

Evaluating Urban Drainage Infrastructure in Nabadwip Municipality through Geospatial Analysis

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Abstract

The study examined the urban drainage system in Nabadwip Municipality, focusing on infrastructure challenges and technological interventions. The goal was to understand the causes and impacts of recurring drainage issues, especially during monsoons, using Digital Elevation Models and data collected from the field based on personal survey. The study revealed significant flooding and consequent water logging due to inadequate drainage systems, heavy rainfall, and debris obstructions. Key findings highlighted the need for comprehensive drainage system overhauls; strategic urban planning, and increased public awareness.

Urban drainage system; Nabadwip Municipality; waterlogging; urban planning

1. Introduction

Uncontrolled and unplanned urban areas often experience flooding accompanied by water logging in cities with inadequate and mismanaged drainage infrastructure. The existing inability of sewerage infrastructure to dispose of excess surface water in a short duration leads to water logging. The longer the duration of submergence, greater the impact on the physical infrastructure, like roads and buildings. It also impacts daily businesses and daily life, and the unhygienic conditions also lead to water-borne diseases. Urban expansion coupled with rising population density exerts pressure on natural resources, disrupts the natural drainage system (Patil et al., 2024; Mishra et al., 2020). Several works have been considered for many major cities in India such as Bangalore (Prasad & Narayanan, 2016), Mumbai (Roy et al., 2021), Chennai (Jamal & Sen, 2024), Bhubaneswar (Mishra et al., 2020), Kolkata (Malik et al., 2020) that assess the relative risk of different anthropogenic activities towards water logging and flooding.

In India, the Brahmaputra and Ganga River basins in the Indo-Gangetic-Brahmaputra plains in North and Northeast India is highly vulnerable to floods. The eastern state of West Bengal experiences frequent floods and except for the small rār region, the entire state is flood-prone. Recurrent floods, lower relative relief, presence of paleo-channels, and heavy rainfall result in water logging conditions in the river basin. The southern part of West Bengal is a part of the largest delta of the world and the central section of West Bengal is a moribund delta. In this light the study aims to investigate the nature of water logging in an old city along the bank of flood-prone river Bhagirathi on a moribund delta.

Among all the municipalities of West Bengal situated on the river bank, Nabadwip in Nadia district is one of the oldest, founded in 1063 CE. The Bhagirathi River originally flowed west of Nabadwip (Fig 1), forming a natural boundary between the districts of Purba Bardhaman and Nadia. With time, it has shifted its course to where it is now, on the eastern margin of the city, cutting the city off from the rest of the Nadia district (Das, 2024; Kar et al., 2020). Thus, the city is surrounded by paleo channels, and the negligible slope of the land makes it prone to water logging. Nabadwip and more recently in 2015. Waterlogging remains a significant

problem, even with minimal rainfall which affects the daily life of the inhabitants, their businesses and impacts on their health. The present study aims to assess the perception of the city residents towards this issue.

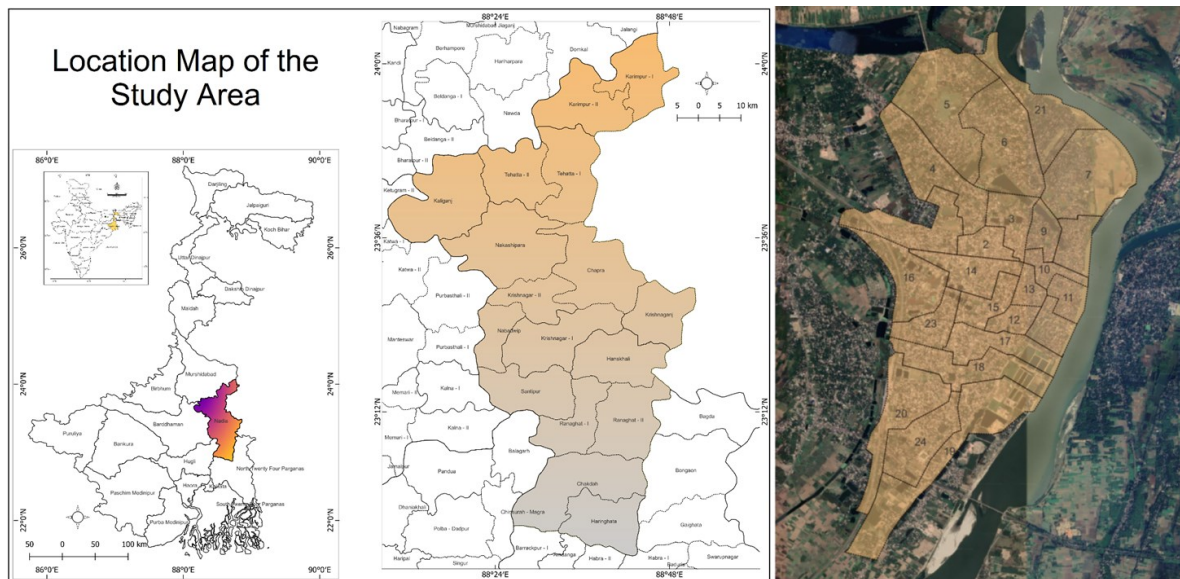


Fig. 1. Location of Nabadwip municipality

2. Methods

The methods utilized for the study are outlined in Fig 2. To infer the geomorphological characteristics of the region, the slope and the resultant drainage lines with their respective Strahler order has been traced out with the help of Digital Elevation Model (DEM). It aids in understanding the spatial extent of flooding with an increase in the water level of the adjacent Bhagirathi river. A Normalized Difference Water Index (NDWI) map has been prepared from the satellite images to map the actual inundated regions during the floods of September 2000 (fig 33). The flood of September 2000 is chosen for the availability of cloud-free images during the flooded condition. Yazdanfar and Ashok (2015) highlight the challenges of urban drainage system planning and design in the face of climate change and urbanization. Continuous urbanization impacts climate change, which, in turn, affects urban drainage systems. The conventional rational method, though an old technique, is being used innovatively to modernize drainage system designs. Ouma and Tateishi (2014) propose an integrated multi-parametric Analytical Hierarchy Process (AHP) and GIS approach for urban flood vulnerability and risk mapping. This technique scientifically measures flood situations by creating an Analytical Hierarchy map through GIS, enabling the division of an area into different flood-affected zones.

Dibaba (2018) reviews the sustainability of urban drainage systems, focusing on the case of Jimma city in Ethiopia. The city faces significant drainage problems due to rapid population growth, which directly and indirectly affects the drainage infrastructure. Issues such as lack of maintenance, wastewater entering the main river channel, and accumulation of city waste in the drainage system led to floods. Additionally, inadequate

sanitation practices in riverside areas contribute to shallow river depths and surface water spreading. Primary and secondary data provide insights into these challenges, and surveys capture personal perceptions.

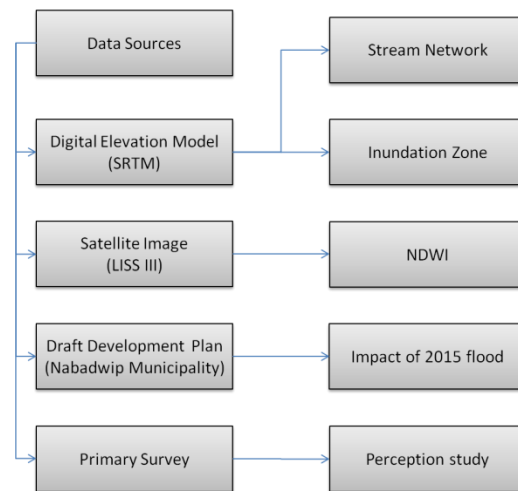


Fig. 1. Methodology

Based on the draft development plan and disaster management plan of Nabadwip, the flood risk of the vulnerable people has been determined by superimposing the risk zones over the population density.

Primary data has been collected through a household survey and interviews with local shopkeepers to assess the impact of water logging on local businesses. The survey focused primarily on the central business district (CBD) that is situated majorly in ward number 13 and partially in the periphery, the reason being that despite the ward being not prone to flood, it is prone to water logging. Since the focus is on water logging, only those affected were surveyed. The study tried to focus on people residing in the non-slum area to explore the perception of people who are financially and socially better off, unlike the marginalised communities often pushed to inconvenient locations bereft of any facilities. Therefore, a sample has been collected only from the CBD that includes twenty-four residential properties and seven commercial properties affected by water stagnation during the monsoon period. Data from primary survey was graphically represented for better visualization of the perception.

3. Results and discussion

This study investigates the drainage conditions and water logging problems in Nabadwip municipality, and the perception regarding water logging. The landuse / landcover map (fig 3) of Nabadwip municipality shows residential non-slum area covers the highest proportion, approximately 41 percent of the total area. A significant portion of the city, approximately 31 percent is occupied by slum areas, particularly in the low-lying northern part of the city (ward nos 1, 4, 5, 6, 21, and 7). The central business district (CBD) (ward no 13) and the adjoining wards (ward nos 12,15,14,10,11) are largely devoid of slum residents. The city is studded with numerous water bodies (8%) with parks, playgrounds, and stadiums (less than 1%) dispersed across wards 3, 4, 21, and 24. About 10 percent land is vacant. The central and northern part of the city has a good interconnected drainage network (fig 4) whereas the southern and south-east portions have a lower density of drainage lines, also because of the presence of the water bodies in this region.

Stream network is a representation of the natural pathways of water which is dependent on the slope of the region. It demonstrates the natural point of convergence of streams. Aligning the sewerage line with the stream network can ensure efficient drainage of excess water (Butler et al., 2018). The streams in a drainage network can be ordered based on their position in the network (Strahler). The streams are categorized into first, second and third order. First order streams are the first channel of water that is initiated, two or more first order streams converge in second order stream and two or more second order stream converge in third order stream, so on and so forth. In Nabadwip Municipality, the slope is negligible and there is no well-developed stream network. The highest order of stream is third order. There is uncountable first order streams and flow to no definite direction. Though the second and third order streams are fewer in number, the length is short and does not flow into Bhagirathi River (fig 11), which means that this land naturally does not have a proper slope for easy drainage of excess water into the river, thus developing condition for water logging.

The highest density of population (fig 5) is observed around railway station and the CBD, decreasing towards the margins of the city. The Draft Development Plan data provided by Nabadwip Municipality identifies most of the wards adjacent to the river as completely flood-prone areas (fig 6). Partially flood-prone areas are observed in the central region. The vulnerable population (fig 7) is identified based on the total population of each ward and the potentially flood affected population. Ward number 6 is most likely to be affected by floods, followed by wards 1, 2, and 14. Conversely, wards 12, 15, 21, and 23 have fewer people affected by floods. Analysis of the flood data for 2015 reveals that ward number 5 had the largest number of fully and partly damaged houses (fig 8). The number of affected houses in the peripheral wards is much higher than those closer to the CBD, directly reflecting the conditions due to flood hazard. Data obtained from the Nabadwip municipality's disaster management plan for 2022-2023 reveals that the communication systems (fig 10) were affected in most of the wards, barring a few wards close to the railway station. The total number of affected individuals in each ward of Nabadwip municipality has been assessed to evaluate the efficiency of the wards in managing floods. The fig 9 highlights that Ward No. 6 has a higher capacity to handle flood-related issues. The distribution of food supplies during floods reveals that northern wards were stocked and supplied food during flooding. Interestingly, though ward number 18 has one of the highest proportion of the population vulnerable to flooding, it does not affect the food supply.

The inundation map (fig 32) generated from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) imagery provides insights into the flood-prone areas of Nabadwip. The map reveals that the depth of the Bhagirathi River is 3 meters above mean sea level during the driest month of the year. Increasing the height to 4 meters does not significantly change the extent of inundation, while a gradual increase is observed from 7 meters. Notably, Ward number 18, which comprises slum areas in the eastern and western portion, is highly susceptible to flooding, while predominantly residential areas in the middle part has lower flood risk. As per municipality data, ward number 18 often gets completely flooded.

It is clear from fig 6 and 7 that the CBD, though generally unaffected by floods do have houses which were partially and fully damaged (fig 8) and communication disrupted (fig 10) mostly in ward number 13. This indicates the severity of the water logging in this ward and to investigate this further, a primary survey based on perception and daily experiences of the respondents has been undertaken.

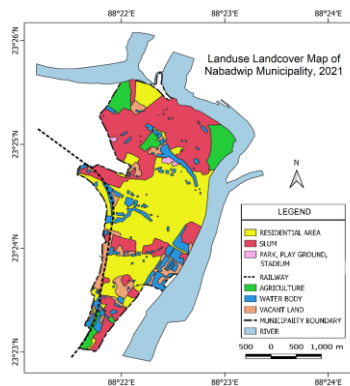


Fig 3: Landuse/landcover

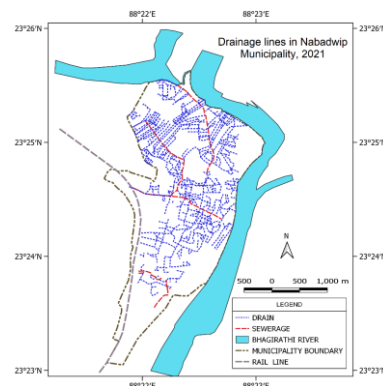


Fig 4: Drainage lines, 2021

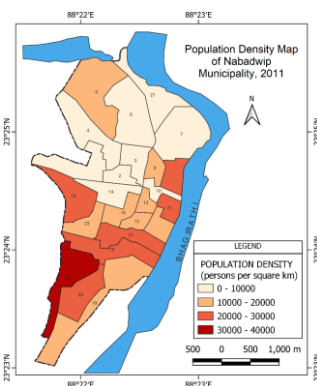


Fig 5: Population Density, 2011

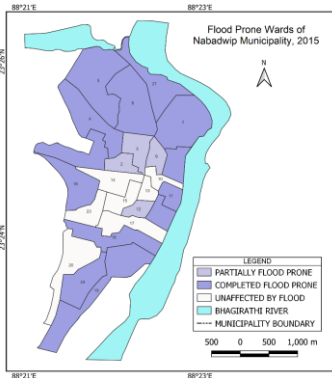


Fig 6: Flood prone wards, 2015

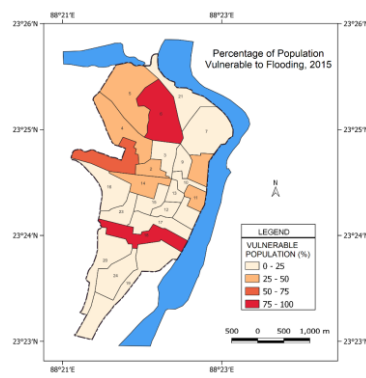


Fig 7: Flood vulnerable population, 2015

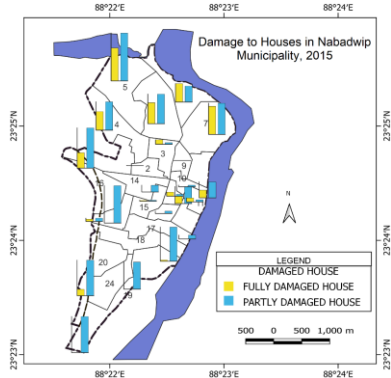


Fig 8: Damage to houses, 2015

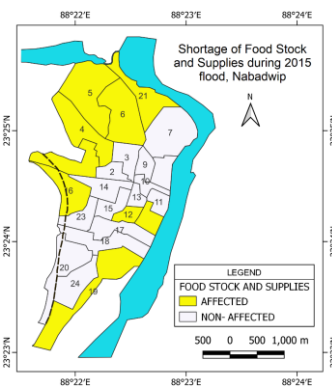


Fig 9: Food Stock and Supplies during 2015 flood

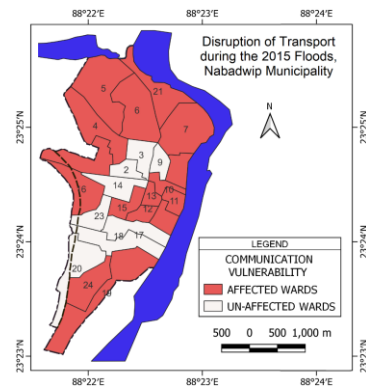


Fig10: Disruption of Transport during 2015 flood

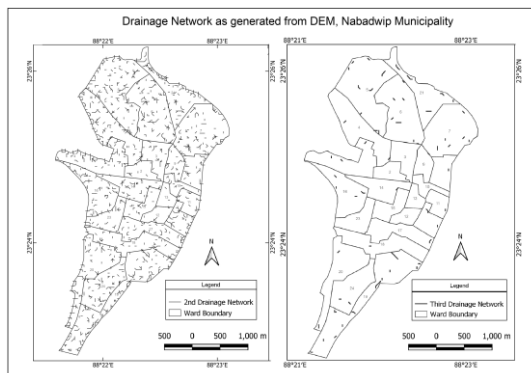


Fig 11: Drainage Network as generated from SRTM DEM, Nabadwip Municipality

Compared to others, the lower elevation of ward 13 aggravates the impact of flooding. Additionally, several other wards, such as 7 and 20 (the convex river bank, which experiences frequent flooding and eventual deposition after every flooding episode), lack of proper drainage channels based on the slope, making them highly susceptible to flooding and water logging.

Over four-fifth of the respondents experienced water logging (fig 12), and more than half said water logging happened every time it rained (fig 13). Most of the time the depth of water on streets was more than 20 cm (fig 14) but in most cases it drains out within four hours. They also reported rare occasions during which water-level during the flood increases up to the waist, mostly blaming it on slope (fig 15). The respondents consider the water logging as severe (fig 16) but around 37 percent hardly perceive the negative impact of stagnant water on health and hygiene (17). Most said that accumulated water drains out in four hours but the water logged areas (fig 18), experience much delay- sometimes a day for the water to recede. Majority of the surveyed commercial property holders stressed on the severity of the flood (fig 19) which impacted their business (fig 20). Normally the more severe the water logging (fig 21 and 22), it takes more time for the water to recede (fig 23, 24 and 25). Half the respondents believe that poor maintenance of the sewerage lines have led to poor drainage condition (fig 26) that adds to the water logging issue, 25 percent attributes the issue to illegal filling up of the canal (fig 27). These issues have been reported to the authorities by more than 70 percent of the respondents (fig 28), mostly whose issue was severe (fig 29). Half of the respondents were not satisfied with the action taken by the government (fig 30). Around 70 percent said that the water logging creates difficulties in their work (fig 31), affects business and makes it difficult to reach their workplace.

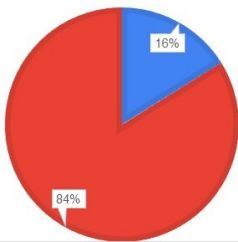


Fig 12: Respondents experiencing floods/inundation

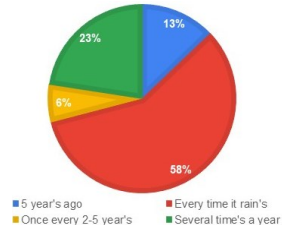


Fig 13: Frequency of flooding/inundation

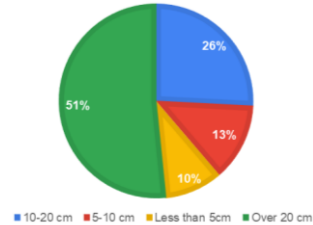


Fig 14: Depth of flood/storm water

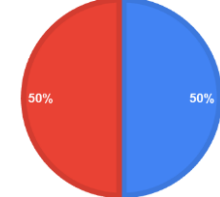


Fig 15: Effectiveness of slope for natural drainage

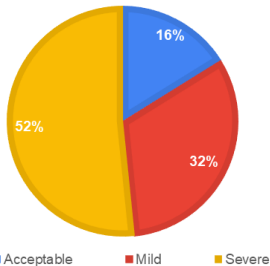


Fig 16: Severity of flooding/inundation

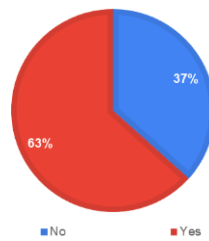


Fig 17: Impact of water stagnation on health and hygiene

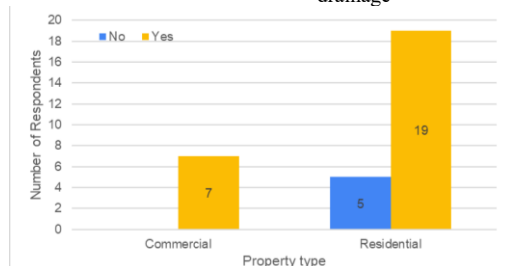


Fig 18: Experience of flooding based on property type

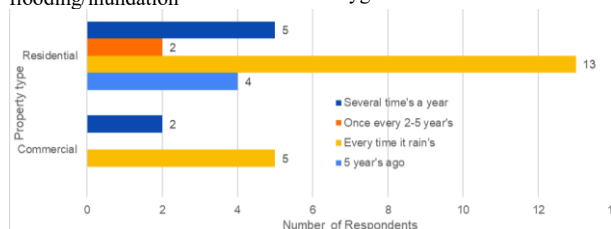


Fig 19: Frequency of flooding

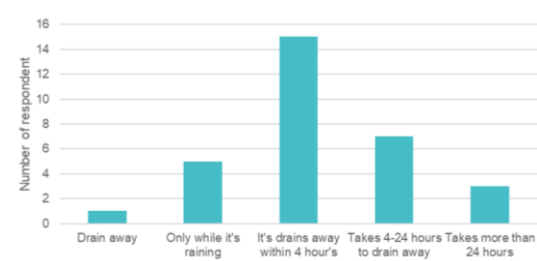


Fig 20: Duration of water stagnation

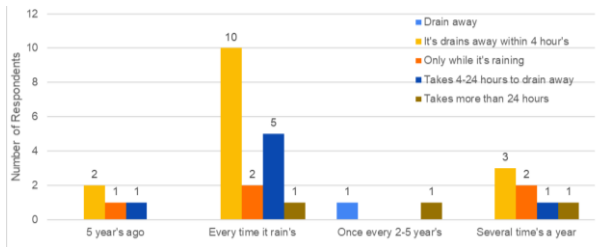


Fig 21: Frequency of flooding and time taken for water to recede

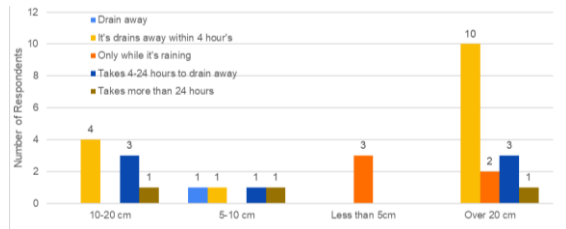


Fig 22: Depth of inundation and time taken for water to recede

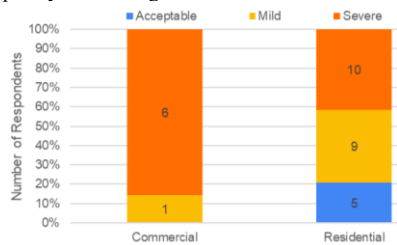


Fig 23: Perception of severity of inundation based on property type

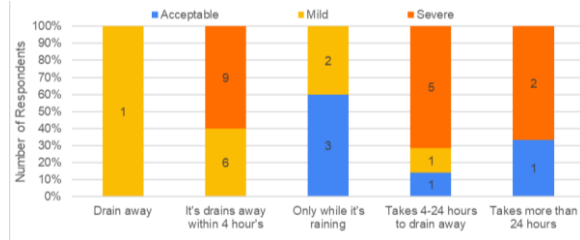


Fig 24: Perception of the severity of inundation based on the time taken for water to recede

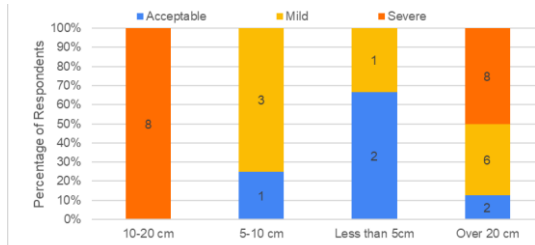


Fig 25: Perception of the severity of inundation based on depth of inundation

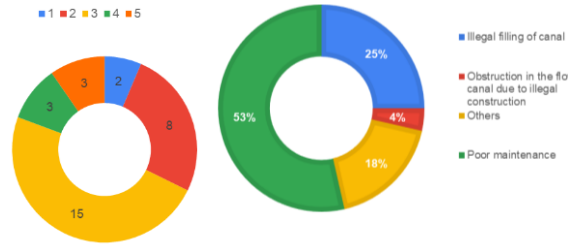


Fig 26: Perception of drainage condition

Fig 27: Probable causes for poor drainage

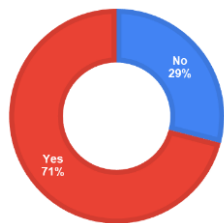


Fig 28: Reporting of the issue to authority

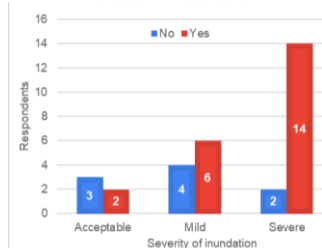


Fig 29: Conditions leading to reporting

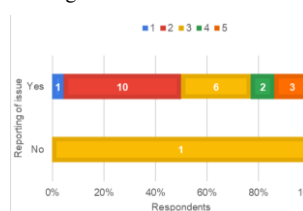


Fig 30: Action taken by the municipality

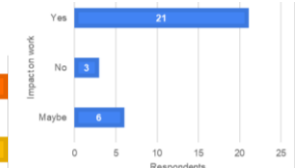


Fig 31: Impact of inundation on work/business

Based on the discussion with the respondents the following observations of the participants were recorded. The CBD of Nabadwip, such as Poramatala and Radhabazar, experience severe water logging. Shops and markets in these areas limit vacant land, preventing proper rainwater infiltration into the ground. Consequently, water logging persists despite natural factors being the primary cause, with human activities contributing directly and indirectly to the problem. Baral Ghat, located in Ward No. 22 of Nabadwip town, is an important area with religious significance, attracting many people daily. The indiscriminate use of the river and drain in this area has harmed the Bhagirathi River. Additionally, during the Holi and Rash festivals (an annual festival which brings many tourists to Nabadwip), the city experiences a surge in population due to the influx of people (mainly devotees), leading to overcrowding and potential burden on the existing resources.

These festive periods put significant pressure on the Bhagirathi River, causing damage to the drainage system due to its excessive use.

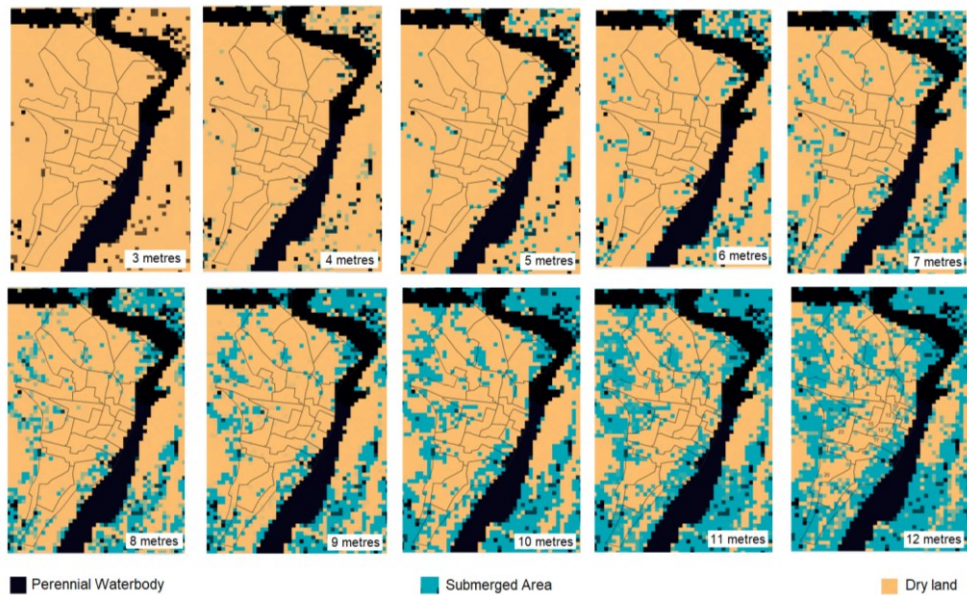


Fig32: Inundation Map generated from SRTM DEM

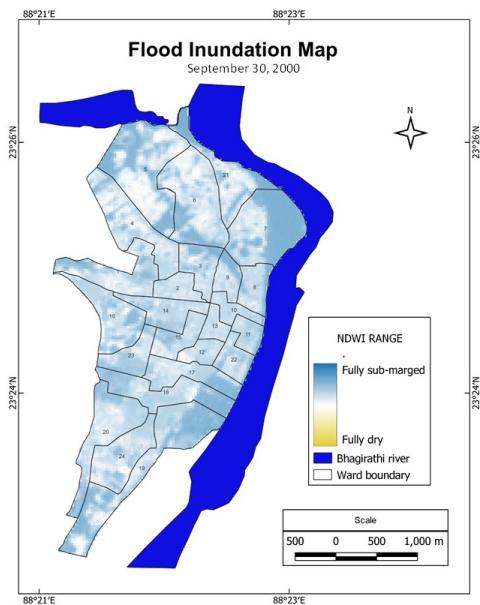


Fig 33: Flood Inundation Map, September 2020 (extracted through NDWI method)

4. Conclusion

This study investigates the urban drainage infrastructure of Nabadwip Municipality, emphasising the critical challenges posed by inadequate drainage systems, heavy rainfall, and human activities leading to frequent flooding and water logging. The analysis employs advanced methodologies, including Digital Elevation Models (DEMs) and Geographic Information Systems (GIS), alongside primary survey data, to assess the current state of the drainage infrastructure and its effectiveness in managing urban flooding.

The general slope of Nabadwip was found to influence flooding, along with the association of the old and new courses of the Bhagirathi-Hugli River. The existing drainage system in Nabadwip is insufficient to handle the volume of water during heavy rainfall, resulting in significant flooding and water logging. The study reveals that several wards are severely affected due to their lower elevation and lack of proper drainage channels. Heavy monsoon rains aggravate the problem, as the drainage systems are frequently obstructed by garbage, plastic, and other debris, impeding the proper water flow. This leads to prolonged water logging and associated health and hygiene issues.

The municipality is currently making continuous efforts to address the flooding problem. Residents report that the municipality regularly cleans drains to prevent road water accumulation. However, to alleviate the issue, it is suggested that waste water and storm water should be channelled separately. Implementing separate pipes or drains for these two types of water would reduce the problem of water accumulation. Additionally, establishing proper drainage channels based on the slope would enable rainwater to flow appropriately, mitigating the severity of flooding. It is emphasised that promoting responsible human activities and raising awareness among residents can also contribute to reducing water accumulation.

Furthermore, the local population has been damaging the smaller rivers in the area for personal use. The misuse of these rivers includes using them as toilets (Bowes et al., 2020; Sigdel et al., 2023) and dumping grounds (Chakrabarty, 2020), decreasing their depth (Salles et al., 2012; Gregory et al., 1992). Poorly developed drainage systems/no drainage systems in cities cause frequent flooding (Misra, 2010). When it rains, the rivers lack adequate capacity to accommodate the rainfall, overflowing excess water onto the ground and causing flooding. The lack of proper drainage channels based on the varying elevation levels directly contributes to flooding. The concentration of water logging is sometimes higher in the developed areas, including portions of the city core, compared to the less developed fringe areas due to this elevation variation.

Areas partially flooded or unaffected by flooding, such as Ward numbers 2, 3, 9, 12, and 13 (closer to CBD), show a higher population movement, as residents with financial means tend to relocate from these areas. Conversely, some wards with significant flood problems, including Ward numbers 18, 15, and 11 (to the south of CBD) have experienced population growth, potentially indicating socioeconomic factors that influence settlement patterns.

The findings highlight the gravity of the flooding problem in Nabadwip, which has led to population movements and changes in land use patterns. The primary causes of flooding include drain obstructions, heavy rainfall, and almost negligible slope of the land. The municipality's efforts to address the issue, such as regular drain cleaning, require further improvement and coordination. Implementing separate channels for wastewater and stormwater and proper elevation-based drainage infrastructure can help mitigate the flooding problem. Moreover, raising awareness among residents and promoting responsible human activities are crucial aspects of long-term flood prevention strategies. The results of this study contribute to the understanding of flooding challenges in Nabadwip and emphasise the need for comprehensive measures to protect the local population and environment.

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