

RESEARCH PAPER

Satellite Nighttime Light and Digital Elevation Data to Assess Urban Expansion in Floodplains of Dhaka City

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Abstract

This study aims to evaluate the potential of DMSP/OLS nighttime light data to investigate human presence and activity in Dhaka City, Bangladesh. The study explores the sensor's ability to detect and monitor urban expansion patterns and human presence and activity at a regional scale. Thematic land cover maps revealed a rapid expansion of built-up areas within the 43-year study period, increasing from 35 km² in 1972 to 378 km² in 2015, representing a net gain of approximately 980% and an average annual growth rate of 6%. Notably, this growth rate was significantly higher in peripheral areas (2903% and a yearly expansion rate of 8%) compared to the central city area (Dhaka City Corporation) (460% and an annual expansion rate of 4%). This substantial urbanisation has primarily occurred in Dhaka's northern, northwestern, and southwestern sectors, transforming previously agricultural land, vegetation cover, wetlands, and water bodies. The findings demonstrate the utility of DMSP/OLS imagery for detecting human activities and presence in the Dhaka region, providing valuable insights into urban expansion patterns and their implications for environmental and social dynamics.

Keywords: Dhaka; Digital Elevation Model; ArcGIS; Urban Growth; DMSP/OLS night-lights; Spatial Analysis.

1. Background

1.1 Introduction

Rapid urbanisation is a defining characteristic of modern societies, and Bangladesh is no exception [1]. Despite its predominantly rural population (66%), the country has witnessed a remarkable transformation in its urban landscape, particularly in its capital city, Dhaka [1], [2]. Unlike the gradual and controlled expansion of urbanization observed in many developed nations, Dhaka's urbanization has been swift and largely unregulated, posing significant challenges to the city's infrastructure, environment, and overall sustainability [3]. Dhaka's population exploded from approximately 1 million in 1972 to an estimated 17 million in 2015, making it one of the world's most densely populated and rapidly urbanising cities [4]. This exponential growth is projected to continue, with forecasts indicating that Dhaka could become the world's sixth-largest urban cluster within the next 10–15 years if current trends persist [5]. The city's megacity status is expected to grow at an annual rate of 2.98% by 2030, reaching a total population of 27.37 million, surpassing the growth rates of other major metropolitan centres like Beijing, Shanghai, and Mexico City.

The rapid expansion of urban areas across the globe has brought benefits and significant challenges, with increased flood risk standing as a pressing concern. This phenomenon can be attributed to various factors, including climate change, inadequate drainage systems, urban form transformation and impervious surfaces' proliferation. Studies have highlighted how certain urban forms can amplify flood risks. Fragmented and dispersed developments, for instance, lead to a reduction in natural drainage pathways and an increase in impervious surfaces, hindering water infiltration and causing accelerated surface runoff. This, in turn, intensifies peak flow rates and overwhelms drainage systems, leading to more frequent and severe flooding. Impervious surfaces, such as pavements, buildings, and roads, prevent rainwater from infiltrating into the soil and instead contribute to rapid surface runoff. This rapid runoff increases peak flow rates and overwhelms drainage systems, leading to more frequent and severe flooding [6]. Studies have established a strong correlation between the percentage of impervious surface area and the extent of flood damage [7], [8].

This massive and rapid urbanisation is primarily driven by an influx of rural migrants seeking better economic opportunities and a higher standard of living. However, this population surge has also been exacerbated by natural disasters such as flooding, deforestation, increased salinisation, and concomitant agricultural productivity decline in the surrounding countryside [9]. These factors have historically fueled large-scale rural-to-urban migration, further straining Dhaka's infrastructure and resources. The uncontrolled nature of Dhaka's urban expansion has had a detrimental impact on the city's environment [10]. The rapid conversion of natural surfaces to impervious structures has significantly reduced urban green spaces, jeopardising the city's delicate ecological balance and its ability to cope with the effects of climate change [11]. Moreover, Dhaka's proximity to highly eco-sensitive wetland areas further complicates its urbanisation process, as development often encroaches upon these critical ecosystems.

Seasonal flooding has long plagued Dhaka City, affecting over 10 million residents virtually every year [12]. The severity of these floods varies depending on rainfall patterns and the water levels of nearby rivers. The city's low-lying topography and inadequate drainage systems exacerbate the issue, leaving many neighbourhoods inundated for extended periods. In light of these challenges, developing strategies for managing Dhaka's urbanisation sustainably and resiliently is imperative [13], [14]. Understanding the spatial extent and patterns of urban expansion is crucial for developing effective planning and mitigation measures. This study aims to utilise Digital Elevation Models (DEMs) to map flood inundation zones in Dhaka City, providing valuable insights for flood risk assessment and urban planning.

1.2 Literature Review

The relationship between urban form and flood damage is a complex one. Some studies have shown that compact urban forms are more susceptible to flood damage than dispersed urban forms [7]. This is because compact cities tend to have a higher proportion of impervious surfaces, which can increase the runoff volume and reduce the infiltration. Additionally, compact cities often have a more intricate network of drainage systems, which can be more easily overwhelmed during flood events [8], [15], [16]. Other studies have shown no clear relationship between urban form and flood damage [17]–[19]. These studies suggest that other factors, such as the location of a city within a floodplain or the intensity of a flood event, are more important determinants of flood damage.

There is a lack of formal methods for assessing flood damage in Dhaka City. This is partly because the city is located in a deltaic region prone to frequent flooding. Additionally, the city has a large informal settlement population, making tracking and assessing flood damage challenging. In the past, flood damage assessment in Dhaka City has been conducted on an ad hoc basis by various government departments or agencies. These assessments have typically relied on surveys or interviews with affected residents. However, these methods are often time-consuming and resource-intensive, and they can also be subject to bias. DMSP nighttime light data can be a valuable tool for assessing

flood damage in Dhaka City. This is because nighttime light data can be used to identify areas of human activity, which can be used to infer the location of settlements and other infrastructure. Additionally, nighttime light data can be used to track changes in land use over time, which can be used to identify areas more susceptible to flooding. A few studies have used DMSP nighttime light data to assess flood damage in Dhaka City.

Several challenges and limitations are associated with using DMSP nighttime light data for flood damage assessment. One challenge is that nighttime light data is not always available for all areas of interest. Also, clouds and other atmospheric conditions can affect nighttime light data. Finally, it can be challenging to interpret nighttime light data in areas with mixed land uses. Despite the challenges and limitations, DMSP nighttime light data can be a valuable tool for flood damage assessment in Dhaka City. This data can be used to identify areas of human activity, track changes in land use over time, and assess the impact of floods on infrastructure and utilities.

1.3 Objectives

The objectives of this study are multi-fold. First, the urban expansion across Dhaka City from 1972 to 2020 is empirically assessed to understand the spatial patterns and temporal dynamics of urban expansion in Dhaka City using satellite-based nighttime light data. This objective aims to provide insights into the city's pace, direction, and characteristics of urban growth. Second, a topographic wetness index (TWI) map for Dhaka City was generated using a high-resolution digital elevation model (DEM), a valuable tool for identifying flood-prone areas. This objective aims to delineate areas susceptible to inundation during flood events. Third, identification identify settlements in floodplains: Integrate the TWI map with nighttime light data to map settlements within floodplains.

The study will focus on Dhaka City, Bangladesh, as a representative case study of rapid urbanisation and its associated flood risks. The temporal scope will encompass the period from 1972 to 2020, allowing for assessing urban expansion and flood susceptibility over a significant timeframe. The study will employ satellite-based nighttime light data from the Defense Meteorological Satellite Program (DMSP) and high-resolution DEM data from the Shuttle Radar Topography Mission (SRTM). These datasets provide valuable information on urban extent and topography, respectively.

2. Study Area and Data Section

2.1 Dhaka city

Dhaka is uniquely positioned as Bangladesh's oldest, historically largest, and most centrally located city (23.3–24.6 N and 90.1–90.3 E). The location of Dhaka on the map of Bangladesh is presented in Figure 1. Dhaka is one of the world's most densely populated metropolises, with an average population density of 48,000 km² in its central business district. The current research area encompasses a polycentric urbanised region expanding into floodplain territory, comprising a network of physically contiguous cities and growth hubs interconnected by population growth, economic activity, and physical infrastructure. Dhaka and its surrounding areas are experiencing a surge in industrial and economic activity, establishing themselves as an attractive destination for foreign direct investment in Bangladesh. This thriving urban centre is a powerful engine of economic growth, generating substantial economic, social, and cultural opportunities for the entire country. The entire aerial extent of this mega-urban zone, designated as the Greater Dhaka Detailed Urban Planning Area (DAP) for this study, encompasses 1528 km².

Dhaka is experiencing rapid and unplanned urbanisation, posing significant environmental, ecology, and flood resilience challenges. Dhaka's rapid and unplanned urbanisation has created a complex interplay between development, environmental degradation, and flood vulnerability. Addressing these challenges requires a holistic approach considering environmental sustainability, social well-being, and urban resilience. The city's expansion into floodplain areas and the filling of wetlands have increased its vulnerability to flooding, a recurring issue that affects millions of residents

annually. Dhaka's urban development began in a small area between the Buriganga and Dulai Khal rivers and extended northward. However, physical constraints imposed by swampy areas to the east and west initially limited the city's growth. As these areas have been filled in or targeted for development, Dhaka's expansion has accelerated in all directions, often in an unplanned and chaotic manner.

Dhaka's rapid and uncontrolled expansion has come at the expense of its natural environment. Wetlands and water basins surrounding the city are being drained to make way for real estate developments, increasing the risk of flooding. This environmental degradation has also contributed to Dhaka's ranking among the least livable cities in the world. Unregulated urbanisation has also had detrimental social and economic consequences. The influx of rural migrants seeking employment and better living conditions has strained the city's infrastructure and services. Additionally, the degradation of the natural environment has negatively impacted the health and livelihoods of Dhaka's residents.

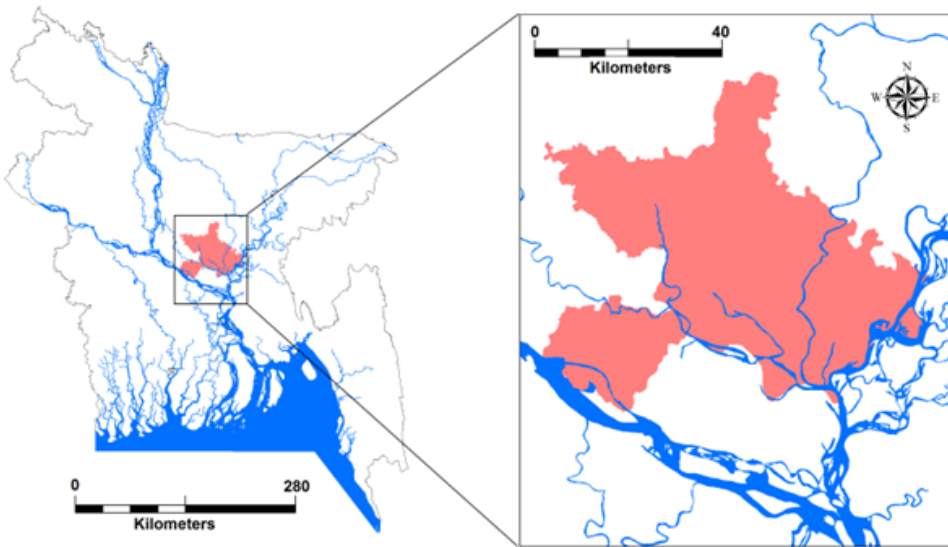


Figure 1: Location of Dhaka on the map of Bangladesh.

2.2 Data

The data used in this study are listed in Table 1. The Defense Meteorological Satellite Program (DMSP) nighttime light (NTL) data serves as the primary data source for this study. These data are freely available to the public and are employed in various stages of the study to achieve its objectives. Each record in the DMSP NTL data is represented by a digital number (DN) value ranging from 0 to 63. DMSP NTL data features a spatial resolution of 30 arc-seconds, providing near-global coverage between 180° W and 180° E longitude and 65° S to 75° N latitude. The DMSP NTL data encompass 1992 to 2000, with satellite observations. Given the inherent inconsistencies in the DMSP NTL time series data due to factors such as the absence of on-board calibration, varying atmospheric conditions, satellite shifts, and sensor degradation, a stepwise calibration approach was implemented to refine the raw DMSP NTL data and generate a temporally consistent NTL dataset. The derived DMSP NTL time series data outperforms those obtained using traditional approaches. It provides a reliable and consistent source of information for analysing urban expansion and nighttime light patterns.

The Advanced Land Observing Satellite (ALOS) is a Japanese Earth observation satellite developed by the Japan Aerospace Exploration Agency (JAXA). ALOS PALSAR data are accessible from the

JAXA Earth Observation Research Center (EORC). The EORC's website and the Earth Observation Data Distribution System (EODDS) can access the data. The Phased Array type L-band Synthetic Aperture Radar (PALSAR) was the primary instrument on ALOS. PALSAR operated at an L-band frequency of 1.2 GHz with a spatial resolution of up to 10 meters. ALOS PALSAR data has been used for a wide variety of applications. PALSAR data can map land cover types such as forests, grasslands, and urban areas. It can be used to monitor deforestation and forest degradation. It can be used to monitor floods, landslides, and earthquakes.

Table 1: Description of data used in this study.

No	Data	Resolution	Purpose
1	The nighttime light (NTL) data from the Defense Meteorological Satellite Program (DMSP)	1 km × 1 km	Demarcation of urban boundary and density of urbanization
2	Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR)	12.5 m × 12.5 m	Topographic wetness index

3. Method

3.1 Data Collection and Preprocessing

The current study utilises freely available satellite remote-sensing data to address the challenges of data scarcity and accessibility in developing countries. The procedures used in this study are outlined below:

1. Analysis of Defense Meteorological Satellite Program (DMSP) Nighttime Light Data: DMSP nighttime light data was analysed to provide valuable insights into urban expansion patterns and the intensity of urbanisation. This data was used to delineate urban boundaries and estimate urban density.

2. Use of Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR) Radiometric Terrain Correction (RTC) Digital Elevation Model (DEM) Data to demarcate floodplains. ALOS PALSAR RTC DEM data, with a resolution of 12.5 meters, served as the basis for generating a topographic wetness index (TWI) map to identify flood-susceptible zones.

3. Interception of DMSP nighttime light data with TWI map to understand Dhaka city's susceptible population of flood risk. A time series of nighttime light data is used to understand the increased flood risk in the Dhaka population.

3.2 Topographic Wetness Index (TWI) Calculation

TWI is a quantitative measure of topographic control on hydrological processes, particularly surface water flow. It is calculated using the following formula:

$$TWI = \ln(A / \tan \beta) \quad (1)$$

where: A is the flow accumulation; β is the slope angle. A higher TWI value indicates a greater potential for water accumulation and overland flow, while a lower TWI value suggests a lower likelihood of flooding. Before TWI calculation, the ALOS PALSAR RTC DEM data undergoes preprocessing steps to ensure its accuracy and suitability for analysis. These steps include: (i) Sink Filling: Sinks or depressions in the DEM data can distort slope calculations and TWI values. To address this, sinks are identified and filled using appropriate algorithms. (ii) Flow Accumulation Estimation: The flow accumulation function is applied to the DEM to determine the volume of water flowing into each grid cell. This information is crucial for calculating TWI, and (iii) Noise

Reduction: Spurious values or noise in the TWI map can arise from various factors. A low-pass filter is applied to smooth the TWI map and remove noise artefacts to mitigate this.

3.3 Analysis of Urbanisation and Flood Susceptibility

DMSP nighttime light data is analysed to quantify urban expansion over the study period. This involves image differencing and spatial metrics to assess the extent and patterns of urban growth. The TWI map is integrated with nighttime light data to identify settlements located within floodplains. This analysis highlights the potential risks settlements face in areas prone to flooding. Changes in urbanisation (intensity of DMSP light) and extreme rainfall are incorporated into the TWI model to estimate the changes in flood susceptibility over time. This provides insights into the evolving flood risks associated with urban expansion and climate change.

4. Application Results

Bangladesh has experienced a remarkable transformation in recent decades, characterised by rapid and extensive urbanisation. This transformation is vividly illustrated by analysing nighttime light (NTL) data from 1992 to 2018. NTL data provides a valuable proxy for human settlement and urbanisation patterns, as it captures the radiance emitted from artificial light sources at night. Figure 2 presents NTL maps of Bangladesh for four key years: 1992, 2000, 2010, and 2018. These maps depict the dramatic expansion of urbanised areas across the country. In 1992, the NTL signal was concentrated primarily around Dhaka, the capital city, and a few other major urban centres. However, a significant increase in NTL intensity and spatial extent was observed over the subsequent decades. Dhaka's urbanisation stands out as the most pronounced transformation. In 1992, the city was relatively compact, with a well-defined urban core. However, by 2018, Dhaka had expanded rapidly, engulfing surrounding towns and villages. This expansion is evident in the continuous growth of the NTL signal, extending far beyond the city's original boundaries.

The urbanisation trend is not limited to Dhaka; other major cities across Bangladesh have also experienced significant expansion. Cities like Chittagong, Khulna, and Rajshahi have seen a substantial increase in NTL intensity, indicating growth in population and economic activity. The expansion of urban areas in Bangladesh is accompanied by a corresponding decline in the NTL signal in some coastal areas. The black areas in Figure 2 represent rural regions without substantial human settlement or electricity infrastructure. The decrease in NTL intensity in these areas suggests a gradual shift of population and economic activity towards urban centres.

Overall, the results revealed that the NTL maps of Bangladesh from 1992 to 2018 provide a compelling visual representation of the country's rapid urbanisation. The expansion of urban areas, particularly Dhaka, is evident in the increasing intensity and spatial extent of the NTL signal. This transformation has profound implications for Bangladesh's social, economic, and environmental landscape.

Dhaka, the capital of Bangladesh, is situated within a relatively flat landscape, a characteristic reflected in its topography. The topographic map of Dhaka city (Figure 3) reveals a subtle yet significant variation in elevation, ranging from 1 to 22 meters above mean sea level. This gentle variation in elevation plays a crucial role in shaping the city's physical features and influencing its development patterns. A closer examination of the topographic map reveals that the lowest elevations are concentrated along the banks of the rivers that traverse the city. These rivers, including the Buriganga, Turag, and Balu, serve as natural drainage channels and play a vital role in the city's hydrology. The areas adjacent to the rivers are generally characterised by lower elevations, with some regions dipping below the 5-meter mark.

Moving away from the riverbanks, the topography gradually rises, transitioning from the low-lying areas to slightly higher elevations. This gently undulating topography is evident in the subtle variations in shading across the map. The higher elevations, up to 22 meters above mean sea level,

are primarily found in the northern and northwestern parts of the city. The topographic map also highlights the presence of several water bodies within the city limits. These water bodies, including lakes, ponds, and canals, contribute to the overall diversity of Dhaka's topography. While some water bodies are scattered throughout the city, others form prominent features in specific areas. For instance, the Dhanmondi Lake in the southeastern part of the city is a notable example of a water body influencing the local topography.

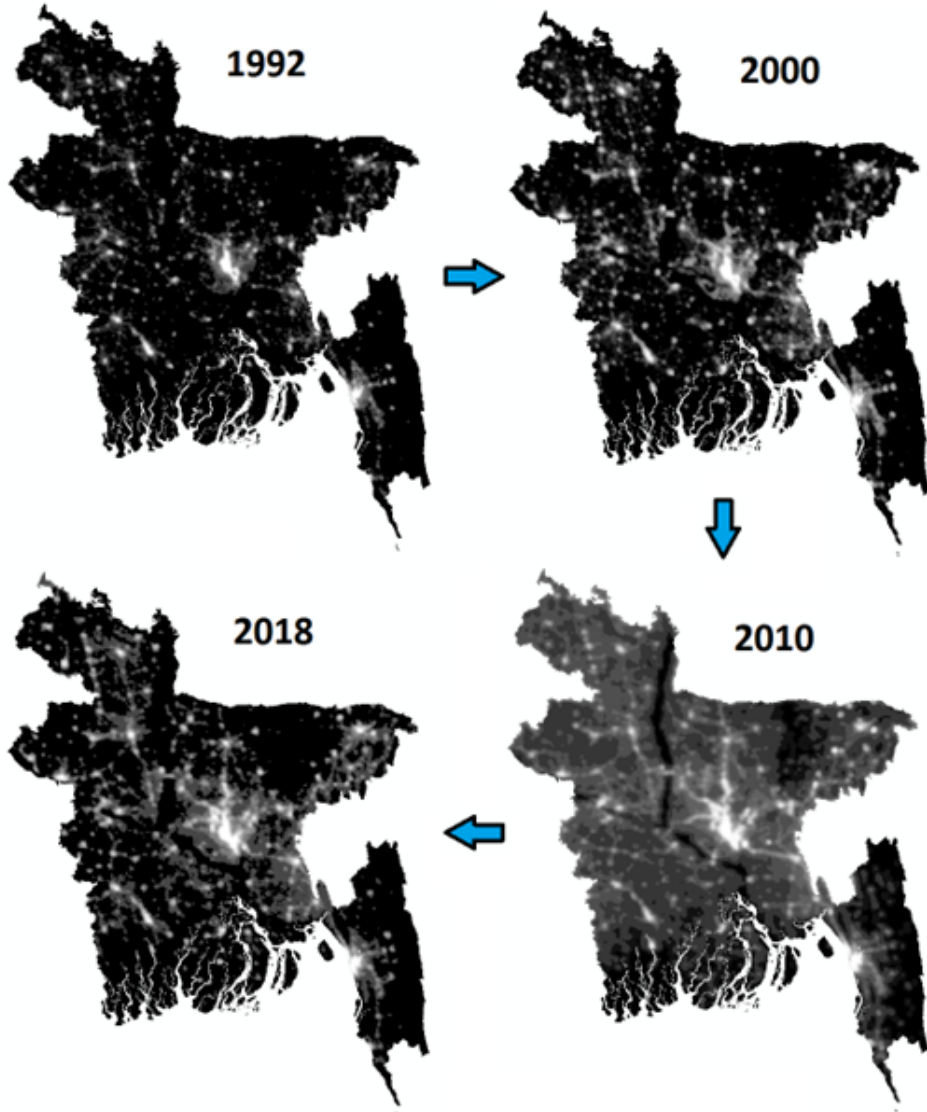


Figure 2: Changes in urban areas of Bangladesh over the period 1992-2018.

The topographic characteristics of Dhaka city have significantly impacted its development patterns. The low-lying areas along the rivers have historically been vulnerable to flooding, shaping the city's infrastructure and settlement patterns. The higher elevations in the northern and northwestern parts of the city have provided more desirable residential and commercial development locations. Overall, the topographic map of Dhaka city provides valuable insight into the city's physical landscape. The gentle

variations in elevation, the presence of rivers and water bodies, and the interplay between topography and human settlement patterns all contribute to the unique character of Dhaka. Understanding the city's topography is essential for planning, development, and disaster preparedness.

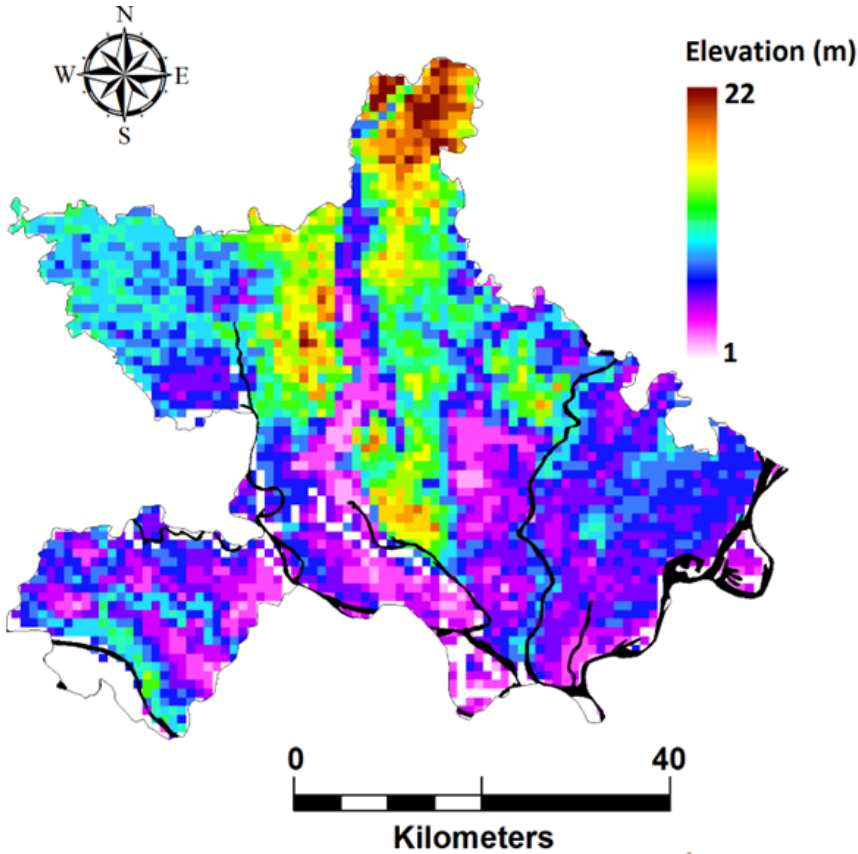


Figure 3: *The topographic map of Dhaka city.*

Figure 4 presents a comprehensive analysis of Dhaka city's topography using three crucial parameters: slope, flow accumulation, and topographic wetness index (TWI). These maps provide valuable insights into the city's physical characteristics and influence on hydrological processes, particularly flood susceptibility. Figure 4(a) depicts the slope of Dhaka city, ranging from 0 to 1. The darkest areas represent relatively flat surfaces, while lighter shades indicate steeper slopes. Most of the city exhibits gentle slopes, with a significant portion falling within the 0-0.2 slope range. This gentle topography is consistent with the overall flatness of Bangladesh. However, there are notable variations in slope across the city. The areas along the banks of the rivers, particularly in the southeastern and southwestern parts of the city, exhibit slightly steeper slopes. These steeper slopes are primarily due to the erosional effects of the rivers and the gradual rise of land away from the riverbanks.

Figure 4(b) illustrates the flow accumulation pattern in Dhaka city. Flow accumulation refers to the upslope contributing area to a specific location, representing the total amount of water that could flow through that point. The map reveals a precise concentration of flow accumulation along the river channels and their tributaries. The highest flow accumulation values are observed along the Buriganga River, particularly in the northern and eastern parts of the city. This is understandable,

as the Buriganga is the largest river traversing Dhaka and has a vast catchment area. Other areas with significant flow accumulation include the Turag River and its tributaries in the central and northwestern parts of the city.

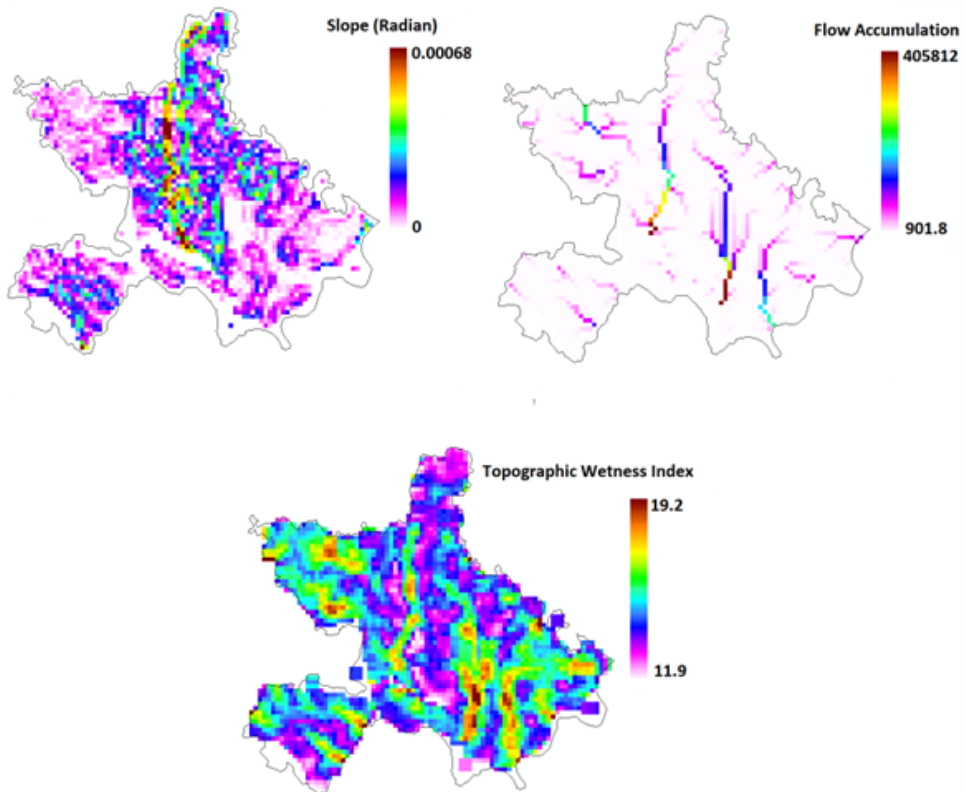


Figure 4: (a) Slope; (b) flow accumulation; and (c) topographic wetness index of Dhaka city.

Figure 4(c) presents the TWI map of Dhaka city, a valuable tool for identifying flood-prone areas. TWI integrates slope and flow accumulation to quantify the potential for water accumulation and overland flow. Higher TWI values indicate a greater likelihood of flooding, while lower TWI values suggest a lower risk of inundation. The TWI map highlights the floodplains of Dhaka city. The areas along the riverbanks, particularly in the southeastern and southwestern parts of the city, exhibit high TWI values, indicating an increased susceptibility to flooding. These areas coincide with steeper slopes and higher flow accumulation regions, confirming the relationship between topography and flood risk.

Figure 5 comprehensively analyses Dhaka city's flood vulnerability using TWI classification and rainwater accumulation zones. This analysis provides valuable insights into the spatial distribution of flood risk and helps identify areas that require targeted flood mitigation measures. Figure 5(a) depicts the classification of TWI values into five distinct classes using the natural break algorithm. This algorithm effectively partitions the TWI range into meaningful categories, allowing for a more nuanced flood susceptibility assessment. The five classes represent varying levels of rainwater accumulation potential, ranging from very low to very high. The highest TWI class, corresponding to very high rainwater accumulation, is primarily concentrated along the riverbanks, particularly in the southeastern and southwestern parts of the city. These areas exhibit a combination of steep slopes, high flow accumulation, and low elevation, making them highly susceptible to flooding.

during periods of heavy rainfall. The second highest TWI class, representing moderate rainwater accumulation, encompasses a broader area, extending beyond the immediate riverbanks. This class includes regions with slightly gentler slopes and lower flow accumulation than the high TWI class. While the risk of flooding in these areas is lower, it is still significant and requires attention. The remaining three TWI classes represent progressively lower levels of rainwater accumulation potential. These classes cover a substantial portion of the city, indicating areas with relatively lower flood susceptibility. However, it is essential to note that even these areas may experience localised flooding during extreme rainfall events.

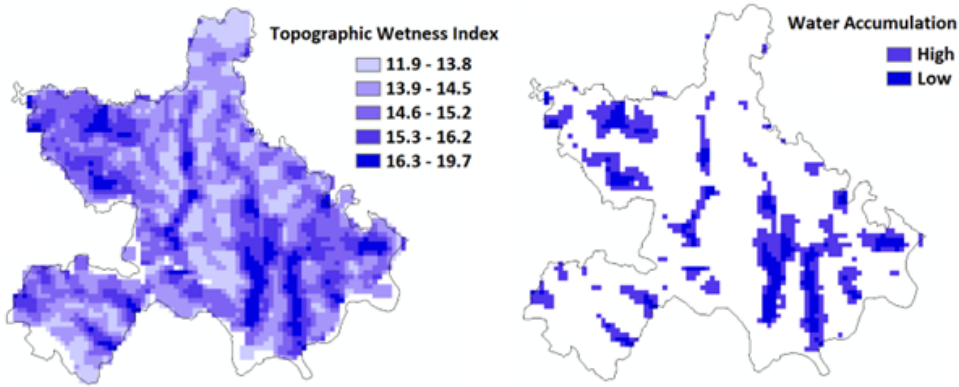


Figure 5: (a) Classification of TWI using natural break algorithm; (b) rainwater accumulation zones of Dhaka city.

Figure 5(b) presents a combined view of Dhaka city's TWI classification and rainwater accumulation zones. This map provides a clear visual representation of the spatial distribution of flood risk, highlighting the areas most vulnerable to rainwater accumulation and flooding. The rainwater accumulation zones correspond closely to the areas with high and moderate TWI values. These zones encompass the riverbanks, their surrounding floodplains, and some low-lying areas within the city. The spatial distribution of these zones underscores the importance of considering topography and hydrological processes when planning urban development and implementing flood mitigation strategies.

Figure 6 presents a compelling visual representation of the changing flood risk in Dhaka city over the period from 1992 to 2018. This analysis overlays the maps of rainwater accumulation zones (flood-prone areas) onto human settlement maps for each of the four years, highlighting the expansion of settlements into flood-prone areas. In 1992, Dhaka city exhibited a relatively low density of human settlements within high floodwater accumulation zones. The settlements were primarily concentrated along the riverbanks, reflecting the city's historical development patterns. However, even at this early stage, some settlements encroached into the high flood-prone areas, indicating an initial disregard for flood risk. As time progressed, the extent of human settlements in high flood-prone areas increased alarmingly. By 2000, the expansion of settlements into these areas became more pronounced, particularly in the southeastern and southwestern parts of the city. Population growth, economic opportunities, and the availability of land likely drove this expansion.

The trend of settlement expansion into flood-prone areas continued unabated in the following decades. The 2010 map reveals a significant increase in the number and density of settlements within high flood-prone areas, particularly in the central part of the city. This expansion reflects the city's rapid urbanisation and the growing demand for housing and infrastructure. The 2018 map paints a particularly concerning picture. The extent of settlements in high flood-prone areas has reached a

critical level, with a large portion of the central city now situated within these vulnerable zones. This expansion has placed a substantial population at risk of flooding and has heightened the city’s overall flood vulnerability. The spatiotemporal analysis presented in Figure 6 underscores the alarming trend of urbanisation encroaching upon flood-prone areas in Dhaka city. This expansion poses a significant threat to the safety and well-being of the city’s residents and calls for urgent action to mitigate flood risk.

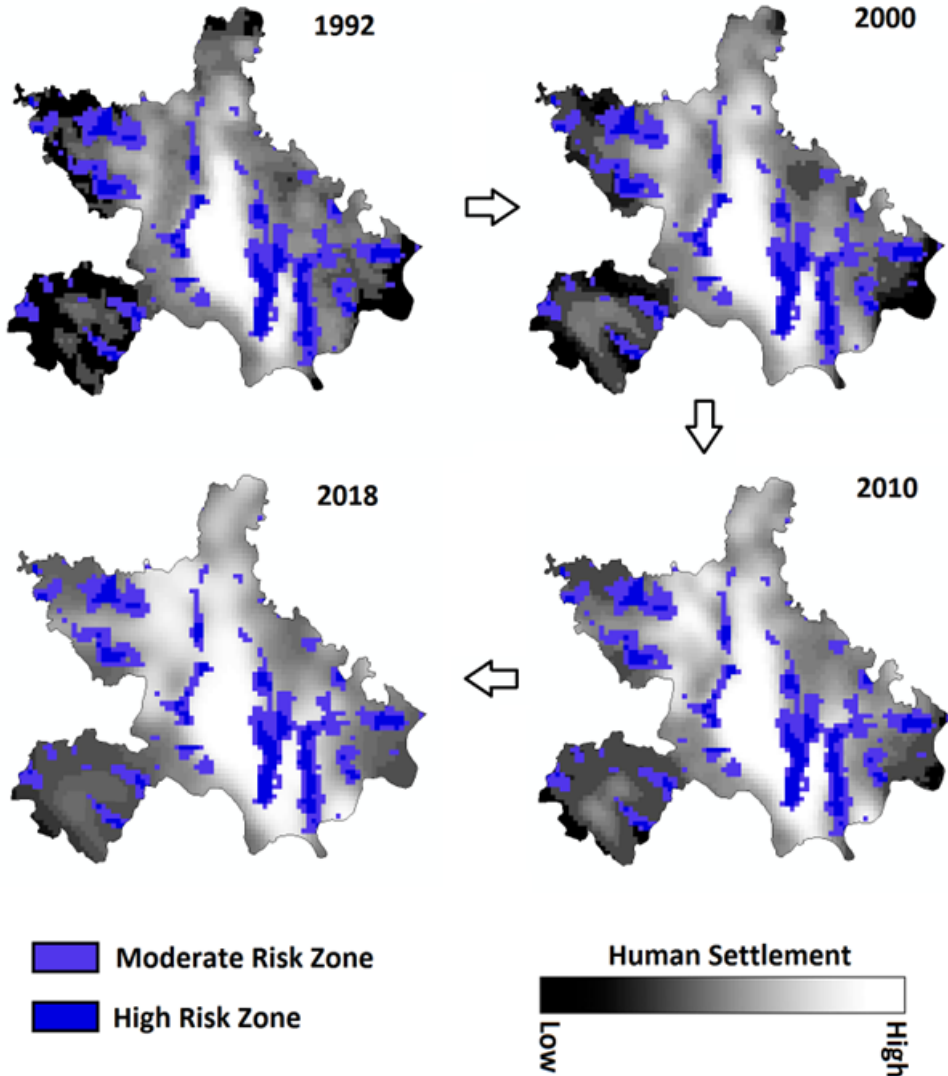


Figure 6: The changes in human settlement in flood water accumulation zones over the period 1992–2018.

5. Discussion

The study presented a comprehensive analysis of flood susceptibility in Dhaka city, remote sensing data, topographic mapping, and spatial analysis techniques. The study’s findings provide valuable insights into the city’s flood risk and highlight the alarming trend of urbanisation encroaching upon

flood-prone areas. The study successfully identified the flood-prone areas in Dhaka city using TWI classification and rainwater accumulation zones. The results revealed a clear spatial distribution of flood risk, with high-risk areas concentrated along the riverbanks and their surrounding floodplains. The results demonstrated an alarming increase in the extent of settlements within high flood-prone areas between 1992 and 2018. This expansion is primarily attributed to rapid urbanisation and the growing demand for housing and infrastructure. The study highlighted the strong correlation between urbanisation and flood risk in Dhaka city. The encroachment of settlements into flood-prone areas has significantly increased the city's vulnerability to flooding. The study employed a robust methodological approach, combining remote sensing data, topographic mapping, and spatial analysis techniques. The natural break algorithm for TWI classification and the overlay of flood-prone zones onto settlement maps were particularly effective in identifying flood risk. The study's spatiotemporal analysis provided valuable insights into the changing patterns of flood risk in Dhaka city over time. The comparison of flood-prone zones and settlement maps across four years (1992, 2000, 2010, and 2018) demonstrated the increasing overlap between urbanisation and flood-prone areas.

The study's findings have significant policy implications for flood risk management in Dhaka city. Identifying flood-prone areas and understanding the urbanisation-flood nexus can inform urban planning policies, infrastructure development strategies, and community awareness programs. Addressing the urbanisation-flood nexus in Dhaka city requires a concerted effort from government agencies, urban planners, community leaders, and the general public. By implementing proactive measures and fostering a culture of flood resilience, the city can mitigate flood risks and protect its residents from the devastating consequences of floods. The increasing overlap between urbanisation and flood-prone areas in Dhaka city highlights the urgent need for a comprehensive approach to flood risk management. Urban planning policies should prioritise land use management that avoids or development in high flood-prone areas. Flood-resilient infrastructure should be and prioritised in vulnerable areas, including drainage systems, flood walls, and elevated structures. Community education and awareness programs should be implemented to inform residents about flood risks and promote preparedness measures. Protecting wetlands and natural drainage channels can help reduce flood risk by enhancing natural water retention and infiltration.

The study could have been further strengthened by incorporating additional data sources, such as historical flood records and detailed land use maps. This would have provided a more comprehensive flood risk assessment and its relationship with land use patterns. While the study focused on the spatial aspects of flood risk, it could have been enriched by considering socioeconomic factors influencing flood vulnerability, such as poverty, access to resources, and disaster preparedness levels. The study could have been extended to develop future flood risk scenarios under different urbanisation and climate change projections. This would provide valuable insights for long-term planning and adaptation strategies. Overall, the study presented a valuable contribution to the understanding of flood susceptibility in Dhaka city. The study's findings highlight the alarming trend of urbanisation encroaching upon flood-prone areas and underscore the need for urgent action to mitigate flood risk in the city. The study's strengths lie in its methodological rigour, spatiotemporal analysis, and policy implications, while its limitations could be addressed in future research.

6. Conclusion

The study effectively integrated topographical wetness index (TWI) with nighttime light (NTL) data to identify settlements in floodplains, providing a comprehensive assessment of flood risk in Dhaka city. The results demonstrated the capability of TWI to delineate floodplains and NTL data to reveal the rapid expansion of human settlements into these vulnerable areas. This increasing encroachment into flood-prone zones has significantly elevated the flood risk for a substantial portion of Dhaka's population. The study's findings underscore the urgent need for proactive measures to reduce the disaster vulnerability of Dhaka's residents. The generated floodplain maps can serve as valuable tools

for urban planners and disaster management authorities to develop effective mitigation strategies. These strategies should include implementing stricter land-use regulations restricting development in high flood-prone areas and guiding urbanisation towards safer locations. Flood-resilient infrastructure, including flood walls, elevated roads, and enhanced drainage systems, to protect existing settlements in flood-prone zones. Foster a culture of flood preparedness among Dhaka's residents through comprehensive education and awareness campaigns. Addressing the growing flood risk in Dhaka city requires a concerted effort from government agencies, urban planners, disaster management authorities, and the general public. By implementing these comprehensive measures, Dhaka can mitigate flood risks, safeguard its residents, and build a more resilient urban environment. Extending the study to develop future flood risk scenarios under different urbanisation and climate change projections would provide valuable insights for long-term planning and adaptation strategies.

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Conflicts of Interest: The authors declare no conflict of interest.

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