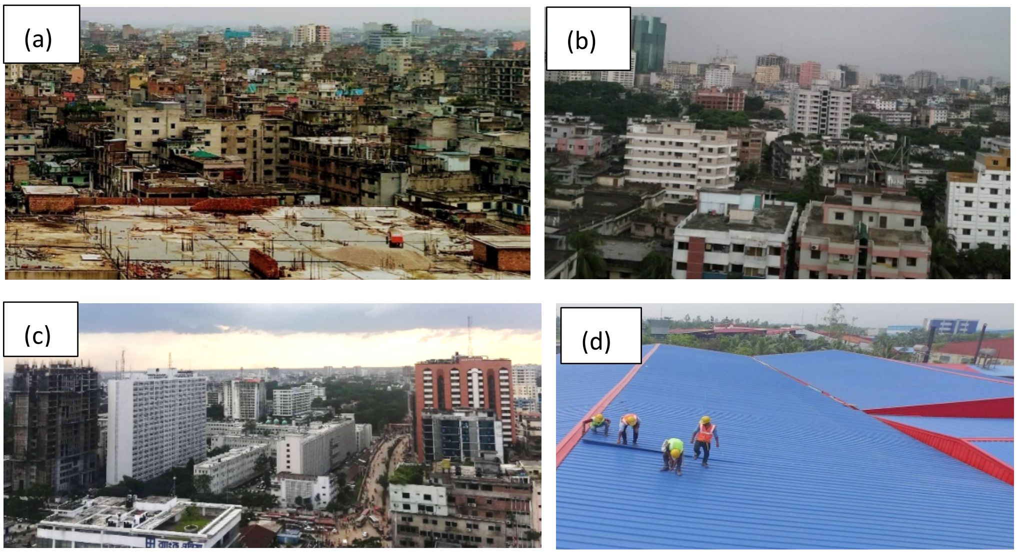

Figure 2. (a) Informal settlement in the old part of Dhaka, (b) planned settlement area, (c) settlement of CBD, and (d) settlement characterized by fabricated steel roofs mostly located in the newly developed area.

Material and methods

Datasets

Multi-sensor remote sensing data can be used primarily for investigating or modeling urban environments as complex systems (Kadhim et al., 2016). In this research, three types of remote sensing data with different spectral and spatial resolutions were employed to accomplish the objective of this study (Table 1).

Table 1. Datasets used in this study

Data	Vertical Accuracy	Band	Resolution	Sources	Acquisition Date
Sentinel-2A	-	13	10 m	https://scihub.copernicus.eu/dhus/odata/v1/Products('e23cb348-87be-4457-ba7807004499d87') /$value	December 2018
TanDEM-X DSM	1.6–6.2 m	1	12 m	https://eoweb.dlr.de/egp/docs/user/downloading_ordered_data.html#	December 2013
VIIRS-DNB NTL data	-	1	742 m	https://earthdata.nasa.gov/earth-observation-data/near-real-time/download-nrt-data/viirs-nrt	March 2018
Ground-Based Building and Land use zoning Data	-	-	-	http://www.rajuk.gov.bd/site/page/68c8d4af-f493-43de-a54c-b0dc83d56bff/-	Building data 2018 and Land use plan (2010-2015)

Sentinel-2A Data

In this research, Sentinel-2A data was downloaded from the Copernicus open-access hub, www.scihub.copernicus.eu/dhus/#/home. The freely available high resolution (10m multispectral) Sentinel-2A data is useful for identifying impervious surfaces, continuous roads, and patterns of development in urban fabric (Xu et al., 2018). It can provide a high accuracy land use/land cover (LULC) map due to its high spatial resolution (Topaloğlu et al., 2016). Moreover, the high spatial resolution (20 m) short wave infrared (SWIR) bands 11 and 12, are useful for metallic roof detection (Mishra, 2017).

TanDEM-X DSM

The TanDEM-X satellite is a space-based X-band Synthetic Aperture Radar (SAR) system that comprises two TerraSAR-X radar satellites flying in close formation to produce global DSM from 2010 December to 2015 January (Moreira et al., 2004). The TanDEM-X mission is financed and implemented as a public–private partnership between DLR and Airbus Defense and Space. Currently, TanDEM-X DSM is extensively used in building height extraction (Geiß et al., 2015; Sadeghi et al., 2016). The TanDEM-X DSM data used in this study was acquired from DLR under the science service system.

VIIRS-DNB

Day/Night Band (DNB) imagery products are produced by NASA's Direct Readout Laboratory (DRL), which provides a direct broadcast of real-time satellite data to ground stations. These imagery products are from the Visible Infrared Imaging Radiometer Suite (VIIRS) nighttime sensor (also called the DNB), and are available generally within three hours of an overflight of the joint NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite. The VIIRS-DNB layer is generated using a sensing technique designed to capture low light emissions under varying illumination conditions and is displayed as a gray-scale image (Meter & Mapper, 2015). These products measure the brightness of artificial lighting from the Earth's surface (Bennett & Smith, 2017; Elvidge et al., 2017). DNB imagery products in NASA's Global Imagery Browse Services (GIBS) have been available from November 2012 to the present. From the establishment of Defense Meteorological Program-Operational Line-Scan System (DMSP-OLS) archive (1992) and the release of the stable light till date, researchers have been using these products in the fields of urban studies, economics, sociology, environmental studies (Doll et al., 2006; Ma et al., 2012; Sadeghi et al., 2016; Zhuo et al., 2009), and energy demand estimation (Avtar, Tripathi, Aggarwal, et al., 2019)

Ground-based survey data

Ground-based building data was collected from the Capital City Development Authority (RAJUK), Dhaka, Bangladesh. Building data was extracted by RAJUK under the DAP project for Dhaka Metropolitan Development Plan (DMDP) in 2018. The ground-based building data is useful for the comparison and validation of our results. The main objective of this project was to review the existing DAP (2010–2015) and prepare a DAP for the Dhaka Metropolitan Region for 2016–2035 that considers the shifting of spatial planning strategies, current situation, and future vision of Dhaka city. Under this project, a detailed physical features survey (buildings, roads, water bodies, utilities, urban spaces, etc., with attributes) and socio-economic surveys were conducted to understand the present scenario as well as to forecast future growth and development mechanisms. The spatial data containing the physical features were extracted from GeoEye-(0.5 m) satellite imagery, which was purchased by the RAJUK for the year 2013. Non-spatial data were collected by ground-based surveys. During the ground-based survey, spatial data was also updated through 2018 and has been made available to the public through (http://www.rajukdhaka.gov.bd). The land use zoning under the present DAP (2010–2015) was also collected from the RAJUK, and compared to the building use that we inferred from remote sensing data. This was to validate the implementation status of the current DAP. This development plan will be valid until the final approval of the revised DAP (2016–2035).

Data processing

Figure 3 shows the flowchart of the methodology used in this study to classify building types. In this research, we have modified the methodology proposed by Sritarapipat & Takeuchi (2017). The novelty of this research is to identify low-height industrial buildings by employing the newly developed Sentinel-2A based Steel Structure Index. First, the building heights were calculated by classifying TanDEM-X DSM into three groups (low, medium, and high height). Second, Sentinel-2A data was classified into three categories (built-up area, water bodies, and vegetation) using ENVI 5.3. Third, VIIRS-DNB was classified into three groups (low, medium, and high brightness). Fourth, the Normalized Difference Steel Structure Index (NDSSI) was calculated using bands 11 and 12 of the Sentinel-2A data to identify industrial buildings with steel structures. After the generation of all thematic layers and the NDSSI of steel structures, building classification (commercial, residential and industrial) maps were generated.

Land use/land cover classification

An LULC map was generated using Sentinel-2A data acquired on 2018 December 23. Only three land cover classes, i.e., built-up, non-built-up, and water bodies, were extracted by applying the Support Vector Machine (SVM) classifier. The landuse classification was validated with Google Earth® where the user accuracies for water bodies, built-up areas, and non-built-up (agriculture, vegetation, and barren land) areas were 90%, 85.41%, and 86%, respectively. The overall accuracy of the classification was 87.16%, and the kappa coefficient was 0.80.

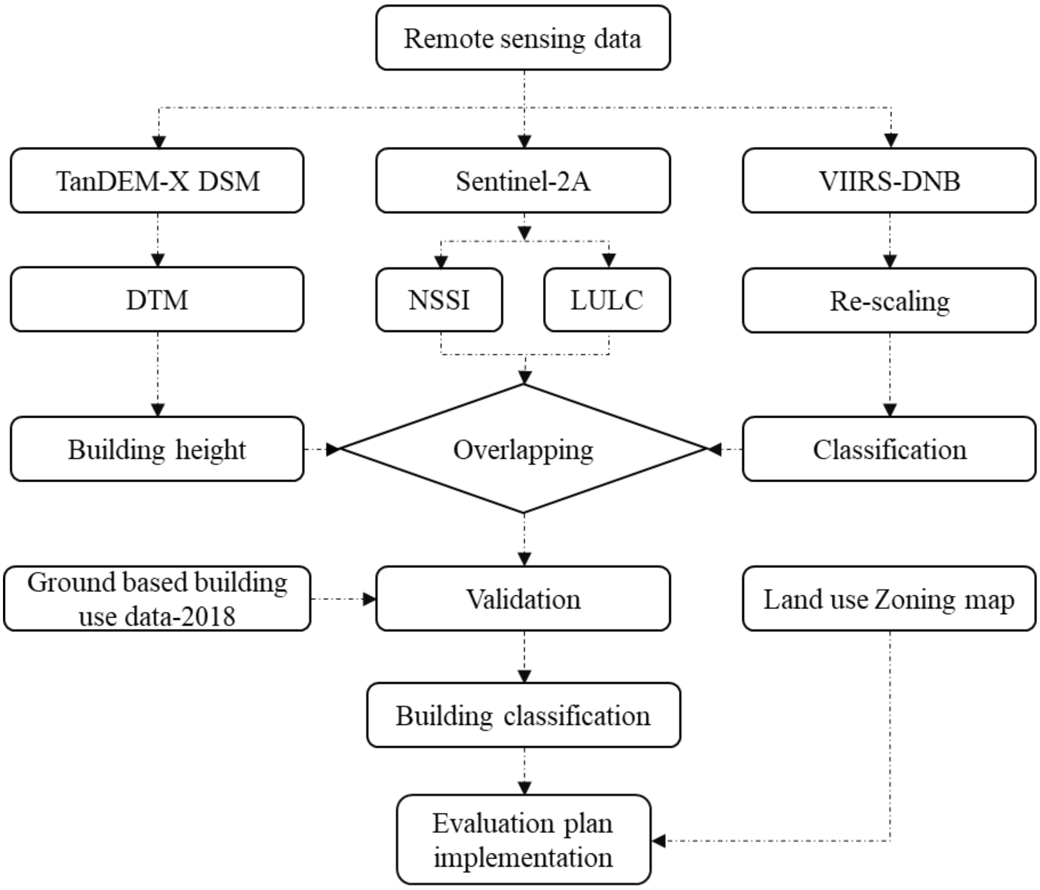

Figure 3. Flow chart of the methodology to classify building types.

Building height classification

Building heights were extracted by generating a normalized Digital Surface Model (nDSM) of TanDEM-X DSM using the digital building height (DBH) algorithm proposed by Misra et al. (2018). Another study revealed that the absolute height error of TanDEM-X data is about ± 1.61, and TanDEM-X DSM is widely used for estimating building height (Avtar et al., 2015; Rahman et al., 2020). After extracting the building heights, we then categorized them into three classes, namely, high (26 m and higher), medium (13 m to 26 m), and low (3.3 m to 13 m). According to the Bangladesh National Building Code (BNBC), the minimum height for a one-story building must be 3.3 m (BNBC, 2015). We used this approach to quantify the total number of stories for different building types.

VIIRS-DNB classification

The VIIRS-DNB data was acquired on March 2018 and classified into three classes, namely, high (30 $nWcm^{-2}sr^{-1}$ and higher), medium (20 $nWcm^{-2}sr^{-1}$ to 30 $nWcm^{-2}sr^{-1}$), and low (1 $nWcm^{-2}sr^{-1}$ to 19 $nWcm^{-2}sr^{-1}$) based on the brightness value. The original spatial resolution of VIIRS-DNB data is 742 m×742m. To avoid the overlapping bias with TanDEM-X DSM, the VIIRS-DNB data was downscaled to 12 m × 12 m pixel size by preserving the same spectral resolution before image classification. The downscaling from a lower (coarser) to higher (finer) spatial resolution procedure does not change radiometric properties of the image (Ha et al., 2013). Re-scaled VIIRS-DNB data matches well with other remote sensing data such as Sentinel-2A and TanDEM-X DSM.

Normalized difference steel structure index

This study develops a new index, the NDSSI, to rapidly map industrial buildings that have steel structures. The NDSSI utilizes two bands of Sentinel-2A namely Shortwave Infrared-1 (band-11) and Shortwave Infrared-2 (band-12). The central wavelength of band 11 and band 12 of Sentinel-2A data is 1610 nm (SWIR1) and 2190 nm (SWIR2), respectively (Wang et al., 2018). Samsudin et al., (2015) reported that the reflected wavelength from metallic roofs falls in the shortwave infrared region (1800–2500 nm) of the electromagnetic spectrum. Equation (1) shows the NDSSI developed using SWIR1 and SWIR2 bands on Sentinel-2A data. Figure 4 shows the spectral reflectance of band 11 and 12 by drawing a profile over industrial buildings covered with steel roofs. As seen in Figure 4, the difference in the spectral reflectance of band 12 and 11 is useful to develop NDSSI. Most of the low- or medium-height industrial buildings are constructed using steel frames, as well as metal-clad fabricated steel roofs because of their higher resale value, fire protection, easy installation, architectural aspects, and ease of movement (The Steel Construction Institute (SCI) Technische Universität Dortmund, 2018). Applying remote sensing techniques, these metallic roofs can be identified in the complex urban fabric. The newly developed NDSSI is useful for extracting low-height industrial buildings. Low-height industrial buildings (e.g., bakery, manufacturing, packaging, small-scale garments, etc.) are characterized by fabricated steel structures and metallic roofs in the DMA. The threshold values for the steel structure industrial buildings were fixed up from 0 to 0.35.

$$NDSSI = \frac{SWIR2 - SWIR1}{SWIR2 + SWIR1} \tag{1}$$

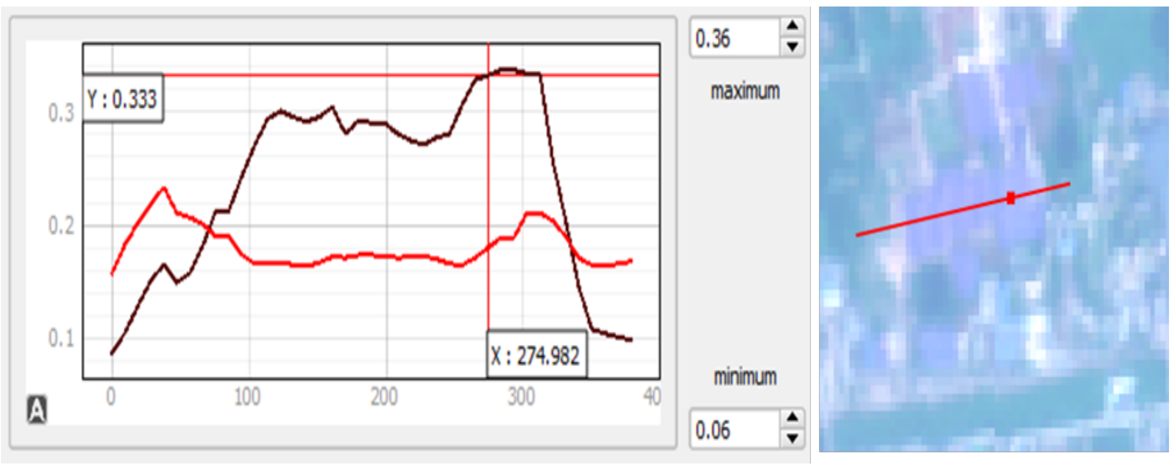

Figure 4. The black and red lines show the spectral reflectance profile of band 11 and band 12, respectively, over industrial buildings covered with steel roofs.

Building type classification

Three types of buildings were extracted, namely, commercial, industrial, and residential, using the above-mentioned methodology. Commercial buildings were extracted by considering the heights of tall buildings, high NLT consumption, and built-up areas. Industrial buildings were classified using two methods. Tall industrial buildings are characterized by high-rise and low light consumption. Low-height industrial buildings are characterized by a fabricated steel structure and were extracted with the use of NDSSI. Therefore, the rest of the buildings were considered residential buildings, which include apartments, mixed-use, government employee residential quarters, dormitories, community facilities, educational facilities, and religious buildings.

Results

LULC and NTL

About two-thirds of the DMA are covered with built-up areas. The results based on Sentinel-2A data reveal that built-up, agriculture/vegetation, sand filling/barren land, and water bodies cover about 50%, 13%, 30%, and 7% of the total study area, respectively (Table 2). In addition, high, medium, and low NTL was observed in 37% (Up to 30 $Wcm^{-2}sr^{-1}$), 53% (20 $Wcm^{-2}sr^{-1}$ to 30 $Wcm^{-2}sr^{-1}$) and 10% of the total area (1 $Wcm^{-2}sr^{-1}$ to 19 $Wcm^{-2}sr^{-1}$) of the DMA, respectively. High NTL was found in the center of the city area, and low NTL was observed at the peripheral areas of the city characterized by agricultural land.

Table 2. Percentage share by different land covers of Dhaka Metropolitan Area, 2018

Land cover Type	Area (km^2)	% of area
Build-up Area	152.41	50
Agriculture/Vegetation	39.62	13
Sand filling/Barren Land	91.26	30
Water Bodies	21.34	7
Total	304.82	100

Digital building height

In general, the mean building height is about 9.25 m (standard deviation 5.67 m) in the DMA area. Most buildings within the DMA are between one and four stories tall (see Figure 5 and Table 3). It appears that the low-height (3.28 m to 13.12 m), medium-height (13.13 m to 26.24 m), and high height (26.24 m and higher) buildings comprise about 68%, 28%, and 4%, respectively, of the total study area. Figure 5 shows the spatial distribution of building height. The building height results show that most of the high-rise buildings are typically concentrated alongside major roads and the CBD area. The low-height buildings are at the periphery of the urban fabric. TanDEM-X DSM–based building height was validated by a total 60 randomly selected ground-based building heights. For sample selection, we have used our field knowledge of core/CBD area, peripheral area and fringe area. From each of the three imaginary boundaries, we randomly selected 20 samples. Among them, 47 buildings showed a 1–2 m deviation, seven buildings show a 2–4 m deviation, five buildings show about a 5 m deviation, and one sample was roadside infrastructure.

Table 3. Estimated building height coverage area of the study area of Dhaka, 2018.

Height Category	Height (m)	Coverage Area (km^2)	% of Coverage
Low	3.28 to 13.12	76.81	68
Medium	13.13 to 26.24	31.61	28
High	26.24 and higher	4.17	04

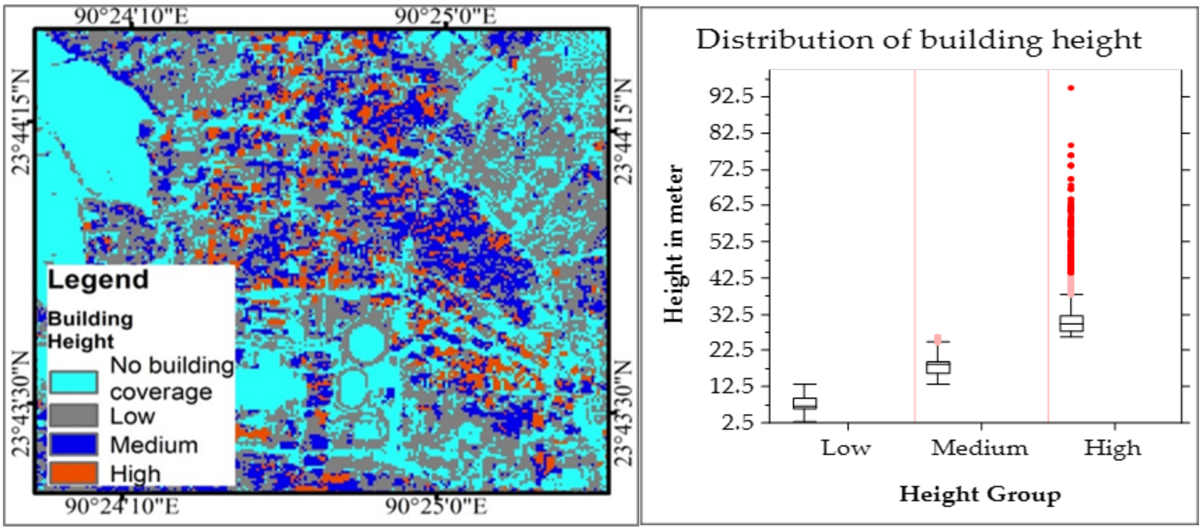

Figure 5. Spatial distribution of building height (left) and their distribution (right) in the DMA.

Low-height industrial buildings

Data for low-height steel structure industrial buildings were also extracted using Sentinel-2 prior to building classification (Figures 6 and 7). Figure 6 shows pictures of the garment building (Figure 6(a)) and spinning mill (Figure 6(b)). The results showed that the coverage of steel structure industrial buildings is about 1.63 km^2 of the study area. About 30 samples were checked randomly using ground-based data and Google Street View® photos; among them, 23 samples were extracted successfully by using the NDSSI as an industrial building. Figure 6 shows the low-height industrial building detected in this study. Figure 7(a) shows the blue color fabricated steel roof of industrial buildings at 23°43'5.41"N and 90°28'18.87"E, confirmed by Google Street View® images, which was detected by the NDSSI approach (Figure 7(b)).

Figure 6. Garments factory (6a) and spinning mills (6b); source: (Google Maps, 2015).

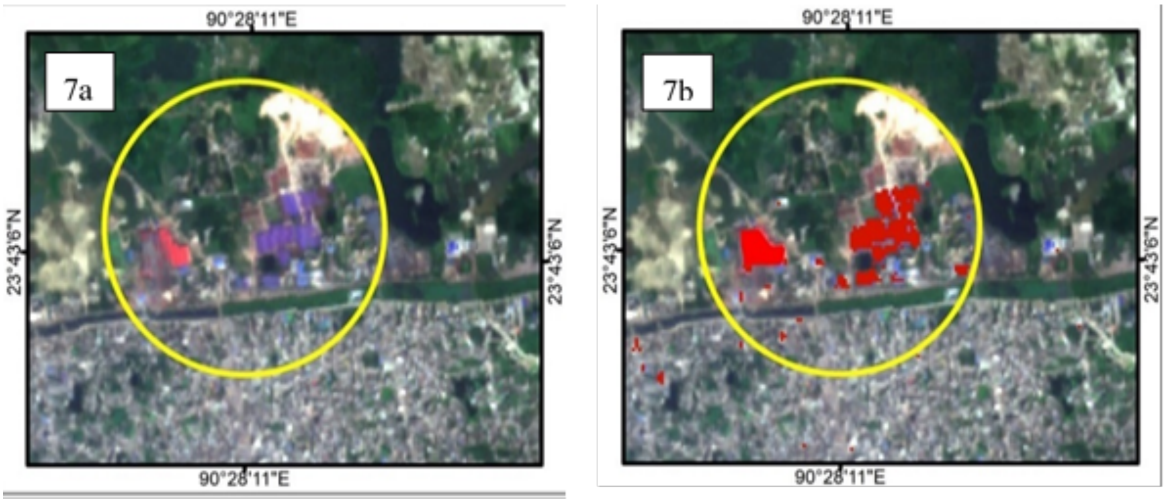

Figure 7. (a) The low-height industrial buildings with steel roofs, and (b) building extracted data by NDSSI.

Building classification

Figure 8 shows the distribution of NTL emission and building heights of different types of buildings. Their function was evaluated by 30 randomly selected samples. It was observed that residential buildings exist as both high rises and low rises in the study area. However, the characteristics of light emission differ. Sometimes, low-height residential buildings show high light emissions due to low-height/medium-height residential buildings being located in commercial areas (including the CBD area). Commercial buildings are characterized by tall height (30 m to 95 m) and high nighttime light values (30$Wcm^{-2}sr^{-1}$ to 40 $Wcm^{-2}sr^{-1}$). Low-height industrial buildings (extracted from the NDSSI) are characterized by low-height and fluctuations in NTL. Similarly, high-rise industrial buildings are characterized by medium light and high rises.

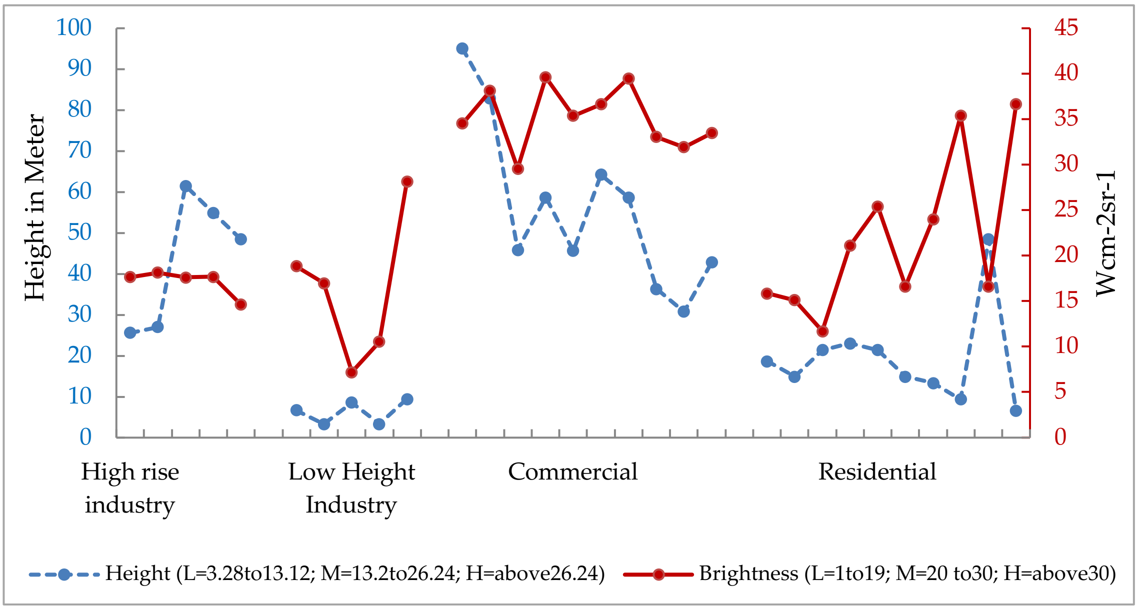

Figure 8. Physiognomies of building height and NTL emission.

The DMA is dominated by residential building coverage. The results revealed that the net residential building coverage is about 90.60%, followed by commercial 6.82%, and industrial 2.58% (Table 4 and Figure 9). Table 4 illustrates the comparison between remote sensing data–based areas of different building types and ground-based areas of different building types. The building-use map shows that the DMA is growing as a city of mixed-use characteristics (Figure 9(a)). Commercial buildings are mainly concentrated in the CBD area and the old part of Dhaka city. Industrial buildings were found to be concentrated in the center of the city, along with some scattered industrial building use. Figure 9 (b) shows the statistical analysis of building distribution through a combination box plot of the DMA. The violin box plot reveals that the mean building heights for residential, commercial, and industrial buildings were about 9.5 m, 28 m, and 6 m, respectively. It also reveals that the minimum heights were about 3 m, 3 m, and 23 m for residential, industrial, and commercial buildings, followed by maximum heights of 27 m, 73 m, and 95 m, respectively. However, the outlier maximum heights for commercial and industrial buildings were 98 m and 76 m, respectively.

Table 4. Comparison of remote sensing and ground-based areas of building types

Type	Remote Sensing–based Building Types		Ground-based Building Types	
	Area (km^2)	%	Area (km^2)	%
Commercial	5.30	6.82	6.47	8.27
Industrial	2.01	2.58	3.34	4.27
Residential	70.50	90.60	68.46	87.46

The residential buildings show higher coverage in remote sensing–based results as compared to the ground-based residential area coverage. Also, we used Google Earth® to verify some designated areas, i.e., the Tejgon industrial area (90°24'1.33"E, 23°45'52.56"N). The user accuracies of the estimated building use with the ground-based data are about 85.36%, 80%, and 69.12% for residential, commercial, and industrial building types, respectively. The overall accuracy is about 78.94%, with a kappa coefficient of 0.68.

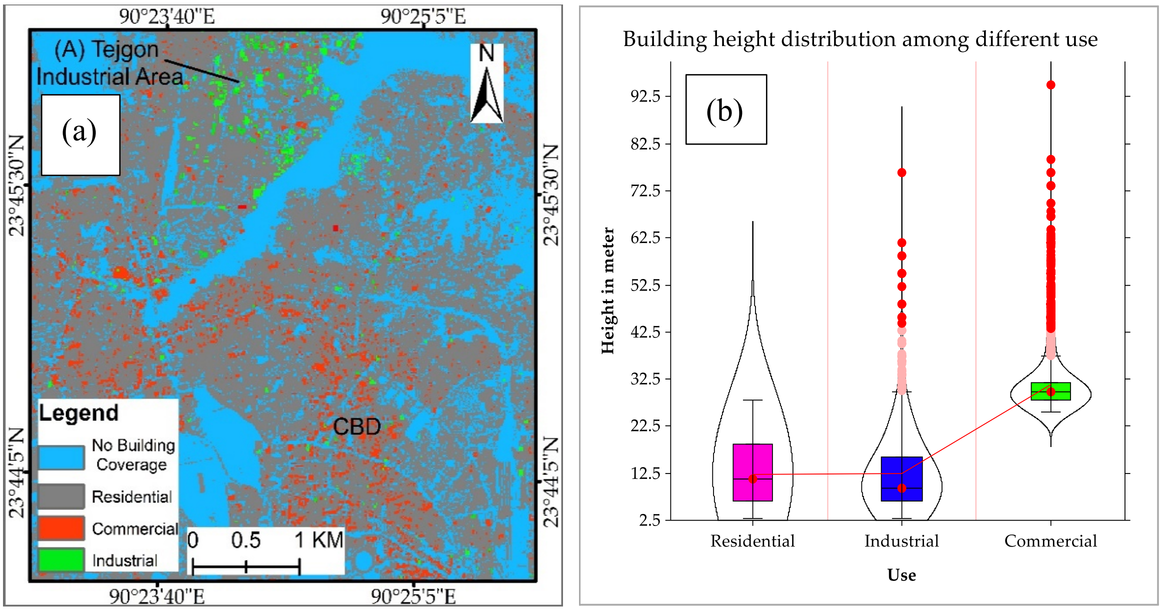

Figure 9. Building-use map partial of the DMA (a) and height distribution (b) with building use in the DMA, 2018.

Urban functional zone

Urban functional zone of DMA was observed based on the spatial distribution of building use and land use zoning by city development authority (Table A1; see the Appendices). The extracted classified buildings type were superimposed on the DAP (2010–2015). The land use plan implementation scenario of the DMA under the DAP (2010–2015) was observed thoroughly. Table 5 illustrates the distribution of building use and its superimposition with the DAP land use zoning. It reveals that 83% of the total classified buildings coverage comply with land use zoning, while 6.57% are located in development restricted zones and 10.26% are located in development Permitted but not complied zones. It also reveals that only 23% of commercial buildings, 40% of industrial buildings, and 89% of residential buildings comply with the land use zoning plan developed under the DAP (Table 5).

Table 5. Distribution of building use with DAP land use zoning

Building Type	Classified Building Area (km^2)	Complied with DAP %	Development Restricted Zone %	Development Permitted but Not complied Zone %
Commercial	5.30	22.57	9.86	67.57
Industrial	2.01	39.57	8.68	51.75
Residential	70.50	88.99	6.26	4.75
Total	**77.81**	**83.17**	**6.57**	**10.26**

Approximately 10% of commercial buildings, 9% of industrial buildings, and 6% of residential buildings are in the restricted development zone. The restricted development zone includes urban green spaces, open spaces, flood flow zone, water retention areas, water bodies, and reserved areas for future road networks. Because of the weak institutional monitoring and lower land price compare to “development permitted zone”, land grabbers buy “development not permitted land” and sell in the local market after illegal development to get the additional benefit (Alam & Ahmad, 2010). Besides, about 68% of commercial buildings and 52% of industrial buildings were not complied on to the land use zones of the DAP (Table 5 and table A2; see the Appendices). However, only 5% of residential buildings did not overlap with land use zoning, which is marginal compared to the commercial and residential building types. The results reveal that 83% of building development within the DMA complies with the DAP, meaning that 17% of the building area did not overlap with the correct zonations.

Figure 10 provides a breakdown of the illegal developments in restricted development zones. It reveals that reserved land for future road extension is illegally occupied by residential (3.59%), industrial (3.17%), and commercial developments (2.76%). Surprisingly, water bodies in the DMA were mostly encroached by commercial use (2.59%) followed by industrial (1.68%) and residential (1.03%). This is caused by the illegal filling up of water bodies for the development of shopping complexes/markets and light industrial buildings (Feldman & Geisler, 2011). A previous study reported that approximately 33% of small water bodies in DMA have decreased over the period 1960 to 2008 (M. S. Islam et al., 2012). It also reveals that open spaces were mostly encroached by industrial use (2.31%) followed by commercial use (1.86%) and residential use (0.93%). A significant percentage of flood flow, water retention and agriculture zones were also illegally encroached by commercial, industrial, and residential use (Figure 10). Hence waterbodies, open spaces, and proposed road networks are the most vulnerable land uses of DAP. On the other hand, commercial buildings are the main contributor to land zoning violation followed by industrial and residential buildings.

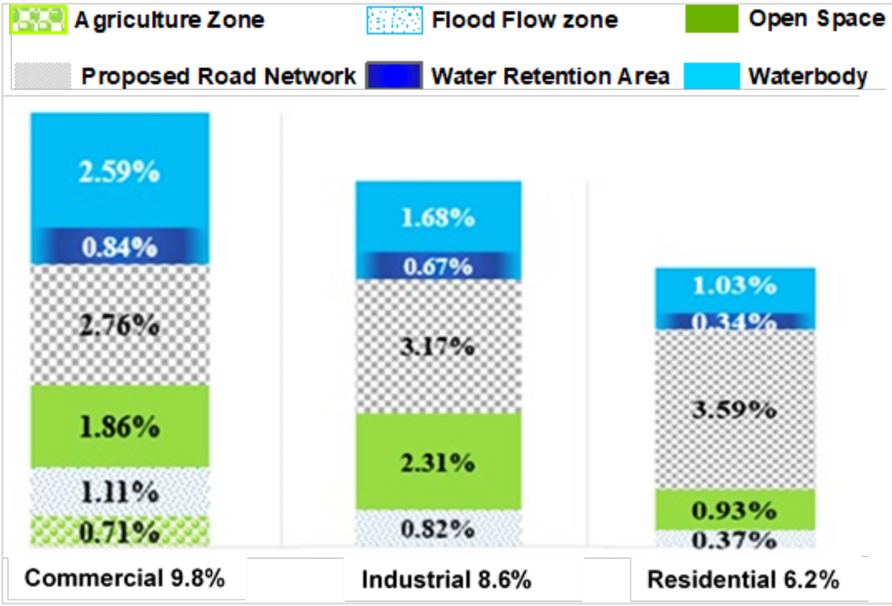

Figure 10. Shows the percentage distribution of non-compliance buildings in development restricted zones.

Figure 11 shows the overlapping layer of building types with respect to land use zoning (green). Figure 11(a) illustrates the three types of buildings, which are represented by different colors: residential (yellow), commercial (violet), and industrial (red), and black represents no building area. The commercial building types overlapping the map reveal that the overlapping area is very small, and there are lots of free land use zones (green; Figure 11b). However, this also shows that many commercial buildings are located within the black shaded area without following land use compatible areas and are distributed haphazardly. Hence, this reveals that the commercial buildings are spatially scattered in the DMA area, and they do not follow the land use zoning, except for at the eastern and northern parts, which have an option for commercial building development. Figure 11(c) illustrates the distribution pattern of industrial building types with respect to its compatible land zoning . Through visual interpretation, it can be ascertained that mostly industrial buildings are located within the black shaded areas without overlapping onto the green layer. Hence, industrial buildings are also distributed haphazardly without following the prescribed zoning by the DAP. Similarly, Figure 11(d) represents the residential building types with respective land use zoning. Because of the overlapping of residential areas and respective land use zoning in Figure 11(d), residential buildings can be discerned as areas of light green instead of yellow. This reveals that mostly residential buildings overlap with compatible land use zones with fewer exceptions. This also illustrates that there is a considerable amount of free land areas that are compatible land for residential building development.

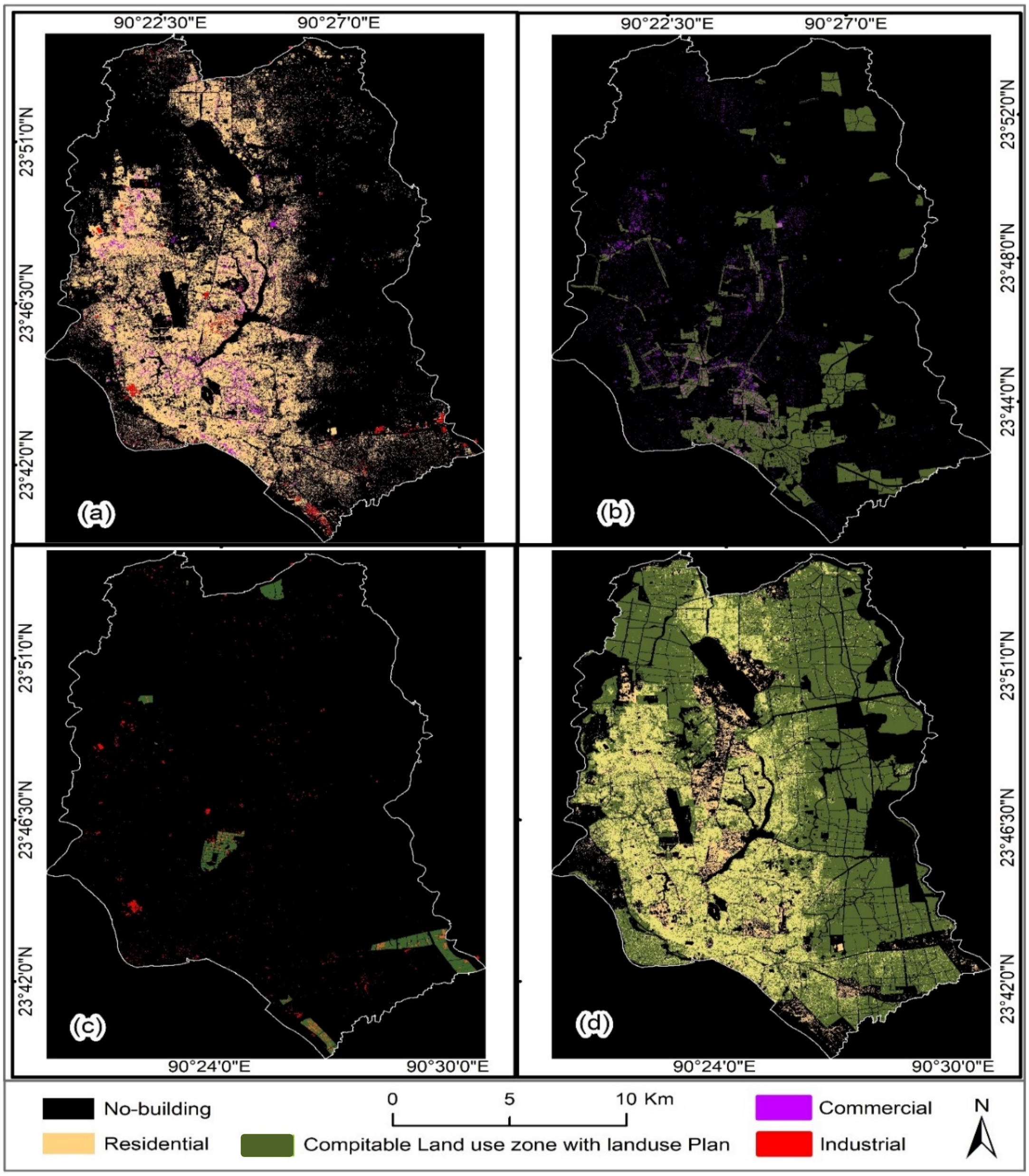

Figure 11. (a) Building use, (b) classified commercial building overlapping onto commercial land use zones in the proposed DAP, (c) the classified industrial building overlapping onto industrial land use zones in the DAP, and (d) classified residential building overlapping onto residential land use zones in the DAP (2010–2015).

Discussion

This is the first study to extract the building type information and to investigate the land use plan implementation status of the DMA. Hence, this research provides an effective approach for urban planning in the decision-making process.

Land use and building information extraction

The proposed method is proficient to broadly categorize residential, commercial, and industrial buildings. Therefore, the distribution of extracted building types information was compared with the existing land use plan of the DMA. First, low-height industrial areas were identified using the NDSSI to avoid confusion with low-height residential and industrial buildings. Second, data on commercial and high-rise industrial buildings were extracted carefully, considering land cover, NTL, and building height. The commercial and high-rise industrial buildings can differ considering NTL consumption.

Residential buildings are distributed across the city, while mixed-use buildings and commercial buildings are mostly concentrated in the CBD area and in the old part of the city. Sikder et al. (2019) had earlier stated that residential buildings residential building structure intensity is prominent and the concentrations are distributed all over the city. The study by Al-Kodmany & Ali (2013) also supported the above findings and revealed that most of the commercial buildings are located in the CBD area, the old part of the city, and alongside the road. The industrial buildings are distributed in the outlier areas of the core city, with fewer concentrated in the old part of the city. The experimental accuracy level of these findings is about 78.94%, with a kappa coefficient of 0.68. This is similar to the study of Yangon city, Myanmar with 76% accuracy and a kappa coefficient of 0.58 (Sritarapipat & Takeuchi, 2017). However, in this research, a new index was added for steel structure identification for low-height industrial buildings that improved the accuracy level. However, different factors such as sample size and distribution, research data, scale, time, and expertise influenced the accuracy of remote sensing–based building types extraction. The use of a confusion matrix and kappa coefficient is a common method to measure the accuracy of building types from remote sensing data (Pal, 2002).

Limitations of building type classification

The main limitation of this study was the availability of VIIRS-NTL data with a 750 m spatial resolution. Coarse-resolution NTL data with 0.57 km^2 pixel size shows the same brightness for the area covered with different building types. The non-availability of the latest TanDEM-X DSM scenes was also another limitation. TanDEM-X DSM data used in this study was acquired in 2013 that shows a difference of 5 years with the ground-based building height data. The possibility of difference in building heights from TanDEM-X DSM and ground-based will be high in fast-growing areas of DMA. Apart from that, the small dimensions and high density of buildings in informal settlements made it difficult to extract building height using low-resolution DSMs. Additionally, the irregular elevation of rooftops, and building shadow effects complicated the delineation of individual buildings. By following Misra et al., (2018), a morphological approach MSD filtering technique, and masking of non-building coverage was used to overcome these challenges. The use of NDSSI to extract low-height industrial buildings was successful. However, mixed reflectance from other materials such as asbestos vs. metal roofs, clay tile vs. concrete tile, and certain roof materials vs. roads may reduce the accuracy of results.

Commercial buildings were considered as high-rise buildings and as having high NTL values. However, the small-scale commercial activities taking place in low-height buildings were not possible to identify in this study. In addition, some anomalies exist in the residential building category. For example, the concrete infrastructure includes public gathering places (open stage/ monuments), and roadside structures were identified as residential buildings. Our methodology cannot detect these types of infrastructures profoundly. To overcome these limitations, high-resolution spatial data, latest DSMs, and better spatial analysis algorithms can be employed for further analysis. The DMA area is very dynamic and a fast-growing urban area; therefore, the use of satellite data with ground-based information will be a useful method to update the existing maps regularly.

Urban planning challenges

The DMA, characterized by mixed-use development, produces a divergence between the land use zoning plan and development, especially for commercial and industrial buildings. This divergence accounts for the growth of economic activities, with a weak institutional capacity of the development authority. Besides, the absence of good governance is one of the causes of the fragile plan implementation status of the government organization. Commercial and industrial activities are mainly influenced by the play of power and money overlooking the urban planning regulations in the absence of systematic monitoring of urban development. Apart from the complex governance and increasing bureaucracy, RAJUK has failed to deliver its urban planning objectives to the development of capital Dhaka (Kalam, 2009).

A previous study stated that limited land use zoning regulations were observed in the study area (Kamruzzaman & Ogura, 2007). Commercial buildings were arbitrarily distributed in the city area, not fully complying with the zoning policy. Although the success of master plan implementation depends on the plan quality, enforcement style, and institutional capacity; rigid planning practices are the cause of land use zoning violation in Bangladesh (Baumgart et al., 2011). Many countries are practicing flexible and adaptive plan preparation and implementation. For example, this approach has become the current preference by smart growth advocates and the New Urbanist movement in New Zealand (Berke et al., 2006), because it requires the promotion of compact and mixed-use urban forms as opposed to the more rigid land use regulations that produce conventional low-density development patterns (Duany & Talen, 2001). However, the flexible and adaptive planning system varies with administrative systems (Moga, 2017; Schmidt & Buehler, 2007).

The zoning regulations in the urban areas of the USA are very stringent, as they do not allow less protected land use (such as commercial, light industry) in the most protected zones (such as residential, sensitive ecosystems; Ikeda, 2018). In Germany, at the other end of the spectrum, the planning system is inclusive. Each zone allows for a predominant use (such as residential), while also considering other complementary uses (such as small shops) as appropriate (Lehavi, 2017), hence effectively supporting a mixed-use approach. The USA follows a large number (21) of zones but is less flexible and Germany follows fewer zones but is more flexible. On the other hand, England is practicing adaptive planning by introducing different zoning tools such as Transfer of Development Right (TDR), Floor Area Ratio (FAR) benefit, and Land Pooling system (Foley, 1963). Although by definition zoning is rigid, there is a trade-off between certainty and flexibility. So, land use policy should be flexible and adaptive for successful plan implementation (Gielen & Tasan-Kok, 2010).

Apart from that, continuous monitoring is necessary for proper implementation of land use zoning, and the lack of man-power and technical support of the city authority are a few of the main barriers toward the planned development of Dhaka city (Swapan et al., 2017). In this context, the application of remote sensing data can assist land use zoning. It is an important tool for implementing sustainable development because zoning ordinances influence land development within communities (Jepson & Haines, 2014; Wheeler, 2013). Hence, remote sensing–based monitoring system can be an attractive option for monitoring development for the city authority.

The findings of this approach can be applied in urban planning, management, and land zoning monitoring. SDGs are global non-binding goals, and there is a need to translate these goals into actionable plans at relevant levels and across sectors. This study has recognized that since more than 50% of the global population lives in urban areas, it is important to find an entry point of sustainable development within urban limits. In the context of achieving SDGs, the findings of this study are relevant in terms of the requirements of SDG 11: future housing development (Elmqvist et al., 2018), SDGs 8 and 9: commercial and industrial infrastructure development assessment for the green economy (Schaubroeck, 2018), SDG 3: healthy living environment preserving green spaces (Mustafizur et al., 2019; Sterling et al., 2020), SDGs 2 and 12: monitoring urban sprawl and protecting agricultural land (Dolley et al., 2020; Nicholls et al., 2020), SDG 13: disaster risk assessment and heat island studies (Sansilvestri et al., 2020), and SDG 7: estimation of utility and energy demand (Schaubroeck, 2018). Therefore, monitoring urban development should be updated, targeted oriented, and cost-effective. High-resolution and accurate spatial information of buildings will be an essential baseline date to develop scenario-based land change modeling for sustainable futures (DasGupta, Hashimoto & Okuro, 2019). Given that traditional survey techniques are costly and time consuming, our approach, which is based on recent advancements in remote sensing technology, could play a crucial role in urban planning processes, particularly in megacities, such as Dhaka. Also, it could be used as a new approach to detect urban slums, using freely available remote sensing data.

Conclusions

Geospatial technology, employing TanDEM-X DSM, Sentinel-2A, and VIIRS-NTL, was applied to classify building use within the DMA into three broad categories, namely, residential, commercial, and industrial. The implementation status of the existing land use plan was evaluated by analyzing the spatial distribution of different types of building use zoning within the DMA. The net residential, commercial, and industrial building coverages were 90.84%, 6.64%, and 2.51%, respectively. In addition, we find that 68% of building heights were about 3.28 m to 13.12 m, 28% of buildings were 13.13 m to 26.24 m, and the remaining 4% of buildings were 26.24 m and higher. The overall accuracy of the result verified by ground-based data is about 78.94%, with a kappa coefficient of 0.68. By using NDSSI, we were able to extract data on low-height industrial buildings using Sentinel-2A, with some limitations.

We have demonstrated that spatial and non-spatial data extracted from geospatial technology can be immensely helpful in the planning, development, and management of urban development in data-scarce and low-income cities, like Dhaka. This approach offers a new method, which is relatively simple and cost-effective for monitoring land use and building development. Monitoring building types play a crucial role in achieving sustainable urban development, particularly where the implementation deficit is one of the major challenges. The sensitivity and uncertainties of building classification and our approaches remain open for further investigation. Despite this room for further improvement, this research will undeniably contribute toward future sustainable urban development.

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Appendices

Table A1: Building Development Permission and Land use Zoning According to DAP (2010–2015) for DMA

Land use Zone (DAP, 2010–2015)	Compatible for building development	Building Development Restricted
Administrative Zone	Administrative purpose	No
Agricultural Zone	Cultivation	Yes
Commercial Zone (Business)	Shopping complex, Market, Shop	No
Commercial Zone (Office)	Commercial	No
Flood Flow Zone	Cultivation, Flood flow	Yes
General Industrial Zone	Industrial	No
Heavy Industrial Zone	Industrial	No
Institutional Zone	Education, Health facilities	No
Mixed-use Zone (Commercial-General Industrial)	Commercial, Industrial	No
Mixed-use Zone (Residential-Commercial)	Residential, Commercial	No
Mixed-use Zone (Residential-Commercial-General Industrial)	Residential, Commercial, General Industrial	No
Mixed-use Zone (Residential-General Industrial)	Residential, Industrial	No
Open Space	Recreation/Greenery/Playground	Yes
Proposed Road Network	Road network	Yes
Rural Settlement Zone	Residential	No
Transportation Facilities	Transport-related infrastructure	No
Urban Residential Zone	Residential	No
Water Retention Area	Water	Yes
Water bodies	Water	Yes

Source: Detailed Area Plan (DAP, 2010-2015), RAJUK.

Table A2: Percentage of identified buildings area in development permitted but not in compatible zone

Land use zone	% of buildings in development permitted but not in compatible zone		
	Commercial	Industrial	Residential
Administrative Zone	1.10%	0.08%	0.08%
Commercial Zone (Business)	compatible	0.60%	0.07%
Commercial Zone (Office)	compatible	0.02%	0.00%
General Industrial Zone	1.28%	compatible	0.10%
Heavy Industrial Zone	-	compatible	-
Institutional Zone	3.29%	0.57%	0.24%
Mixed use zone	25.36%	7.43%	3.37%
Overlay Zone	0.06%	8.04%	0.42%
Rural Settlement Zone	2.11%	15.01%	compatible
Transportation & Communication	3.33%	1.01%	0.44%
Transportation Facilities	0.05%	0.05%	0.02%
Urban Residential Zone	31.12%	18.88%	compatible
Total	**67.71%**	**51.68%**	**4.74%**

Source: Author estimated based on NTL and digital building height data,2020

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