A quantitative approach for geographical vulnerability assessment of Bhasan *Char*, Bangladesh, using Remote sensing and GIS

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ABSTRACT
The relocation of 100 thousand Rohingya refugees is expected from camps in Cox's Bazar to Bhasan *Char* (BC) (island), Bangladesh. The BC is located at the mouth of the Ganga-Brahmaputra-Meghna river system in the Bay of Bengal, ~30-40 km from the nearest water port of the mainland. This study aims to assess geographical vulnerability based on frequent erosion and deposition of the island. Therefore, Landsat satellite images during 1975-2020 are used to detect the areal changes using Geographic Information System (GIS). Since the BC didn't appear 20 years back, nearby islands are studied as similar geographical characteristics. A normalized difference water index is applied to identify the land area. Further, the erosion-deposition and migration of shorelines are identified and quantified. The islands are expanded since 1975. Most erosion occurs along the direction of the main flow of upstream water and the islands' southern face, including BC. Temporarily, a settlement at BC may be no harm by maintaining engineering works of infrastructure, e.g., cyclone against standing buildings, tidal wave, and surge-protected infrastructures. However, the most important, sustainable components, e.g., economic stability and social interaction among the refugees in BC and camps in Cox's Bazar, need to be implemented.

1. INTRODUCTION

Rohingya is a minor Muslim ethnic group in Rakhine State, Myanmar, facing force migration to mainly Bangladesh and other countries in the world since the 1970s as ethnic cleansing (Grundy-Warr and Wong 1997). In the most recent massive migration of ~742,00 Rohingya people crossed the border to Bangladesh during September–November 2017 (OCHA 2020). Now, more than one million refugees live in Cox's Bazar District, Bangladesh, due to the proximity of Myanmar (Fig. 1). They are currently residing overcrowdedly in unhumanitarian conditions with predominantly support from foreign aid. Their housing comprises a room of ~16-22 m^2, including a kitchen and bathing (for women) place. It is bamboo based which is covered by polythene sheets for fence and roofing. Men and children use a communal bathing place, and all refugees use a communal toilet. To improve this situation, Bangladesh Government (BG) constructed a Bangladeshi Taka (Tk) of 2,312-crore (US\$274.011 million) housing project at Bhasan *Char* (BC) (Island) (Fig. 1) under Ashrayan-3 policy (Palma and Jinnat 2020). The island is ~40 km^2 and consists of 120 cyclone shelters (CSs) cum schools,

medical and community centers, two helipads, and housing blocks built above a four-foot concrete structure from the ground, and protected by a 3-m height 13-km long flood protected embankment. BG aims to relocate 100 thousand refugees to this area, expecting little gardening and cultivation opportunities (Palma and Jinnat 2020).

BG started to shift 1,642 refugees on 4th December 2020 with the help of the Bangladesh Navy Ship and so far (by 3 March 2021), 12,276 refugees are shifted (Prothom Alo 2021). BC is located at the mouth of the Ganga-Brahmaputra-Meghna river system in the Bay of Bengal (Fig. 1). It is a sandy island with an average altitude of 2.86 m from the sea level, which did not exist 20 years ago (Banerjee 2020; DW News 2020). BG stated that the refugees are relocated by their own choice, so-called "Willingly"; however, the mainstream media reported that the refugees' relocation is forcefully by pressuring (DW News 2020). Whether the relocation is willingly or forcefully is out of the scope of this study. This study aims to assess BC's geographical vulnerability by comparing neighboring islands using Landsat remote sensing image and geographic information system (GIS).

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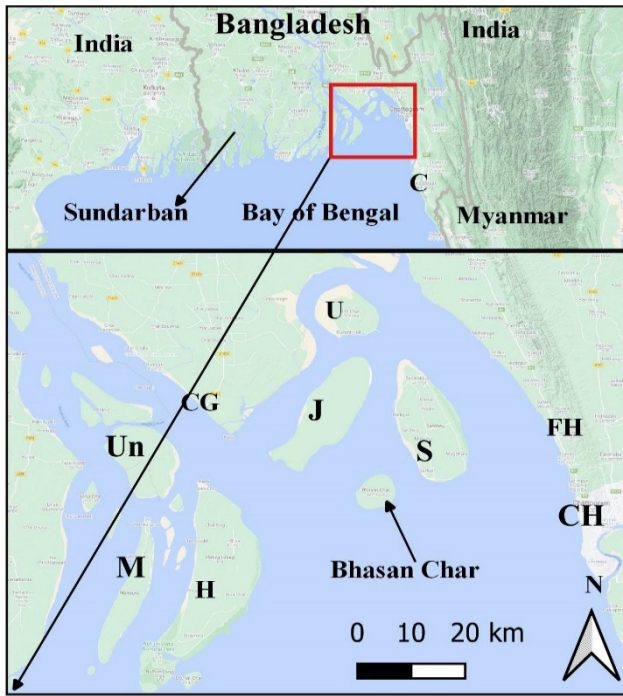
Figure 1. Location of the study area. Location of Chairman Ghat (CG), Cox's Bazar (C), Chittagong seaport (CH), Faujdarhat (FH), Hatiya *Char* (H), Jahangir *Char* (J), Manpura (M), Sandwip (S), Urirchar (U) and an un-named *char* (Un) is also illustrated.

2. METHOD

The geographical vulnerability is assessed by quantifying how often the nearby Islands, e.g., Hatiya *Char*, Sandwip is eroded and deposited since the BC was not existed 20 years back, despite the natural calamities e.g., severe tropical cyclones (TCs), similar to Islam (2013, 2010). First, the data set for BC is obtained from OpenStreetMap Foundation (2018), giving the most updated features' location, e.g., built-up area, housing, road network, flood protection embankment, tidal wave protection infrastructure. The area of polygon features and length of line features are calculated applying ArcGIS pro 2.4.3 using reference system UTM Zone 46N (Fig. 2a). Second, the Landsat satellite images are used, processed, and quantified to estimate the islands' physical sustainability, what is commonly used for such studies (e.g., Islam 2009, 2009a, 2010a). The images are accessed from EarthExplorer, science for a changing world archive of USGS (United States Geological Survey-USGS n.d.). All these data sets are cloud-free and sensed during the dry seasons (November–February), except an MSS data set on 15 April 1978 due to considering better data quality (Tab. 1). The data sets during 1972-1978 (MSS) and 1999-2001 (ETM+) are expected to present the landcover in 1975 and 2000, respectively. This approach was followed to maintain data quality, similar to Islam (2014) (Tab. 1). The Used data sets are georeferenced by the European Petroleum Survey Group (EPSG) with Projection Coordinate System: WGS (World Geodetic System) 1984 UTM (Universal Transverse Mercator) Zone 46N, Linear Unit: Meters.

The images are processed by applying the Normalized Difference Water Index (NDWI) following the equation as Li et al. (2013):

Table 1. Properties of Landsat remote sensing data.

| Sensor	Path	Row	Acq. date	Representing yr.
OLI/TRIS	136	45	04 Feb 2020	
OLI/TRIS	136	44	04 Feb 2020	
OLI/TRIS	137	44	11 Feb 2020	2020
OLI/TRIS	137	45	11 Feb 2020	
ETM+	136	44	07 Feb 2001	
ETM+	136	45	19 Dec 1999	
ETM+	137	44	24 Nov 1999	2000
ETM+	137	45	26 Nov 2000	
MSS	146	44	15 Apr 1978	
MSS	146	45	03 Nov 1972	
MSS	147	44	08 Feb1977	1975
MSS	147	45	03 Jan 1977	

$$NDWI = (R_{GREEN}-R_{NIR})/(R_{GREEN}+R_{NIR})$$

where R_{GREEN} is reflected/radiated digital numbers (DNs) value of green band, R_{NIR} is DNs value of near-infrared band. The spectral range of green band is 0.53-0.59 μm for OLI/TRIS, 0.52-0.60 μm for ETM+, 0.50-0.60 μm for MSS, and the near-infrared band is 0.85-0.88 μm for OLI/TRIS, 0.77-0.90 μm for ETM+ and 0.70-0.80μm for MSS. The spatial resolution of the visible bands blue, green, red, and near-infrared for MSS is 60 m and for ETM+ and OLI/TRIS is 30 m. Usually, the NDWI value is obtained from -1 to +1. Ideally, -1 to 0 and 0 to 1 NDWI values represent non-water and waterbody land cover.

However, this classification scheme was slightly modified and judge by comparing it with a visual interpretation of False Color Composited images (e.g., Manugula and Bommakanti 2017) where near-infrared, red, and green bands were set to the red, green and blue channel, respectively, applying the ArcGIS Pro tools: Imagery Composite Bands. The classified NDWI layers of different years were converted to a polygon with two majors land covers: waterbody and non-water. The polygons were converted to polyline, generalized and modified as the shoreline of different years, and visually compared the most eroded and deposited location. A cross-section was made at each nearby island of BC and quantified the erosion and deposition of shorelines/boundaries of islands (Fig. 2b).

3. RESULTS

The Bhasan *Char* is located in the Bay of Bengal, ~35-40 km from the nearest water ports of Faujdarhat and Chairman *Ghat* (Fig. 1). It is an isolated island between the Hatiya *Char* and Sandwip (Fig. 1). The primary transportation system between the BC and the mainland of Bangladesh is the waterway, and a Navy ship takes ~3 hours from the Chittagong seaport. Two helipads can be used emergency basis. The BC consists of two blocks of islands with ~35 km², where the bigger block is ~32 km². The habitable area is ~6.95 km² (the project area), protected by a tidal protection embankment (Fig. 2a).

The built-up area is ~144 hectares with mainly housing and road network within the island (Figs. 2a, 3a). A pond of ~3.9 hectare (38854 m²) exits here for a fresh water source and some fisheries opportunity. Some part of this area is tried to protect by sandbags (Fig. 3b).
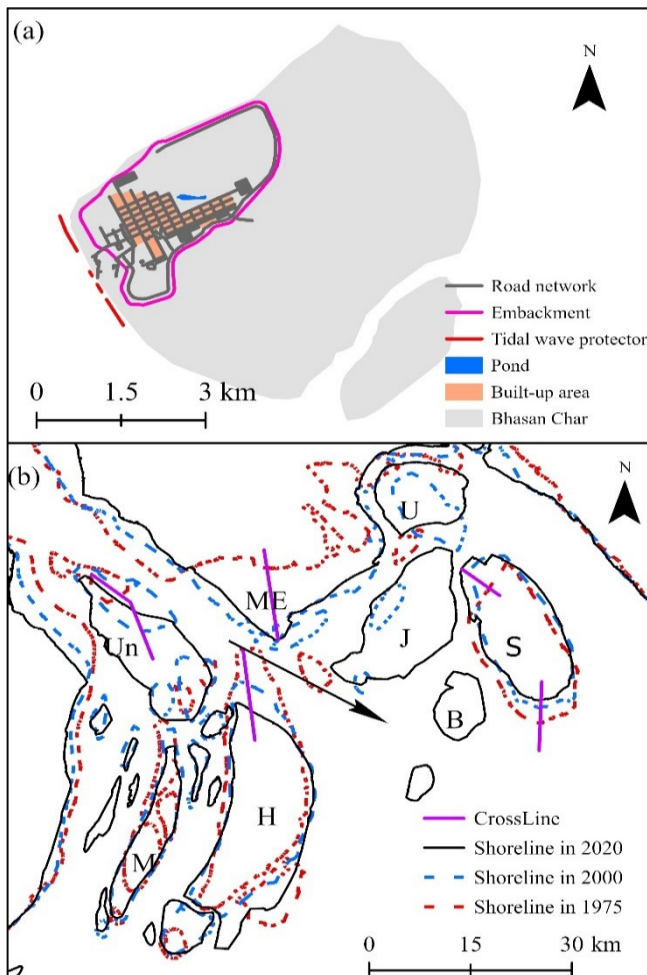
Figure 2. Features in Bhasan char (a). Different year shorelines at the mouth of Ganga-Brahmaputra-Meghna river system at Bay of Bengal (b). Location of Bhasan *Char* (B), Hatiya *Char* (H), Jahangir *Char* (J), Manpura (M), Sandwip (S), Urirchar (U), an un-named *char* (Un) and easter part of the mouth (ME) is also illustrated. Arrow indicates general flow direction.

A tidal wave-protected metallic infrastructure of ~2.3 km locates at the island's southwest face (Figs. 2a, 3c). There are 120 CSs in BC for 100 thousand persons that mean 833 people per CS can be accommodated during the cyclonic events.

The erosion and deposition of the islands at the mouth of the Ganga-Brahmaputra-Meghna river system are very regular (Fig. 2b). In 1975, the Hatiya *Char* and Sandwip were visible, including some tiny pieces of Manpura islands those become united to ~97 km² and visible in 2020 (Fig. 2b). About 31.7 km² of a piece of an island (un-named in Fig. 2b) appeared at the rivers systems mouth in 1975, which was getting larger to ~73 km² during 1975-2000 and shifted ~7.3 km towards southeast. Further, it's shape becomes ~192 km² in 2020 and moves 9.6 km in the same direction. The northern shoreline of Hatya *Char* shifted ~5.6 km and ~4.5 km during 1975-2000 and 2000-2020, respectively, towards the south. The northern and southern shorelines of Sandwip migrated ~5.2 km and ~3.5 km toward the northwest and northeast, respectively, during 1975-2020 (Fig. 2b). The area of Urirchar in 1975 was ~11 km² that is expanded to ~73.5 km² during 1975-2000 and become ~117 km² in 2020.
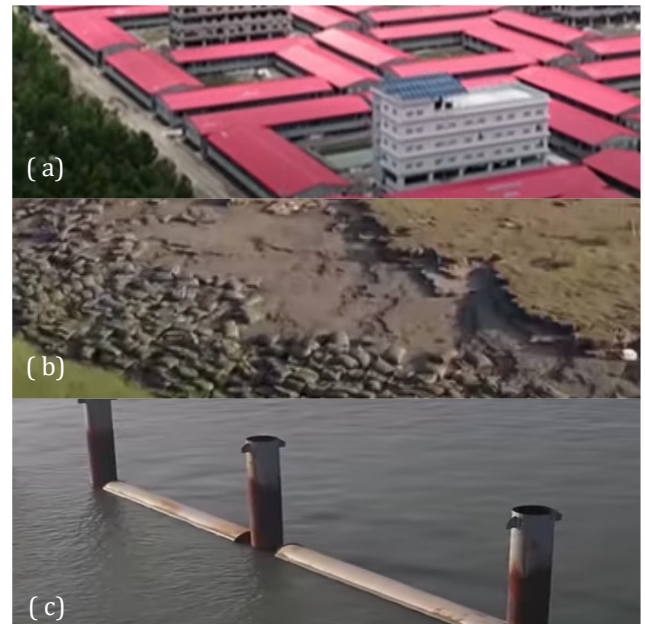
Figure 3. Bhasan char; Housing infrastructure (a), sandbag to protect the coastal erosion (b) and metallic infrastructure to protect from tidal wave (c).

The Jahangir *Char* did not appear in 1975 but became visible ~17 km² in 2000; however, in 2020, it becomes ~216 km² (Fig. 2b). Erosion at the northern shoreline at the Hatya is clearly influenced by the upstream water flow force (Fig. 2b). A massive deposition happens during 1975-2020 at the southeast mouth (ME in Fig. 2b), and the shoreline moves ~11.5 km toward the south.

4. DISCUSSION

The Bhasan Char is a sandy, newly formed island (2005-2006) with an altitude of 2.5 m that makes the island very susceptible, and many claims that it may be eroded and/or washed away by a strong flood and cyclone (Banerjee 2020; Castell 2021). This assumption becomes valid for the other surrounding islands that have eroded and migrated frequently (Fig. 2b) (Ciavola et al. 2015). During the monsoon, the rivers' flow increases, and it overflows the *Chars*, damage the infrastructure, including CSs, flood-protected embankments, crops, and livestock (Banerjee 2020; Castell 2021). A remote sensing study during 2015-2017 also suggests that BC experiences erosion at the south face and migration towards the north (Banerjee 2020).

However, some living condition in BC is far better than camps in Cox's Bazar, e.g., security and safety, housing situation and in context of landslide hazard. Some physical infrastructure in BC, e.g., CSs, embankment, wave protector is better than the nearby islands, Sandwip (450,000 population in 2016) and Hatiya *Char* (452,463 population in 2011) where the host community lives. For example, a CS for 1000 person available in Sandwip, whereas in BC, a CS is for 833 people (Castell 2021; WION 2020). But economic and social concerns may be an issue regarding a sustainable settlement.

Global warming causes an average temperature increasing of 0.019 °C/yr on the Bay of Bangle (Islam 2014; Islam et al. 2021). It increases the frequency and more intense TCs, and the Northern Indian basin shares

4%-10% TCs globally (Islam et al. 2021). Bangladesh shares 1% TCs and 53% of deaths globally (Islam et al. 2021). Before the 1990s, one severe TC occurred; however, now, 2-3 severe TCs per decade are experienced by the coastal communities in Bangladesh (Islam et al. 2021). The refugees' relocation's complete phase increases 100,000 more people in the vulnerable group in coastal Bangladesh. To protect these coastal communities from the tidal surge of a severe TC, an embankment of an average height of the tidal surge of TCs (six meters), plus one meter for expected sea-level rises by 2050, is necessary (Islam et al. 2021).

BC is a Ashrayan-3 (temporary solution for homeless) policy, not a permanent solution for the refugees. However, geopolitical behavior between Bangladesh and Myanmar suggests that the Rohingya refugee reparation is a long-term conflict since 1970s. Bangladesh enjoys very little success on this issue. An international effort, including the foreign policy of Bangladesh, could not resolve this issue, and therefore many Rohingya refugees have been living in Bangladesh since 1970s (Banerjee 2020; Grundy-Warr and Wong 1997).

5. CONCLUSION

Indeed, the Bhasan *Char* is a vulnerable place to live in terms of sustainable concept. However, this is not a place for the refugees to live permanently. Infrastructure in BC is better than that in the camps in Cox's Bazar and even in the nearby island where host communities live. If the present-day infrastructure in BC can withstand a severe TC and devastating flood, on the temporary, it may be a better place than the existing camps in Cox's Bazar.

However, many claims that BC would be like an open jail for the refugees (Castell 2021) and, therefore, sustainable parameters, e.g., economic activities, particularly income generation and social activities and network among the refugees within the Bhasan *Char* and the camps area in Cox's Bazar need to be researched.

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