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Environmental challenges of deltaic towns in West Bengal, India: A perspective on sustainable development at the local level

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Abstract

The sustainability of an area is inextricably linked to environmental challenges. Growing environmental challenges exacerbate local crises and increase society's risk. Such localized crises are prevalent in small towns of the Sundarbans Delta in India due to their climate-sensitive location and uncontrolled population growth. This article examines the present environmental crises and the effects of tropical cyclones and urban flooding on the citizens of the deltaic towns of Budge Budge, Diamond Harbour, and Pujali, located in South 24 Parganas, West Bengal. In this study, we collected both primary and secondary data through empirical research. Perceptions from 208 households, 18 municipal officials, and 52 councilors were obtained through in-depth interviews and a semi-structured questionnaire survey. The population projection, spatial analysis index, and land use and land cover maps for 2011 and 2023 were used to assess population growth and ongoing land dynamics in the towns. To identify the impact of cyclones, data on cyclone frequency and intensity from 1900 to 2023 were also analyzed. The study shows that the towns of the Sundarban delta are facing severe environmental crises for multiple reasons: High rate of population growth; development of informal settlements; destruction of blue and green infrastructure; the increasing impact of cyclones and flooding; and the lack of financial strength of the ULBs to overcome those crises.

Keywords: Deltaic towns; Environmental sustainability; Population growth; Land use and land cover change; Tropical cyclone

1. Introduction

The process of urbanization is intricately linked with the deterioration of environmental conditions (Bai *et al.*, 2017; Patel & Raval, 2024). With the increasing level of urbanization, especially in Asian and African countries, various environmental crises are emerging at a higher rate, leading to unsustainable development (Arfanuzzaman & Dahiya, 2019; Buhaug & Urdal, 2013; Hardoy *et al.*, 2013). According to the United Nations' (UN) estimates, the global urban population is expected to reach around 68.4% by 2050 (United Nations, 2018). People are attracted to urban areas for improved and diverse socioeconomic and cultural conditions, and that prompts the process of migration and urbanization (Bhagat & Mohanty, 2009; Kundu, 2011; Nijkamp & Kourtit, 2013). The growing urban population puts pressure on the urban environment to meet their needs, which ultimately leads to severe environmental damage (Chu & Karr, 2016; Moore *et al.*, 2003). Urban environmental challenges, such as the rapid transformation of land use and land cover (LULC), pollution, and the effects of climate change, are currently affecting every country worldwide (Esfandeh *et al.*, 2021; P. Roy *et al.*, 2022; Singh *et al.*, 2020). These challenges are global in nature, but each nation has its own responsibilities toward its environment (Jelin, 2000; Mason, 2012; Rio Declaration on Environment and Development, 1992). Rasoolimanesh *et al.* (2013) argue that to manage the growing urban population, a sustainable development framework for urban areas that protects the environment and balances human needs with available natural resources is needed.

The discussion of city-centric sustainable development gained greater institutional recognition in 1996 at the second UN Conference on Human Settlements (Habitat II) (Parnell, 2016; Satterthwaite, 1997). In 2015, the UN Environmental Programme provided a unified roadmap for peace and prosperity, both for the present and the future, by adopting the 2030 Agenda for Sustainable Development (Grenville *et al.*, 2019). In this agenda, 17 sustainable development goals (SDGs) have been listed, where the sustainable development of cities and communities has specifically been emphasized in Goal 11. In 2016, the third UN Conference on Human Settlements (Habitat III, Quito) directly linked the issue of urban sustainability with SDGs to reduce urban inequality and encourage city-based climate action (Parnell, 2016).

Considering the pressures of growing urban populations, the UN emphasizes the role of Urban local bodies (ULBs) in maintaining urban sustainability at the national as well as the global levels (United Nations Development Programme, 2014). They state that each urban unit needs to take a distinct path to achieve sustainability. This is because the criteria for urban sustainability differ widely across local environmental, social, economic, and political conditions (Giddings *et al.*, 2002; Little *et al.*, 2016; Purvis *et al.*, 2019). For example, some urban areas should focus on blue–green infrastructure; others should prioritize pollution control; some areas should emphasize waste management and sanitation; and others should focus on improved drainage systems to reduce the impact of urban flooding and create a sustainable and resilient environment.

Existing research on the post-2015 SDGs suggests that, through ignorance of nature, we commit massive, irreversible harm to the physical environment on which our lives and well-being depend (Guite *et al.*, 2006). If this situation continues, it will not only lead to the depletion of natural resources but will also ultimately lead to human misery (Ploeg, 2011; Reid *et al.*, 2017). However, the concept of urban sustainability arises from urban environmental degradation caused by unplanned urban growth and excessive population pressure on available natural resources (Perdan, 2004; Smith, 2020). Global environmental issues such as natural resource degradation, rapid changes in LULC, and the impacts of climate change are primarily driven by ongoing human activities in urban areas (Mir *et al.*, 2025). Specifically, the United Nations Human Settlements Programme (2024) states that since 1975, flood risk in urban areas has increased 3.5 times more than in rural areas. The report also states that due to the rapid rate of urbanization, the share of urban green cover globally has declined by more than 5.6% since 1990.

The selected deltaic towns, namely Budge Budge, Diamond Harbour, and Pujali, are not free from the above-mentioned environmental crises. However, these issues are more complex and intensify in these deltaic towns due to their growing populations and the risk of cyclones and urban flooding. Being small in size, these towns are apathetic to urban scholars and policy-makers. Moreover, these towns are home to large urban populations, and their total populations are growing rapidly due to migration from surrounding rural areas affected by the vulnerable conditions in the active part of the Bengal Delta. The growing population and uncontrolled expansion of built-up areas in these towns strain environmental resources, such as land, water, and vegetation.

To analyze the sustainability of these towns, the Urban Ecological Approach (UEA) framework was used, which helps to understand how both the physical environment and the citizens of an urban area impact each other. A town is also part of the biosphere, where environmental changes can significantly affect its socioeconomic dynamics (Tanaka *et al.*, 2025), especially in the delta region. The transformation of blue and green infrastructure and land use patterns not only alters the town's environment but also creates inequality in access to land, recreational space, and occupation (Pauleit *et al.*, 2021). To comprehend the interrelationship between the human and physical environments in these towns, the UEA framework serves as a conceptual foundation. The UEA offers a valuable perspective on the environmental challenges faced by deltaic towns in their pursuit of sustainability. The central research question of this article is: What types of environmental challenges arise in the deltaic towns, and how do they disrupt sustainability? To address this research question, this article analyzes the impact of increasing population pressure, the accelerated transformation of land use, and the increasing intensity of natural disasters affecting the deltaic towns. The article is divided into five sections. First is the introductory section, which addresses the research question, objectives, and the theoretical framework of urban environmental sustainability. The second section discusses the data and methodology, including the study area, data sources, and the techniques used for data analysis. The results and discussion are presented in detail in the third and fourth sections, respectively. The conclusion of the study is presented in the final section.

1.1. Context of urban environmental sustainability

This research adopted the UEA to conceptualize the idea of urban environmental sustainability. The urban ecological approach emerged within human ecology in the early 1920s to examine the relationship between people and the urban environment (Collins *et al.*, 2000; Grove & Burch, 1997). The UEA aims to assess urban environmental sustainability and human well-being (Panagopoulos *et al.*, 2016; Van Kamp *et al.*, 2003). At present, urban areas around the world are more responsible for the environmental crisis, as more than 70% of greenhouse gas emissions and 75% of natural resource consumption occur in towns and cities (Perrotti *et al.*, 2021). That is why towns and cities have to be more responsible for ensuring the sustainable use of land and other resources.

The UEA received significant attention following the publication of *Our Common Future* (1987) by the World Commission on Environment and Development (Martinez-Moscoso & Warner, 2025; Saruchera, 2025). The report revealed an essential connection between environment and development. Since then, both academic and policy discourses have prioritized the global sustainable development issues by linking them with the environment. UEA emphasizes urban areas as an integral part of the natural world rather than using a narrow lens of efficient, equitable, and resilient paths to achieve urban sustainability (Yigitcanlar & Dizdaroglu, 2015). UEA treats urban areas not just as built environments or economic systems, but as dynamic socioecological systems in which human and natural components are deeply interconnected. A change in one affects the entire system. It investigates governance services, urban development patterns, and environmental inequality to address urban sustainability. It argues for bringing scholars, practitioners, policy-makers, and urban residents into dialogue about ecological knowledge and its implications for the specific urban area.

At the beginning of the 21st century, urban areas became a key concern for sustainability due to unprecedented urban population growth and intensive pressure on the natural environment. The construction of roads, housing, power lines, and industrial and commercial sites creates new urban landscapes while simultaneously fragmenting former forests, grasslands, and farmlands in the relentless march of development (Rudel, 2021). These changes create serious environmental problems that threaten the health and well-being of urban citizens worldwide (Choudhury *et al.*, 2023; Douglas, 2012; Rana, 2011). According to this approach, the unabated exploitation of natural resources has been the primary reason for the deterioration of the urban environment (Mondal & Palit, 2022; Rees & Westra, 2012).

This approach focuses on urban environmental challenges such as the exploitation of natural resources, changes in urban LULC, biodiversity degradation, deforestation, pollution, and the impact of climate change on cities and future urbanization on a sustainable path (Wolf *et al.*, 2023; Yigitcanlar & Dizdaroglu, 2015). In general, urbanization alters the composition and spatial arrangement of the landscape elements. These changes affect the biodiversity, ecosystem functioning, and environmental quality, as well as human behavior, community structure, and social organization (Di Giulio *et al.*, 2009; Grimm *et al.*, 2008; Opoku *et al.*, 2022; Su *et al.*, 2012). This framework conceptualizes how the combined interactions between people and the environment shape the structure and function of urban landscapes.

Since the late 20th century, research on urban ecology has been rapidly expanding in the context of climate change and exposure to urban floods (Hobbie & Grimm, 2020; Hodson & Marvin, 2009; Trisos *et al.*, 2020). Numerous studies show that urban green and blue infrastructure provides a range of environmental and socioeconomic benefits, such as stormwater management, noise reduction, air purification, climate regulation, and cultural and recreational values (Dhyani *et al.*, 2022; Lawson *et al.*, 2014; Thorne *et al.*, 2015). In that context, this research emphasizes the composition and spatial change of urban LULC, besides the risk of tropical cyclones and urban floods. The urban ecosystems of these towns are already fragile and susceptible to natural hazards, given their proximity to coastal areas. The increasing population pressure, along with the growth of built-up areas, including roads, residential, and commercial areas, destroys blue and green infrastructure, agricultural land, and open spaces. The impact of both physical and economic factors is high, taking a toll on the sustainability of these towns.

2. Methodology

2.1. Study area

In this study, Budge Budge, Diamond Harbour, and Pujali municipalities were selected for a case study of the South 24 Parganas district of deltaic West Bengal, India (Figure 1). These towns are smaller, with populations under 1,00,000, and 16–20 wards each. These towns receive an average of 140 cm of rainfall/year, with about 75% falling during the monsoon season. The average elevation of these towns is

<9 m above sea level in India. These towns experienced significant sea-level rise (5.16 mm/year between 1948 and 2005), severe-to-very severe tropical cyclones, and intense rainfall due to their location near the Bay of Bengal coast. Since 1900, these deltaic towns have experienced more than 100 cyclonic storms and 19 severe-to-very severe cyclonic storms. However, the frequency and intensity of severe-to-very severe cyclonic storms have increased over the past two decades due to rising temperatures in the Bay of Bengal (IMD report, 2024).

2.2. Data source and techniques used for analysis

This research utilized the urban ecological approach to comprehend the spatial arrangement of different kinds of LULC classes and to analyze the impacts of natural disasters on the citizens of the deltaic towns. Both primary and secondary data were collected to analyze the environmental challenges and their impacts on the sustainability of the deltaic towns. To fulfill the research goal, a total of 208 households, 30 key respondents, 18 municipal officials, and 52 councilors' perceptions were obtained through in-depth interviews and a semi-structured questionnaire survey (Table 1) between April and October 2023. The following paragraphs detail the data collection method.

To examine the impact of environmental vulnerability on different economic classes, household information of these towns was collected from two strata: (i) Low-income group (households with income under Indian Rupees [₹] 6 lakhs/annum) and (ii) middle-income group (households with income between ₹6 lakhs and ₹18 lakhs/annum). To cover both classes of citizens, we approached households in slums and middle-class neighborhoods across different wards. The data on the number of households and the area covered by the slums were collected directly from municipal offices. To identify middle-class households, we used the building structure of houses as a proxy for income. Stratified random sampling was used to collect household-level data. According to the Municipality reports (2023), about 40% of households in Budge Budge, 22% in Diamond Harbour, and 61% in Pujali live in slum areas. Based on that ratio, 32 slum households in Budge Budge, 14 in Diamond Harbour, and 39 in Pujali were selected for the household survey. To cover middle-income households, 48 households from Budge Budge, 50 from Diamond Harbour, and 25 from Pujali were selected.

The perceptions of 30 key respondents, 18 municipal officials, and 52 councilors were collected through in-depth interviews and a semi-structured questionnaire

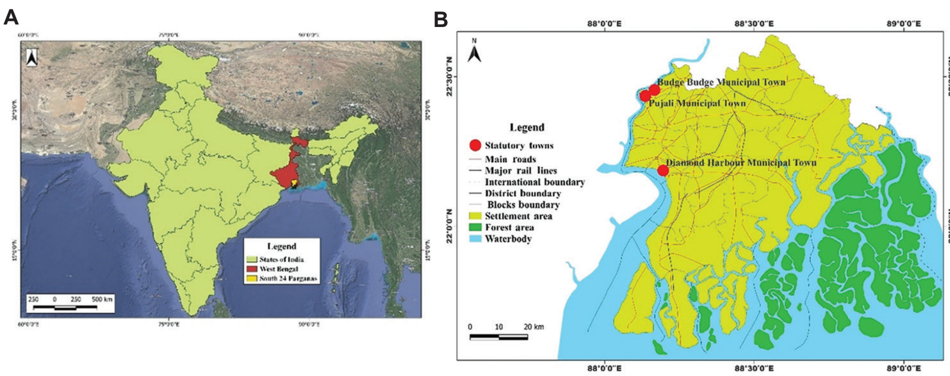

Figure 1. The study area of selected deltaic towns. (A) A map of India highlighting the (B) South 24 Parganas region. Adapted from the Census of India, 2011.

Table 1. Specificity of the primary database

Selected target groups	Sampling techniques	Town		
		Budge Budge	Diamond harbour	Pujali
		Number of samples		
Households (slums+middle-income group)	Stratified random sampling (four samples from each ward)	80	64	64
Key respondents (elderly people, teachers, doctors, advocates, social workers)	Purposive sampling+Snowball sampling	10	10	10
Municipal officers	Purposive sampling	6	6	6
Councilors	Whole population	20	16	16
Total	308			

survey. Using purposive and snowball sampling, 10 key respondents were selected from each town to obtain information from specific and diverse groups of people. Snowball sampling helped us find key respondents across different fields, and reaching them through an insider contact helped us secure their participation in the interview. The specific target respondents are referred to as key respondents. They include elderly people, academic experts, and social workers who are residents of the towns and possess extensive local knowledge. Six municipal officials were selected in each town through purposive sampling based on their responsibilities related to our research agenda and were interviewed using an open-ended questionnaire. This interview included an urban planner, a finance officer, a drainage officer, a sanitation inspector, an emergency management officer, and a surveyor in each town. The interview aimed to understand the governance services and their role in managing the environmental crisis. In addition, the census data, municipal reports, Indian Meteorological Department (IMD) reports, and previous literature were used as secondary data in this research. To represent the current population growth in the study area, the 2001 and 2011 Census of India reports have been used, along with 2023 population data from the respective municipality.

2.3. Population projection

To predict the future population pressure in these towns, a population projection was calculated. From 1901 to 2011, the data from the Census of India were used for population projection. No population census has been conducted by the government of India since 2011. Therefore, we used the data against the year 2011. Among the different population projection methods, the incremental increase method was considered for Budge Budge, the geometric method for Diamond Harbour, and the arithmetic method for Pujali. These different methods of population projection were adopted based on the town's population growth rate (PGR) and the trend of population growth in the previous census years.

2.3.1. Incremental increase method of population projection for Budge Budge

Scholars (Ismael and Aziz, 2024) used the incremental increase method of population projection to forecast future population growth, accounting for both the average population increase and the average incremental increase. This method is specifically helpful for mid-sized old towns with progressive population growth and an increasing or decreasing rate of incremental increase over time. The Budge Budge municipality is one of the oldest municipalities, established in 1900. At present, the Budge Budge town covers around 9.06 km^2, but its total area was 4.83 km^2 in 1900. It is found that from 1901 to 2011, the population increased progressively in each census year, with incremental increases and decreases in growth. The extension of the town area adds an opportunity for population growth. Therefore, the incremental increase method is suitable for this town to predict increasing population growth.

2.3.2. Geometric increase method of population projection for Diamond Harbour

The geometric increase method of population projection assumes that the population's growth rate is constant in each decade (Hiben *et al.*, 2024). This method is more applicable to cities and towns in a developing phase. Diamond Harbour is a newly developed town (established in 1982) with a vast scope for expansion. Being a sub-divisional town, this town not only faces rapid population growth but also offers job opportunities in non-farm sectors, which drive in-migration. According to the 2011 census, the total population of Diamond Harbour was 41,802, which increased to 56,922 in 2023 (The Diamond Harbour municipal report, 2023). Therefore, this town is currently experiencing exponential population growth.

2.3.3. Arithmetic increase method of population projection for Pujali

The arithmetic increase method of population projection assumes constant population growth (Spears *et al.*, 2024). This population projection method was applied in Pujali due to its consistent PGR over time. Pujali town was established in 1996 and now spreads over 8.32 km^2. It is a small town, both in terms of area and total population, compared to the other two towns. According to the 2001 and 2011 censuses, the population growth in this town has been steady. Therefore, using the arithmetic increase method, the average annual population increase was calculated from the 2001 to 2011 census data to estimate the population in 2040.

2.4. Land consumption rate to population growth rate

This research used Landsat and Google Earth imagery from 2011 to 2023 to identify LULC changes in the towns. Based on the contemporary LULC patterns of these towns, five categories—water bodies, vegetation cover, built-up area, agricultural land, and open space—were classified to prepare LULC maps. To obtain a detailed picture of LULC classes at the local level, the percentage of covered areas and growth rates over 12 years were calculated in the Quantum Geographic Information System software (version 3.20).

To assess population pressure on urban areas, the land consumption rate to PGR (LCRPGR) index was calculated using the SDG indicator 11.3.1 (UN-Habitat, 2018). For the LCRPGR evaluation, the proportions of LULC cover area for 2011 and 2023 were considered. Generally, the LCRPGR index value indicates three states of population pressure on the urban landscape: (i) Index value +1 indicates a favorable ratio between land consumption rate and PGR, (ii) an index value <+1 to minus value indicates population growth is faster than land consumption, and (iii) index value >+1 indicates land consumption is faster than population growth. In this article, Equation (1) was used to calculate the LCRPGR value over 12 years. Equations (2) and (3) were used to calculate the land-use rate (LCR) and PGR for the same period.

$$\text{LCRPGR} = (\text{LCR}/\text{PGR}) \quad (1)$$

$$\text{LCR} = (V_{present} - V_{past})/V_{past} \times 1/(t) \quad (2)$$

where $V_{present}$ is the total built-up area in the current year, V_{past} is the total built-up area in the past year, and t is the number of years between $V_{present}$ and V_{past}.

$$\text{PGR} = \text{LN}\,(\text{Pop}_{t} + n/\text{Pop}_{t})/(y) \quad (3)$$

where LN is the natural logarithm value, Pop_t is the total population within the urban area/city in the past/initial year, $\text{Pop}_t + n$ is the total population within the urban area/city in the current/final year, and y is the number of years between the two measurement periods.

3. Results

3.1. Growing population pressure in the towns

According to the UN, more than 4.40 billion people worldwide currently live in urban areas (UN World Urbanization Prospects, 2019). However, most of this urban growth occurs in smaller towns and cities. This type of population growth is particularly evident in Central and South Asian countries. In the Indian context, India's small towns are expanding faster than India's large cities and metropolises (Samanta, 2017). Our study areas are no exception to this trend (Figure 2). According to the 2011 population census, the total populations of Budge Budge, Diamond Harbour, and Pujali were 76,837, 41,802, and 37,047, respectively, with corresponding population densities of 8,481, 4,035, and 4,453 persons/km^2. This population density is higher than the state's average urban population density (1,029 persons/km^2) and the country's average urban population density (382 persons/km^2). In 2023, the absolute population increased to 88,070 persons in Budge Budge, 56,922 persons in Diamond Harbour, and 41,331 persons in Pujali, with corresponding population densities of 9,721, 5,494, and 4,968 persons/km^2, respectively (Municipality reports, 2023). However,

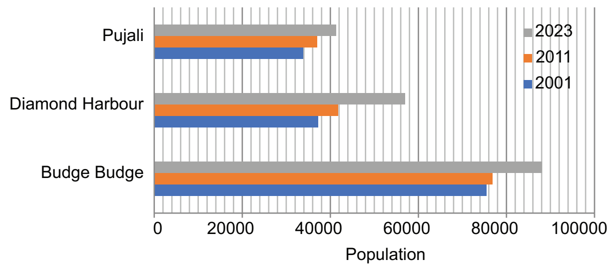

Figure 2. The present status of population growth. Data obtained from the Census of India 2001 and 2011, and 2023 municipal reports of the towns.

the total area of the towns remained constant. According to population projections, by 2040, the populations of Budge Budge, Diamond Harbour, and Pujali will reach 91,603, 73,879, and 46,295, respectively.

One of the significant reasons behind the high population growth in these deltaic towns is the localized migration. By the turn of the 21st century, with the spread of the neoliberal economy, the deltaic cities of African and Asian countries began to experience rapid population growth due to high rates of in-migration and a thriving economy (Haq & Milliman, 2023; McGranahan *et al.*, 2023). Following the same trend, these towns are also growing faster due to local migration. Between 2011 and 2023, the number of households increased by 13.41% in Budge Budge, 66.60% in Diamond Harbour, and 11.59% in Pujali. As per our field research across different parts of the towns, this increase is entirely due to migration from the villages in the fragile coastal areas of the Sundarbans, such as Namkhana, Patharpratima, Canning, Kakdwip, and Sagar Island. It has also been observed that the people migrate to these towns mainly for two reasons: (i) To access urban opportunities, including employment, medical facilities, education facilities, and markets, and (ii) to search for a more secure living condition in comparison to the highly vulnerable coastal areas exposed to repeated natural calamities such as floods and land erosion. Moreover, the ease of commuting to Kolkata for work is another factor in the growth of these towns, which are well-connected by suburban trains. Specifically, people from the Sundarban delta come to these towns not only for economic well-being but also to escape the environmental crisis caused by climate change. The lives and livelihoods of the people in this region are highly vulnerable due to the impacts of climate change, including sea-level rise, tropical cyclones, floods, and storm surges (Arto *et al.*, 2019; Becker *et al.*, 2020; Das *et al.*, 2020). The people of Sundarban highly depend on natural resource-based activities, such as farming and fishing, which are highly susceptible to climatic vagaries (Jamal *et al.*, 2022; C. Roy & Guha, 2017;

Sahana *et al.*, 2019; Schneider & Asch, 2020). The impact of rising sea levels in the Sundarban region has been evident in extensive land erosion and riverine and marine encroachment (Datta *et al.*, 2024; P. Roy *et al.*, 2023). Cultivated land area has been decreasing due to coastal erosion, island inundation, and soil salinization (Banerjee *et al.*, 2023; Mandal *et al.*, 2023). Crops are lost almost every year due to severe cyclones, embankment failure, and erratic rainfall (Dutta *et al.*, 2020; S. Ghosh & Roy, 2022). Due to reduced land area and increasing livelihood pressures, people are forced to migrate from vulnerable parts of the Sundarbans to nearby towns. These migrants are of two categories. One is middle-income people who sell their properties in villages and move to towns, building their own houses. The second group consists of poor migrants who cannot afford to buy land in the towns. They are either compelled to occupy land along canals and riverbanks or to live in small, overcrowded rented places on a shared basis. In this process, unorganized and overcrowded slum areas have proliferated in these towns. The proliferation of such slum areas not only destroys the natural balance of these towns but also undermines their sustainability. The ULBs, with their already overstrained infrastructure, cannot provide urban basic services to these unorganized slums, which creates an unsustainable future for the towns. Scholars (Adeniyi & Olayiwola, 2025; Singh *et al.*, 2025) have also identified similar uncontrolled slum growth and inadequate governance services, leading to environmental degradation of urban areas in the Global South.

3.2. Environmental assessments of the towns

Land use relates to human activities on land, whereas land cover describes the natural envelope that covers the land surface (Mustard *et al.*, 2012). LULC maps from different years help detect changes in land-use patterns (Dadashpoor *et al.*, 2019; Kafi *et al.*, 2014; Lambin *et al.*, 2003). LULC maps of Budge Budge, Diamond Harbour, and Pujali show that the proportion of built-up areas has increased rapidly. It is also observed that residential apartments, commercial establishments, industrial zones, roadways, and railway networks are encroaching upon the green cover, water bodies, and agricultural lands. LULC maps of 2011 and 2023 show that vegetation cover and water bodies in these towns are gradually being encroached upon by unregulated expansion of built-up areas (Figures 3-5). The following statements (one from each town) by the key respondents support our observations from the LULC change analysis.

Budge Budge is one of the oldest towns under the Kolkata Metropolitan Development Authority. This town has become overcrowded, which imposes pressure on the natural assets, particularly on open space and blue and green infrastructure, especially for new construction. (An older adult resident of Budge Budge, May 18, 2023).

Rapid population growth disrupts the balance between citizens and the natural environment. Water bodies, green cover, and agricultural land are rapidly being converted to built-up areas, and this problem has become more acute due to the indifferent attitude of the municipality and the lack of planning initiatives. (A retired municipal clerk of Diamond Harbour, April 16, 2023).

Pujali is a small town and lacks sufficient opportunities to generate its own revenue to meet the basic needs of its citizens. Poor people come to the town to work in the jute mills and brick kiln industries and also to commute as wage laborers to Kolkata city, resulting in the unorganized growth of built-up areas, which poses a serious threat to the town's environment (The Councilor of Pujali, personal communication, June 12, 2023).

According to the 2011 LULC map, the built-up area was 44.94% in Budge Budge, 25.88% in Diamond Harbour, and 31.59% in Pujali (Table 2). In 2023, the built-up area increased to 48.44% in Budge Budge, 32.12% in Diamond Harbour, and 32.74% in Pujali. Between 2011 and 2023, these towns experienced an overall 12.42% increase in built-up areas. Consequently, vegetation cover, water

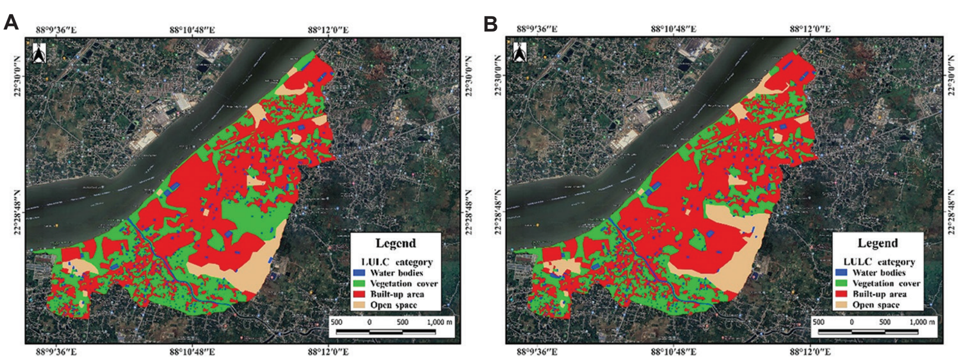

Figure 3. Land use and land cover (LULC) map of Budge Budge in (A) 2011 and (B) 2023. Images taken from Landsat/Copernicus from Google Earth.

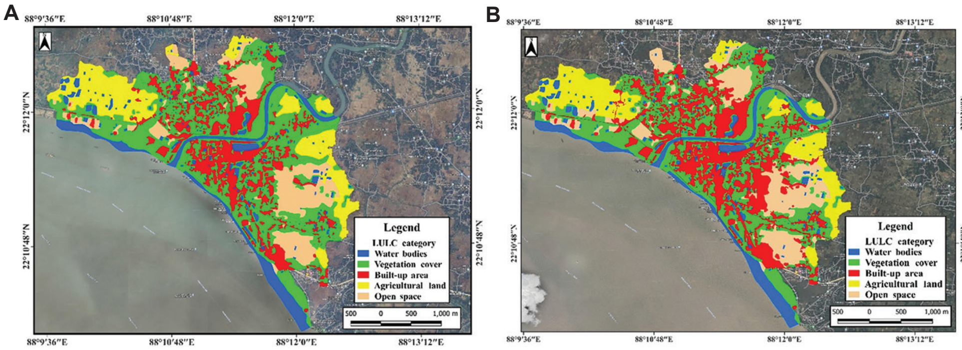

Figure 4. Land use and land cover (LULC) map of Diamond Harbour in (A) 2011 and (B) 2023. Source: Images taken from Landsat/Copernicus from Google Earth.

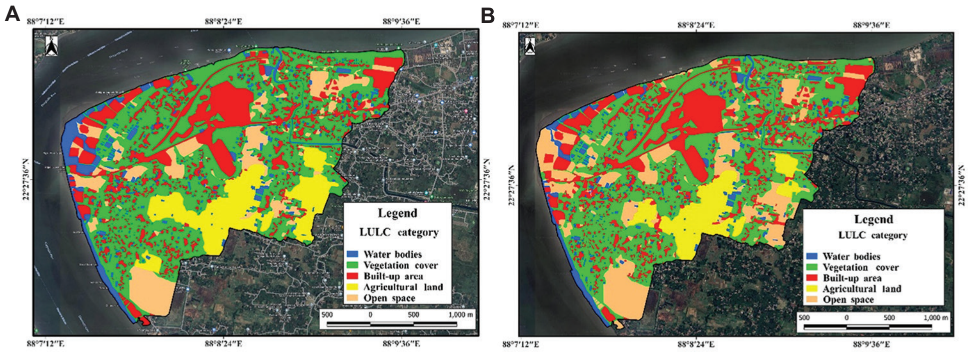

Figure 5. Land use and land cover (LULC) map of Pujali in (A) 2011 and (B) 2023. Images taken from Landsat/Copernicus from Google Earth.

Table 2. Category-wise land use and land cover changes of towns in 2011 and 2023

Land use and land cover category	2011		2023		Growth rate (%)
	Area (m²)	Percentage	Area (m²)	Percentage	
Budge Budge					
Water bodies	829,896	9.16	774,630	8.55	−6.66
Vegetation cover	3,254,352	35.92	2,860,242	31.57	−12.11
Built-up area	4,071,564	44.94	4,388,664	48.44	7.79
Open space	904,188	9.98	1,036,464	11.44	14.63
Diamond Harbour					
Water bodies	1,267,028	12.23	1,244,236	12.01	−1.27
Vegetation cover	2,918,412	28.17	2,303,028	22.23	−8.96
Built-up area	2,681,168	25.88	3,327,632	32.12	25.84
Agricultural land	1,910,384	18.44	1,804,712	17.42	−25.33
Open space	1,583,008	15.28	1,680,392	16.22	6.16
Pujali					
Water bodies	7,654,400	9.2	6,755,840	8.12	−11.74
Vegetation cover	33,296,640	40.02	32,647,680	39.24	−1.95
Built-up area	26,282,880	31.59	27,239,680	32.74	3.64
Agricultural land	8,519,680	10.24	7,438,080	8.94	−12.69
Open space	7,446,400	8.95	9,118,720	10.96	22.45

bodies, and agricultural land have experienced steady declines during the same period. Between 2011 and 2023, the percentage of vegetation cover decreased to −12.11% in Budge Budge, −8.96% in Diamond Harbour, and −1.95% in Pujali, and the decline rates of water bodies were −6.66% in Budge Budge, −1.27% in Diamond Harbour, and −11.74% in Pujali.

Based on the five land use categories of the LULC map, Diamond Harbour (−25.33%) and Pujali (−12.69%) experienced the most significant decline in agricultural land over the past 12 years. Agricultural land in Budge Budge was absent because the land was previously occupied by commercial establishments and residential apartments. We found that the proportion of open spaces increased by 6–23% in newly emerging towns due to land speculation, with farmland bought at low cost and kept fallow to raise land prices for residential and commercial use.

Rapid urbanization alters LULC and disrupts the ecological balance by destroying blue and green infrastructure and reducing food production (Mir *et al.*, 2025; Wahla *et al.*, 2025). The decline in blue and green infrastructure increases land surface temperatures and makes urban areas more vulnerable to cyclones and floods (Bagheri, 2025). Over the past 12 years (2011–2023), these towns have experienced rapid growth in built-up areas through the conversion of vegetation, water bodies, and agricultural land. Consequently, the share of urban green spaces, water bodies, and agricultural lands has declined considerably in these towns. Due to the conversion of blue and green infrastructure, citizens experience intense heat during the summer and waterlogging during the rainy season, even after moderate rainfall of 0.65 mm/h–2.68 mm/h. In addition, agricultural land has decreased at an alarming rate due to land speculation, the practice of buying land in the hope of increasing its price in the future.

Between 2011 and 2023, although the proportion of open space in Budge Budge increased by 14.63%, in Diamond Harbour by 6.16%, and in Pujali by 22.45%, citizens face socio-ecological problems due to land speculation. Generally, open space pertains to a portion of land and water that is unobstructed and exposed to the sky. It is an unbuilt area used for recreation, with an increase in contact with nature, which can also increase a sense of community, reduce socio-economic inequalities, and maintain the urban biodiversity, temperature regulation, and water retention (Aiymeku *et al.*, 2024; Qi *et al.*, 2024; Shamaee *et al.*, 2024; Yan *et al.*, 2024).

In these towns, politically and socially influential people purchase land with the expectation that its value will increase over time. Land is treated as an investment asset. As per the field investigation, it has also been observed that real estate owners in Kolkata invest in buying open land in these deltaic towns and later sell it to buyers for residential and commercial use at a higher price. In Diamond Harbour and Pujali, those who sold land in 2011 received approximately 3,000 Indian Rupees (INR)/m^2, whereas in 2023, landowners sold their land at approximately 11,000 INR/m^2, a 267% increase in land values over just 12 years. However, land values increased from 6,000 INR/m^2 in 2011 to 25,000 INR/m^2 in 2023 in Budge Budge, a part of the Kolkata metropolitan area. The local communities used the common open lands for grazing, farming, and recreation. After being transformed into private property through real estate, those open lands became inaccessible to common citizens.

3.2.1. Spatial analysis

The LCRPGR indicates that the temporal patterns of land consumption rates and PGRs in these towns have drastically changed over the past 12 years. The positive LCR value of Budge Budge (0.01), Diamond Harbour (0.02), and Pujali (0.01) indicates that the built-up areas of these towns have significantly expanded over the past 12 years, coinciding with high population growth. However, the LCRPGR index values are 0.01 in Budge Budge, 0.02 in Diamond Harbour, and 0.01 in Pujali (Table 3). This index value indicates a shortage of suitable built-up land in these towns due to population growth. As a result, vegetation cover, water bodies, and agricultural land have been significantly encroached upon by the built-up areas.

Google Earth archive images also clearly show how the LCR has increased over the past 12 years due to population growth and unregulated urban planning (Figures 6-8). The development of built-up areas shows that new construction sites have grown rapidly in areas of newly built-up areas. These increasingly built-up areas disrupt the ecological balance by changing the natural landscape. Therefore, these towns need to prioritize spatial planning for the well-being of present and future generations of citizens.

3.3. Deltaic towns as a playground for tropical cyclones and floods

One of the significant aims of urban sustainability is to

Table 3. Spatial analysis of towns in 2011 and 2023

Indicators	Budge Budge	Diamond harbour	Pujali
Land-use rate	0.01	0.02	0.01
Population growth rate	0.78	0.80	0.70
Land consumption rate to population growth rate	0.01	0.02	0.01
Total change in built-up area (%)	7.79	24.11	3.64

Figure 6. Satellite view of Budge Budge in (A) 2011 and (B) 2023. Images taken from Landsat/Copernicus from Google Earth.

Figure 7. Satellite view of Diamond Harbour in (A) 2011 and (B) 2023. Images taken from Landsat/Copernicus from Google Earth.

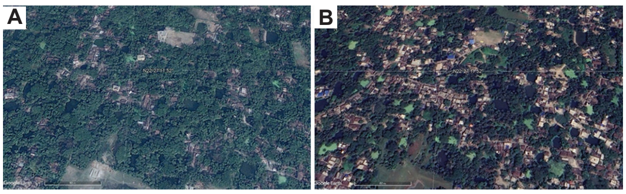

Figure 8. Satellite view of Pujali in (A) 2011 and (B) 2023. Images taken from Landsat/Copernicus from Google Earth.

reduce the adverse consequences of climate change and water-related disasters, with a particular focus on protecting the poor and other vulnerable people (Nagabhatla & Brahmbhatt, 2020; UN-Habitat, 2018). Cyclones are becoming increasingly common and intense worldwide due to a significant increase in ocean temperatures caused by global climate change (Bengtsson *et al.*, 2007; Khan *et al.*, 2000; Loukas *et al.*, 2021; Walsh *et al.*, 2012). In India, the natural calamities and the consequences of climate change together are putting cities at greater risk (Mall *et al.*, 2011; Revi, 2012). About 40% of the total Indian population lives within 100 km of the coast, and approximately 340 million people are significantly affected by tropical cyclones each year (S. Ghosh & Mistri, 2023). The three towns under study are significantly affected by tropical cyclones and the flooding they cause (Figure 9). This is because these deltaic towns are located at the crest of the Bay of Bengal, the cyclone genesis region of the eastern coast of India. In the last 20 years, tropical storms such as Aila in May 2009, Bulbul in November 2019, and Amphan in May 2020 have severely disrupted the lives and livelihoods of the citizens of these towns. During these three intense cyclones, these towns experienced severe storms (60 knots/h–100 knots/h) and heavy rainfall (varying from 10 mm/h to 18 mm/h) within a short duration. Therefore, property damage and citizen suffering are common phenomena in these towns due to frequent cyclones and urban flooding.

3.3.1. Citizens' perceptions on the causes and impacts of cyclones and urban flooding

Cyclones and urban flooding are the main natural disasters in these towns. Respondents state that the frequency of cyclones and urban floods has increased over the past two decades. Cyclones cause immense damage in these towns. Many parts of these towns remain cut off from water supply and electricity for days, sometimes for weeks, due to the impact of cyclonic storms. The high-speed winds destroy vegetation, houses, power poles, transportation infrastructure, and communication infrastructure. Some respondents also reported that they often go hungry during the rainy season because the ground floors of their homes, where the kitchen is located, are submerged in water, preventing them from cooking. The research participants identified the challenges associated with natural hazards. They are well aware that these places are prone to natural hazards, and to address this, the towns cannot grow like other inland towns. During the monsoon period, low-lying areas near the Pujali riverbank remain submerged for about 2 months, predominantly affecting settlements where poorer communities reside. This is a normal situation for the town, as it is located in the delta region. The respondents opine that this kind of situation has worsened over the years due to unchecked construction activities in the towns. They developed their own coping strategies by temporarily leaving the house and taking shelter on the local school premises during waterlogging. The normal waterlogging situation worsens further during the onset of cyclones. According to the Municipality report (2023), around 40% of stormwater drains in these towns are earthen, and 90% of those are open. These drains are losing their capacity to carry rainwater due to waste dumping, siltation, and encroachment. Although waterlogging poses a significant threat to the sustainability of these towns, no stormwater management system has yet been developed.

Over the past three decades (as per the IMD report, 1990–2024), the average annual rainfall in the deltaic part of West Bengal has increased significantly. Scholars claim that this is happening due to climate change. As a result, waterlogging is becoming a common phenomenon in these low-lying deltaic towns. According to field survey reports, all citizens of these towns experience waterlogging. The respondents identify four reasons for the occurrence of waterlogging: (i) Inadequate drainage systems, (ii) unplanned urbanization, (iii) poor management of drainage systems, and (iv) natural calamities. About 77.88% of the respondents reported that inadequate drainage is one of the main factors behind waterlogging, followed by unplanned

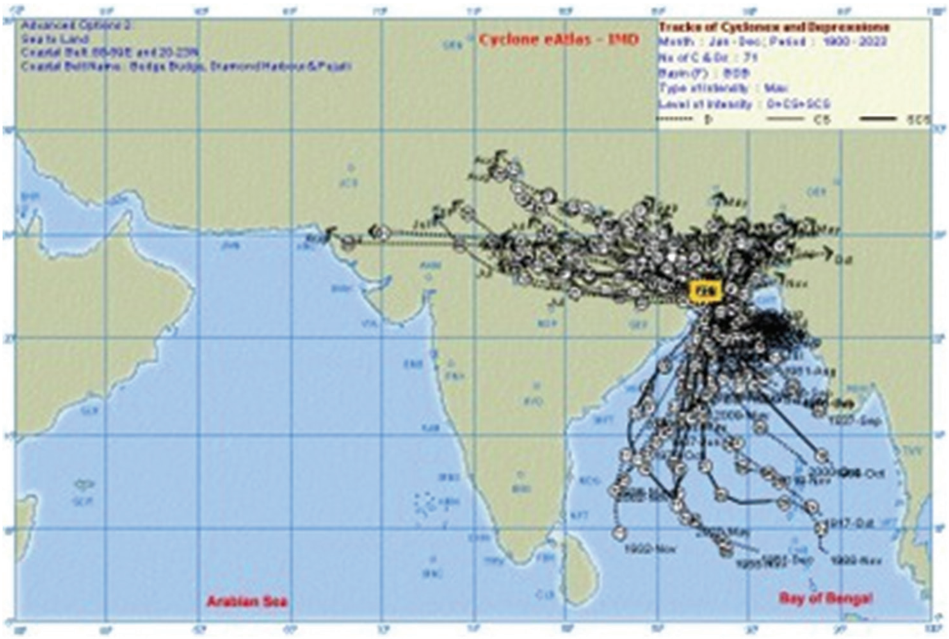

Figure 9. Severe cyclonic storms and very severe cyclonic storms affected the study area from 1900 to 2023. Image taken from the Cyclone e-Atlas of the Indian Meteorology Department.

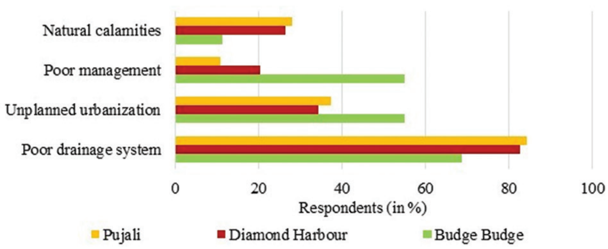

Figure 10. Citizens' perception of waterlogging

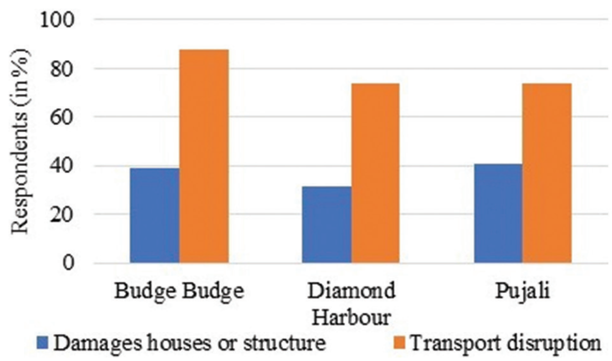

Figure 11. Citizens' perception of the significant impacts of waterlogging

urbanization (43.27%), poor management (30.77%), and heavy rainfall (21.15%) (Figure 10). However, 27.34% of respondents in Diamond Harbour and Pujali claimed that waterlogging is mainly caused by heavy rainfall.

Respondents asserted that waterlogging disrupts the peaceful lives of citizens by destroying their houses and roads. On average, 37.02% of respondents reported damage to their homes and other structures, and 78.85% reported problems due to transportation disruptions (Figure 11).

4. Discussion

This research investigated the environmental challenges faced by deltaic towns and analyzed how these challenges affect their sustainability. Urban environmental sustainability provides perspectives on emerging issues in urban areas and explores risks to human well-being and ecosystems (Haas, 2024; Maqbool *et al.*, 2025). Environmental sustainability in urban areas is increasingly being threatened by rapid population growth, uncontrolled urban expansion, ineffective governance, and the increasing frequency and intensity of extreme climatic events (Ahmed & Tobawal, 2025; Gupta *et al.*, 2025; Parvin & Ara, 2025). It has been found that the worldwide proportion of green space in urban areas has decreased from 19.5% in 1990 to 13.9% in 2020, and the risk of urban flooding due to extreme weather has increased by 3.5 times since 1975 (United Nations Human Settlements Programme, 2024). According to estimates, by 2050, more than 143 million people across sub-Saharan Africa, South Asia, and Latin America will be displaced due to adverse climate impacts, with most of this occurring within countries rather than across borders (Gupta *et al.*, 2025).

The literature on urban environmental research shows that urban areas face various environmental challenges, unevenly distributed across different geographic areas. This situation is particularly critical in deltaic towns due to increasing population pressure, the impact of natural disasters, and poor governance (Becker *et al.*, 2023). This research indicates that the environmental sustainability of these towns is primarily affected by increasing population pressure, rapid changes in LULC patterns, and the escalating frequency of tropical cyclones and floods. Based on the results, the first challenge to the sustainability of these towns is growing population pressure. These towns experience high population growth due to migration from the surrounding rural areas and the vulnerable parts of the Sundarban delta. Migrants come to these towns to secure their lives and livelihoods. People in vulnerable coastal areas of the Global South migrate to nearby small and mid-sized towns due to either social and economic constraints or climatic stresses (Ahmed *et al.*, 2025). Budge Budge and Pujali, being industrial towns, offer employment in jute mills, oil refineries, and brick kilns. Diamond Harbour, being the sub-divisional headquarters town, attracts migrants for jobs in administrative services in addition to other professions such as driving, masonry, fishing, street vending, and labor in brick kilns. Rural-to-urban migration, which is quite common in India for better services and opportunities, also draws migrants from surrounding rural areas (Randolph, 2024). Among the respondents interviewed, many said they moved to these towns because of better access to medical facilities and good educational institutions. Some of them also opted for staying in these towns for the ease of commuting to work in Kolkata. These towns are well connected to Kolkata by a good suburban train service, with a 1-h journey time. People choose to live in these towns to reduce the high cost of living in Kolkata. However, the concentration of people in these ULBs puts pressure on the finite land resources for housing, industry, and infrastructure, altering LULC patterns. These towns under-prioritize budget allocations for any infrastructure or service improvement. This situation significantly affects the carrying capacity of towns' environments because each additional citizen puts pressure on natural resources, ultimately creating ecological imbalances. The ecological problem finally takes a toll on poor citizens, increasing poverty and social and economic inequality in these towns.

Drastic alterations in LULC represent the second major challenge to the sustainability of these towns. The LULC change illustrates how human activity and natural landscapes interact dynamically (Katna *et al.*, 2023; Yang *et al.*, 2022). The expansion of built-up areas to meet the growing population's housing needs has led to changes in LULC. As a result, green cover, water bodies, and agricultural lands have been altered to built-up areas. Moreover, the LULC of these towns is heavily affected by land speculation by the local rich and powerful. Due to increasing population pressure, land prices in these towns have risen rapidly. Wealthy individuals began investing in land by buying farmland from farmers at low prices and keeping it fallow for several years. When land prices reach a certain level, they sell the land at prices suitable for residential and commercial use. These land dynamics have been detected through LULC change analysis, which shows that open space has increased considerably in these towns. The common spaces are often encroached upon by the real estate developers. To cater to the increasing demand of the growing population, apartment buildings, gated communities, rental housing, and hotels are being built not only on agricultural land but also on green spaces, marshy land, and filled-in water bodies. The increase in land prices reduces the availability of land for affordable housing, especially for marginalized people. Increasing land prices force economically marginalized people to live in overcrowded conditions in environmentally sensitive areas, such as along rivers, canals, and in the low-lying areas. This change leads to environmental degradation and social inequality, which together negatively impact the resilience of these towns. Although the 12th Schedule of the Constitutional Amendment Act (CAA) emphasizes the responsibility of maintaining urban forestry and environmental management, these ULBs have not implemented these provisions effectively. Environmental development is neglected in these towns due to power play in the political economy, the protection of individual interests, vote bank politics, and land speculation. Across the world, economically and politically influential individuals abuse their power by pursuing activities without considering environmental interests (Raiden & King, 2021; Saif *et al.*, 2022), a pattern similar to that in these towns. However, the environmental problems in these towns are far more complex due to the additional vulnerability posed by their location in fragile deltaic areas.

Based on our results, the last sustainability challenge of these deltaic towns is the adverse effects of frequent severe tropical cyclones and urban flooding. Nowadays, the primary threat to urban sustainability worldwide is urban flooding (Kumaresen *et al.*, 2025; Mukherjee *et al.*, 2025). The lives and livelihoods of urban dwellers are severely impacted by flooding. The situation is terrible for citizens living in low-lying areas, especially for those who work in local transport and street vending, as both are affected by flooding. Due to their deltaic location and proximity to the coast, these towns receive heavy rainfall from frequent, intense tropical cyclones. On average, these towns receive 1,800–1,900 mm of rainfall/year, with around 75% of rainfall occurring during the monsoon season (IMD Report, 2024). It has been found that under normal situations, approximately 20% of the area in Budge Budge, 25% in Diamond Harbour, and 35% in Pujali experience waterlogging during the monsoon season. This situation is further aggravated by cyclones in the Bay of Bengal, which form when low-pressure systems develop during the monsoon season. The uncontrolled growth of built-up areas, the lack of infrastructure, and the impact of climate change are recognized as significant threats to the sustainability of these towns. The conversion of water bodies into built-up areas has reduced the towns' natural water-holding capacity, worsening waterlogging. In addition, the accumulation of waste in the drainage system exacerbates waterlogging. Despite the vulnerable location of towns and the growing population, ULBs remain reluctant to take legal action against illegal encroachment into water bodies and to expand drainage infrastructure. The 74th CAA mandates ULBs to protect green cover and water bodies as a measure against natural disasters, but in reality, no such efforts have been observed in the towns during our field survey. The conversation with the municipal officers also authenticates that no such policies have been either taken up or implemented. One of the significant obstacles to urban sustainability in developing countries is the lack of coordination between policy and its implementation based on local needs (Adebayo, 2025; Atmoko *et al.*, 2025). In particular, ULBs in India face challenges in implementing urban development programs due to their financial dependence on state and central government grants (Bal & Chhetri, 2025; Sood, 2025). The towns under study are not exceptions to the general trend of urban management and governance in India, which affects their sustainable development.

5. Conclusion

This research focused on the challenges of environmental sustainability in deltaic towns, which are of significant importance to understand, as deltas are at the forefront of the environmental and climate crises. Environmental challenges are common in cities and towns around the world, but this article argues that towns in delta areas are particularly vulnerable to the climate crisis and the rising risk of disasters. This article, based on grounded research, argues that, given the high rate of migration from coastal areas, severe environmental deterioration, and the rapid onset of disasters, towns are challenging to manage. These towns are also not in a financial position to have a full-fledged planning department to prepare land-use plans and control illegal encroachments on blue and green infrastructure. ULBs face substantial obstacles in providing basic urban services to cater to the growing population. On top of that, sudden cyclones and flooding triggered by the climate crisis put the existing service and infrastructure systems in a problematic state, and recovery from those situations puts extra pressure on towns' limited financial resources. Understanding the complex interactions between citizens and the environment, and the adverse effects of climate risks, these towns need to pay more attention to the equitable and effective use of natural resources and to disaster management strategies.

In these towns, the concern is not only about the accelerating change in LULC but also about disasters triggered by the climate crisis. Therefore, the government, at both the local and state levels, needs to develop disaster preparedness policies without further delay. Citizens cannot avoid these natural disasters due to their location, but their adverse effects can be reduced through effective governance measures such as stormwater management, efficient sewage systems, conservation of urban greenery, and the restoration and renovation of ponds and canals. To accomplish this step, coordination between citizens and ULBs is required. ULBs in these towns cannot manage the growing population due to insufficient funds and inadequate substantive initiatives in the policy-making process. According to the 12th schedule of the CAA of 1993, these towns have 18 responsibilities for effective local development. Among these 18 responsibilities, urban planning, environmental development, and protection have been listed, with sustainable development of the towns in mind. However, in reality, ULBs cannot make decisions on urban planning because they lack sufficient sources of income, skilled manpower, and advanced technological support. To mitigate the present and future environmental crises, ULBs need to make tremendous efforts to negotiate with the state government for additional funding to develop disaster mitigation plans and ensure their effective implementation.

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Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: All authors
Formal analysis: All authors
Investigation: All authors
Methodology: Babusona Gharami

Writing–original draft: Babusona Gharami
Writing–review & editing: Gopa Samanta

Ethics approval and consent to participate

The authors confirm that all ethical standards were observed during the conduct of the field survey, the preparation of the manuscript, and its publication. This study used a basic paper-based semi-structured questionnaire and posed no potential risks to participants. Participants were made aware of the purpose of the study, and their participation was anonymous and voluntary.

Consent for publication

All participants provided consent for the publication of anonymized data.

Availability of data

All data utilized in this article are publicly accessible online and through the references provided.

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