Hydrodynamics survey along embankments of Kumirmari Island Gosaba, Indian Sundarban

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INTRODUCTION

The West Bengal Irrigation and Waterways Department has identified Kumirmari Island, Gosaba Community Development Block, Indian Sundarban, to be at particular risk of embankment failure given the present high rates of coastal erosion and previous embankment overtopping or breaching after cyclones Amphan (May 2020) and Yaas (May 2021).

Using an innovative methodology, researchers in the UKRI GCRF Living Deltas Hub have quantified exposure of the island's embankments to current and wave forcing, and through participatory research ascertained delta communities' perceptions of the causes behind coastal erosion and flooding of Kumirmari and surrounding islands. Hydrodynamics were measured using Mini Buoys and RBR Solo D Wave loggers.

This time-limited study has helped to provide a preliminary understanding of the hydrodynamics around Kumirmari Island. For more holistic understanding, it is essential to conduct year-long hydrodynamic surveys to better inform coastal protection design. While we make outline recommendations for erosion management, designing detailed solutions for coastal protection were beyond the scope of the present study, and will require the expertise and input of the civil engineering community.

Photo courtesy: Gopal Mondal

Eroding embankment in Kumirmari with visible signs of undercutting. The embankment is the only defense between the saline water and the homestead and cultivable lands of the residents.

STUDY SITE - KUMIRMARI ISLAND

Kumirmari Island is located on the north-eastern edge of the Indian Sundarban National Park, within the Gosaba Community Development Block. The Raimangal River flows past the island along its eastern flank, with the Puinjali River bordering the north, Sarsa River along the west, and Korankhali Khal along the south.

According to Census (2011) data, the island has 4,344 households and a population of 17,451, with 51% male and 49% female. Kumirmari Island covers a total area of 2,021 hectares, 76% of which is sown for agriculture. The net area sown is equal to the total unirrigated land, implying that the island is dependent on monsoons for cultivation and as a result relies on mono-cropping, rising vulnerability to climate-related disturbances. **Spring tide during monsoons can cause breaches in embankments, with overtopping also leading to the percolation of saline water into cultivable lands, posing a risk to livelihoods.** 87.9% of houses are temporary dwellings, 75% of houses are dilapidated, and 97.7% are owner-occupied. Building materials – roofs (81.1%), walls (63%), and floors (97.1%) are predominantly made of grass, thatch, bamboo, wood and mud. **These dwellings are particularly prone to damage in the event of saline water inundation caused by embankment failure, thereby exacerbating the vulnerability of the people.** Repair and maintenance of housing in the aftermath of embankment failure constitutes a significant financial burden for individuals given the 97%+ level of owner-occupation.

Photo courtesy: Gopal Mondal

A breached embankment along southern Kumirmari. The breach in the older embankment caused during Cyclone Yaas is visible in the foreground and the new embankment constructed further inland is visible in the background.

STUDY SITE - KUMIRMARI ISLAND

As reported by locals, **bank erosion rates have been highest along the south-western part of Kumirmari over the last 25 years**. This area was also significantly affected by inundation during Cyclone Yaas in 2021 after overtopping and breaching of embankments [1]. The south-eastern side of the island has also historically experienced significant erosion. A 2.3 km brick embankment extends from the south-eastern tip of the island, merging with a recently completed concrete sea defence (brick pitched on geotextile) along eastern Kumirmari. Both have served to protect the coast from flooding. The rest of the island is protected by mud embankments and an (often narrow) intertidal vegetation zone comprising mangroves and saltmarshes. Mangrove restoration projects have been attempted at various locations across the island where there is existing foreshore and established saltmarsh / mangrove vegetation.

Three sites were selected for hydrodynamics surveying across Kumirmari (Figure 1). Along the western and eastern sites, exposure was assessed along areas of the coast protected by both concrete and mud embankments, with vegetated foreshores being either present or absent. Along the southern site, exposure was assessed around the rapidly eroding edges outside the old mud embankment and also in the interface between the new and old embankments.

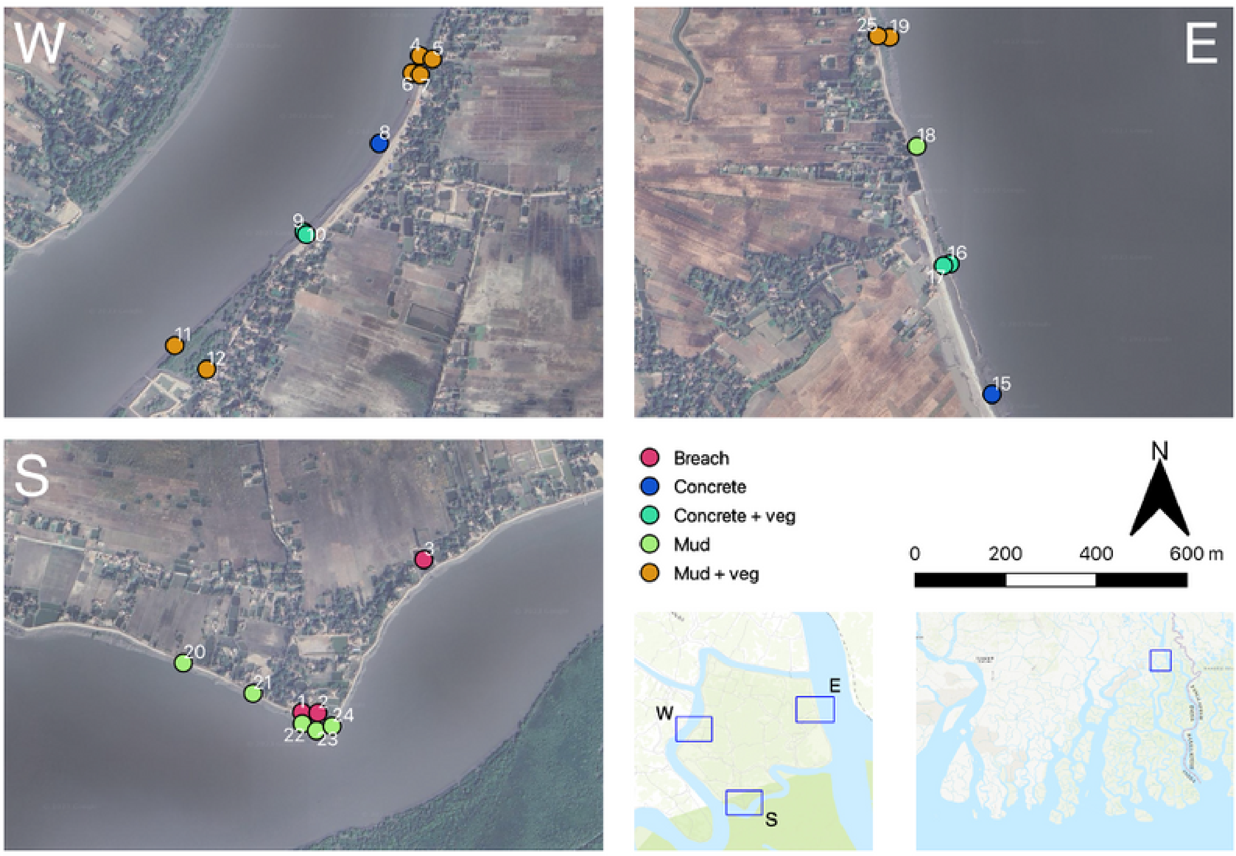

Figure 1. Locations for hydrodynamics survey along the 3 sites (West = W, East = E, South = S) of Kumirmari Island, Gosaba

THE MINI BUOY

The Mini Buoy is a custom-made device for measuring hydrodynamics along the coast. Materials to assemble a Mini Buoy are relatively inexpensive (when compared to conventional equipment) and globally available. So, these are an ideal solution for mangrove restoration practitioners to test the suitability of a site for mangrove planting. Mini Buoys have been used in several South East Asian deltas so far to test the suitability of a site for mangrove restoration but this is the first time that it is being used to monitor embankment health based on the local hydrodynamics.

The Mini Buoy comprises an acceleration data logger placed inside a small, bottom-mounted float. The data logger measures acceleration along three axes relative to the Earth's surface and is used to determine the inclination and direction of motion. When properly calibrated, the dip angle of the Mini Buoy can determine:

- **start and end time of submersion periods;**
- **current velocity near the bed;**
- **wave orbital velocity near the bed**

For further information, see Balke et al. (2021): https://doi.org/10.5194/hess-25-1229-2021.

Photo courtesy: Sumana Banerjee

Mini Buoy in the mudflat of Indian Sundarban to characterise the hydrodynamics

Hydrodynamic exposure along Kumirmari Island was highest along coastlines with mud embankments and no fronting vegetation

Concerningly, mud embankments experienced greater exposure to currents and waves than concrete embankments, even though the period of inundation was comparable. **The south-western peak of Kumirmari, where only mud embankments with unvegetated foreshores are found, had the greatest level of exposure.** Increased exposure to wave and current forcing is expected here, as water depths in front of the coastline were, on average, 6.7 m greater than the western side, allowing larger waves and currents to reach the eroding coast. Southern Kumirmari has suffered the highest rates of coastal erosion compared to anywhere else on the island over the last decade and so warrants special attention when developing coastal flood risk mitigation strategies.

Photo courtesy: Sumana Banerjee

Newly constructed mud embankment along south-western peak of Kumirmari after it breached in multiple sites during Cyclone Yaas (2021).
Only mud embankments with unvegetated foreshores are found here which had the greatest level of exposure. The land of the foreshore and the newly constructed embankment now exist at the spot where once stood homestead land and property of residents. Destruction of property bears the tangible mark of erosion and the countless human lives bear the intangible marks where erosion affects their identities, memories, and wellbeing.

KEY FINDINGS

Attenuation of currents and waves was little to none after passing through sparse mangroves and saltmarsh vegetation

Where foreshores were present, their value in flood protection likely stems from elevations being raised at the base of embankments and thus reducing inundation duration and exposure to potential erosion during high tides. Studies of flood protection by mangrove forests have shown that a minimum width of 50m (depending on species and planting density) is needed for reasonable reductions in cyclone surge levels [2]. Mangrove restoration planting for coastal flood protection in the area under current conditions is unlikely to be successful, as there is little foreshore in front of these defences that could support sufficiently dense mangrove and saltmarsh vegetation to function as a 'Nature based Solution' to mitigate the coastal erosion risk. Foreshore widths were between 18-35 m around Kumirmari, with the widest forested patch on the western side being 84 m. Unfortunately, this was also the site where the Mini Buoy nearest to the embankment was lost. Although a replacement device was put in its place, the recorded data is not sufficient to come to any conclusion.

Sparse vegetation in front of a newly constructed concrete embankment

Young mangrove and saltmarsh plantation with two mature mangroves in front of mud embankment

Creating Intertidal Land by retreating inland - Space for mangrove establishment would have to be made by realigning existing embankments further inland, allowing the land in front to be flooded. The double-buffer of breached embankments and regenerated mangrove forests can be a long-term solution to coastal erosion risk management [3]. However, such land use change in the buffer area poses significant challenges to the livelihoods, culture, and wellbeing of impacted individuals and communities. Even with sufficient compensation, displacement can create intergenerational trauma.

Tidal beels - Targeted localised embankment breaching for the formation of tidal beels has also had early success as a flood risk management method. The beels alter tidal currents, mobilising riverbed sediment to enhance deposition along the delta.

Other novel approaches - Growing intertidal areas include the use of sediment arrestors and wave breaks deployed along coastal fringes. Effective use of such techniques requires understanding the underlying cause of erosion (e.g., insufficient sediment supply to keep pace with sea level rise, excessive current flow by migrating channels, and propagation of large waves along river channels).

Porcupine System used to trap sediments and prevent erosion in Indian Sundarban

POTENTIAL SOLUTIONS

Increasing Sediment Accretion to build coastal habitats seaward - Rather than creating intertidal land by retreating inland, increasing sediment accretion in front of embankments can build coastal habitats seaward. Beneficial use of dredged sediment is one such way, where dredged material is deposited in areas to build up tidal flat elevations suitable for mangrove establishment or is deposited at a location to act as a sediment source for deposition elsewhere along the coast [4]. There may be scope to treat dredged material as a resource for coastal flood protection [5]. Dredging is carried out to maintain navigability across rivers and channels in the delta. If the dredged material is used regularly for embankment building, maintaining, and retrofitting instead of depositing it in the river beds, it may strengthen the mud embankments for coastal protection.

Hard engineering approach - A 'hard engineering' approach would be to increase the extent of concrete embankments across the island, which would require minimal realignment, can be instigated relatively quickly, and provide a sense of security for communities. However, such embankments in soft-sediment landscapes of river deltas are rarely considered long-term successful adaptation methods, given their propensity to fail due to subsidence [6]. Additionally, significant financial resources are needed which may not always be available to the authorities for construction of such concrete embankments all over the Indian Sundarban.

Long term hydrodynamic monitoring - Selecting suitable management intervention for Kumirmari would require repeated monitoring of average and extreme hydrological conditions along the coast. Our test case of the Mini Buoy shows potential for their use to identify at-risk sites and which mechanism may be driving flood risk (current and/or wave forcing). Coupled with further work on monitoring sediment fluxes, likely success of potential management options can be assessed.

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ACKNOWLEDGEMENT: We acknowledge the funding received from the UKRI GCRF Living Deltas Hub under Grant Reference NE/S008926/1. We are truly indebted for the guidance and support received from the team of Sundarban Safari during fieldwork.

Cite as: Ladd C, Banerjee S, Balke T, Chanda A, Ghosh T (2023) Hydrodynamics survey along embankments of Kumirmari Island Gosaba, Indian Sundarban. UKRI GCRF Living Deltas Hub Report, pp 1 – 8.