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Assessing the Impact of Super Cyclone Amphan on Indian Sundarban Biosphere Reserve

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Abstract: Evaluation of a natural disaster's impact is essential for formulating preparedness, mitigation, and response plans. This study evaluates the impact of super cyclone Amphan, which hit the Indian Sundarban Biosphere Reserve on May 20, 2020. Pre- and post-cyclone land use/land cover (LULC) maps were created using LANDSAT 8 OLI, while flood inundation was mapped using Google Earth Engine (GEE) cloud platform and Sentinel-1 A C band Synthetic Aperture Radar (SAR). The study revealed that tropical cyclone Amphan had a significant impact on dense/mangrove vegetation (5%) and agricultural (2%), as well as an increase in flooded areas (40%). The proximity of 3% (290.62 km^2) of the area near the path of the cyclone was impacted by flooding, particularly in low elevation areas (5m). The investigation observed that cyclone Amphan caused extensive damage to open vegetation, agricultural lands, and urban areas. These findings provide a quantifiable estimate of cyclone Amphan's damage and will help decision-makers improve disaster preparedness. Native-based intervention initiatives, including natural ecosystem-based disaster risk reduction strategies, can be implemented to promote and conserve mangroves, rehabilitate human populations from highly vulnerable areas to safer areas, and ensure their livelihood security in cyclone-prone regions.

Keywords: Amphan Cyclone, Mangrove forests, LULC, Sundarban Biosphere reserve, Sentinel-1

Over the years, the regular occurrence of cyclones in the Bay of Bengal (BoB) has caused severe damage to eastern India, especially the states of Odisha and West Bengal, had faced the wrath of the various cyclones incurring heavy financial and environmental losses (Kumar et al 2020). The Super Cyclonic Storm (SuCS), Amphan, hit as a Very Severe Cyclonic Storm (VSCS) at Sundarbans with 155-165 kmph (maximum 224 kmph) wind speed on 20th May after landfall (IMD, July 13, 2020). Amphan damaged ~1200 sq km of reserve forest, including ~28% of mangrove forest, and affected the floral diversity through increased soil salinity (Singh 2020). The forest ecosystem's functionality, diversity, and composition get altered due to natural disturbances, including cyclones (Xi 2015). Tropical cyclones continually affect the structure of tropical forests (Ibanez et al 2019). Many studies performed globally on the impact of natural disasters on forest ecosystems suggest that natural disaster events have an intense effect on forests leading to altered forest composition, fire hazards, and decreased carbon sink (Lin et al 2017). Loss of vegetation is one of the major contributors to climate change, resulting in high temperature and precipitation variability, and rising sea levels that accelerate runoff and sedimentation flow (Al-Nasrawi et al 2018). Global warming has severely impacted the ecosystem through the frequent occurrence of natural disasters leading to enormous loss of life and property (Einsty 2017). The oceans absorb over 90% of the heat trapped by anthropogenic greenhouse gas and abruptly increase ocean surface temperatures (Guldberg et al 2018).

Previous research reported the effective use of remote sensing technology in understanding the critical role of cyclone monitoring, and effective planning in response, mitigation, and damage assessment. The concurrent availability of satellite images through open archives significantly increased the efficiency of analyzing and determining forest habitat (Zanndouche et al 2022) land cover variation due to any hazardous event (Jamali and Kalkhajeh 2020). Lal et al (2020) analyzed flood inundation in the lower Indo-Gangetic-Brahmaputra plains (IGBP) using C-band Sentinel-1A SAR using Google Earth Engine. Pheri et al (2020) used object-based image analysis (OBIA) to understand the effect of cyclone Idai in Mozambique, employing a threshold method for flood inundation.

The existing literature suggests that the studies on the impact of cyclone-induced floods concerning elevation range are limited and need further understanding. Another major issue that researchers face is the processing of remote sensing data sets. Google Earth Engine (GEE) provides a reliable and efficient platform for accurate and fast processing of remote sensing data (Mutanga and Kumar

2019, Jamali et al 2022). We intend to fill this gap and better understand the cyclonic impact in the present investigation through the present study. The present study analyzed the impact of super cyclone Amphan on the Indian Sundarban Biosphere Reserve using geospatial tools, including the Google earth engine platform. The Sundarban Biosphere Reserve is a World Heritage site because of its ecological significance (UNESCO). The region is prone to cyclones and has a long history of cyclones causing destruction and loss of life and property. The present study was carried out with the objectives to (i) study the changes in different LULC due to the Amphan, (ii) map cyclone-induced flood inundation and its impact, and (iii) investigate the relationship of elevation with flood-affected areas.

MATERIAL AND METHODS

Study area: Sundarban is the world's largest contiguous mangrove forest and delta, originating from the Ganges, Brahmaputra, and Meghna rivers in the Bay of Bengal (Ghosh et al 2015). The present study was conducted in the Indian Sundarban Biosphere Reserve (SBR), encompassing six blocks of North 24 Parganas and thirteen blocks of South 24 Parganas district of West Bengal. The word 'Sundarban' is made up of two Bengali words, one is 'Sundar' which means beautiful, and the other is 'Ban,' which means forest. The study area lies between 88° 01' E to 89° 5' E and 21° 40' N to 22° 35' N, covering a geographical area of approximately 9630 km^2 (Fig. 1). Of these, ~4264 km^2 falls under wetlands and dense mangrove forests, while the remaining ~5366 km^2 area is under inhabited lands. The term 'Sundarban' originates from one of the significant mangrove tree species, 'Sundari' (*Heritiera fomes*) (Sahana et al 2015) and has a prominent distribution of primary mangrove species, including *Avicennia marina*, *Avicennia officinalis, Avicennia alba, Ceriopsdecandra, Excoecariaagallocha, Xylocarpus mekongensis, Nypafruitcans, Aegicerascorniculatum, Sonneratiacaseolaris, Rhizophora apiculata, Sonneratia apetala, Xylocarpus granatum, Bruguieragymnorrhizaetc.*(http://naturewildlife.org).

Data collection: The land use/ land cover of the SBR was prepared using the LANDSAT 8 OLI images for the pre-Amphan period (acquired on 6th April (Path 138, Row 44,45) and 13th April 2020 (Path 139, Row 45) and post-Amphan period (acquired on 27th July and 15th October 2020) processed in Google Earth Engine (GEE) cloud platform. Using two months post-Amphan data enabled to address the possible overestimation of vegetation loss due to mud or floodwater. While C band Sentinel-1A Synthetic Aperture Radar (SAR) ground range detected (GRD) Interferometric Wide (IW) swath mode datasets were used to map flood inundation. The Sentinel-1A VH (Vertical transmit and Horizontal receive) and VV (Vertical transmit and Vertical receive) polarization were also acquired and processed in GEE throughout the pre-cyclone (28^{th} April and 4^{th} May 2020) and post-cyclone (28^{th} May 2020) periods. Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) data was also downloaded from the USGS earth explorer site to prepare the relief map of the study area. Secondary data collection, including the administrative boundary maps of the selected districts of West Bengal, was acquired from the census commissioner of India website (https://censusindia.gov.in/). We used 225 random points generated from the pre-cyclone LULC map for validation using Google earth pro software. For the post-cyclone LULC map and flood map, we collected 50 and 18 ground observation points.

Data processing: GEE was used to reduce the error of topographical distortion, atmospheric, geometric corrections, and cloud masking for LANDSAT 8 OLI data. The simple composite cloud score algorithm to overcome the cloudy condition in the post-Amphan dataset was applied. The classified map for the pre and post-Amphan period were generated using a supervised classification approach. Data processing for the Sentinel-1A dataset was done using GEE instead of SNAP software as it does not require high configuration devices and satellite data download like SNAP software. For preprocessing, the Sentinel-1A data employed Apply orbit file, thermal and border noise removal, terrain correction, and conversion backscatter coefficient. The binary flood extent raster layer at 1.25 threshold to assess the cyclone-induced flood map was created. The threshold method (binarization) was applied to verify the flooded and

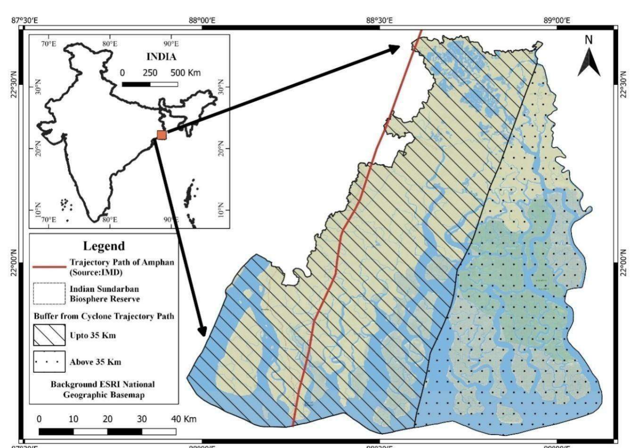

Fig. 1. Location map of Indian Sundarban Biosphere Reserve with the trajectory path and proximity of Tropical Cyclone Amphan up to 35 km and above 35 km zone (May 2020) overlaid on ESRI national geographic base map

non-flooded areas and validate the flood map using 18 ground truth points' data, where 14 points fell under the flood area, and the rest of the points fell in the non-flood class (Fig. 2).

Land Use/ Land Cover mapping: The LULC maps of the pre and post-Amphan scenarios were prepared using Random Forest (RF), a supervised classification approach. Six major LULC classes, *i.e.,* agricultural land, built-up land, water bodies, waterlogged, open vegetation, and dense vegetation/Mangrove, were generated for the pre and post-Amphan periods. The LULC map was validated for accuracy and measurement of map errors using randomly chosen 225 reference points from Google earth pro software for the pre-Amphan period. For the post-Amphan scenario, we collected 50 random points through a field survey. The overall accuracy of classified maps was 89 and 80%, while the Kappa coefficient value was 0.87 and 0.75, respectively.

RESULTS AND DISCUSSION

The pre-Amphan LULC mapping showed that the large geographical area of SBR was occupied by the water bodies (~31% of the geographical area related to the Bay of Bengal), followed by dense vegetation/mangroves (~23%). There were significant changes in the LULC pattern of SBR during the post-Amphan scenario. The notable change was observed as a considerable increase in the waterlogged area (~40%; from 342.24 km^2 to 482.36 km^2), open vegetation (~3%), and water bodies (~0.5%), in contrast to a marked decrease in dense vegetation/ mangrove (~5%) and agriculture land (~2%) during post-Amphan compared to pre-Amphan (Fig. 3- 4). Sentinel-1A C band SAR-based flood inundation in SBR was overlaid on the LULC map of pre-Amphan periods to deduce the impact of cyclone-induced flood inundation on land use/ land cover in SBR (Fig. 6). The comparison of the bimodal histograms generated for the VH polarization images for pre and post-cyclone (Fig. 5). The intensity (dB) of the VH polarization is high in the post-cyclone image. The study showed that 240.91km^2 (2.50% of total area) was affected due to the cyclone-induced flood, primarily in the northern parts of SBR after landfall. The study revealed severe impacts of tropical cyclone Amphan on agricultural lands (182.14 km^2; 75.61%), open vegetation (36.30 km^2; 15.07%), and built-up land (22.47 km^2; 9.32%). The impact of flood inundation was analyzed over the relief zones of the SBR, which is located up to 46 m relief zone in the Indian subcontinent. The elevation-wise analysis of the flooded area demonstrated that the zones having elevation <33 m were affected by the flood, which constitutes about ~3% of the total geographical area. The majority of the flood (~99%) occurred under a <9 m elevation zone due to the low-lying landscape of the SBR (Fig. 7).

The current study found significant changes in vegetation and waterlogged areas in Indian Sundarban reserve forests. A significant proportion of mangrove forests (5.71 %) have been severely damaged, resulting in the fragmentation of the vegetative cover. The loss in mangrove vegetation supports

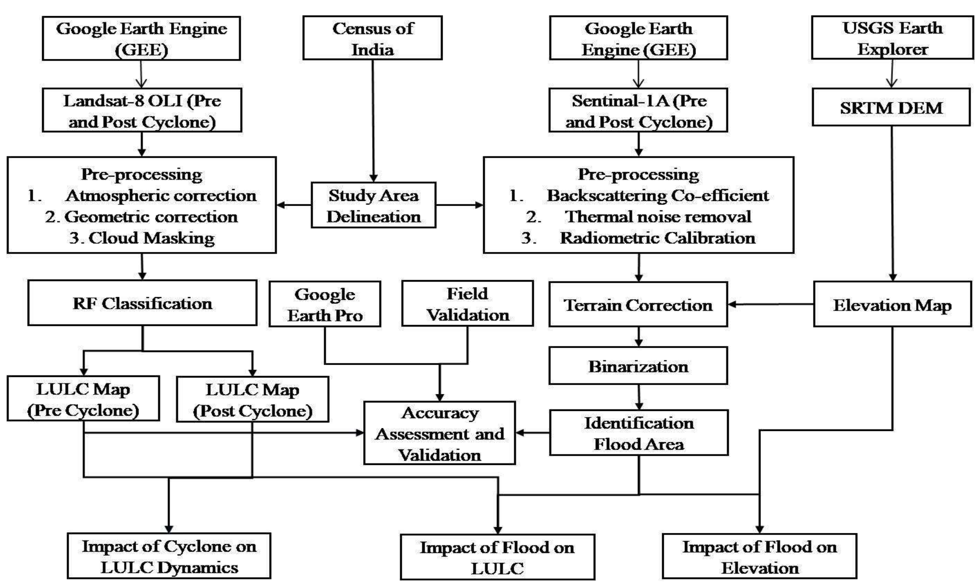

Fig. 2. Flow chart of the methodology depicting the procedure of impact assessment of cyclone Amphan on LULC and assessing the impact of flood over different land cover and elevation range

the conclusion that 13.4% of mangroves in the Indian Sundarban region were damaged by Cyclone Amphan (Acharyya et al 2021). The damage to the dense mangrove patches is of great concern as mangroves act as a barrier to cyclones (Sakib et al 2015) and preserve significant biodiversity. It significantly reduces the cyclonic wind speeds and breaks the storm waves due to the compact structure of

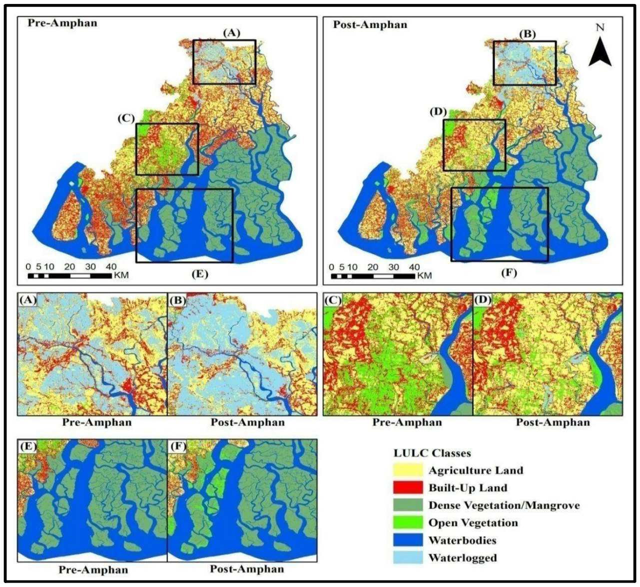

Fig. 3. Map showing the comparison between pre and post-Amphan LULC map of Sundarban Biosphere Reserve and revealed (A & B) expansion of the waterlogged area in the northern part of the study area including Minakhan, Sandeshkhali, Nyazat, and Jibontola, (C & D) damaged open vegetation area at Kultuli and Tulshihata, (E & F) lose of the dense mangrove forest in the island of Ajmalmari, Bulchery and Holiday

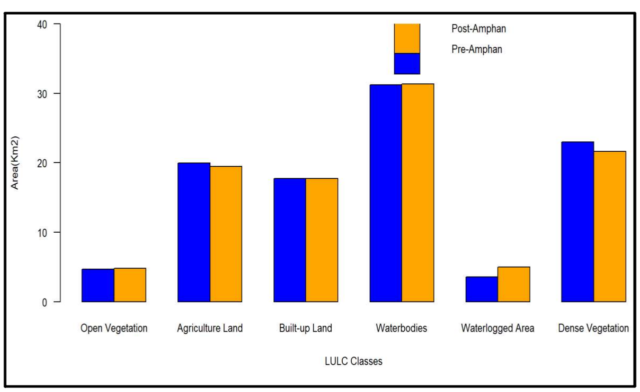

Fig. 4. Graph shows the area of different LULC classes for pre-Amphan and post-Amphan period. The graph clearly indicate the damage to open vegetation, Agricultural landscape, dense vegetation, and increase in water bodies and water-logged area due to the cyclone over the Indian Sundarban Biosphere Reserve

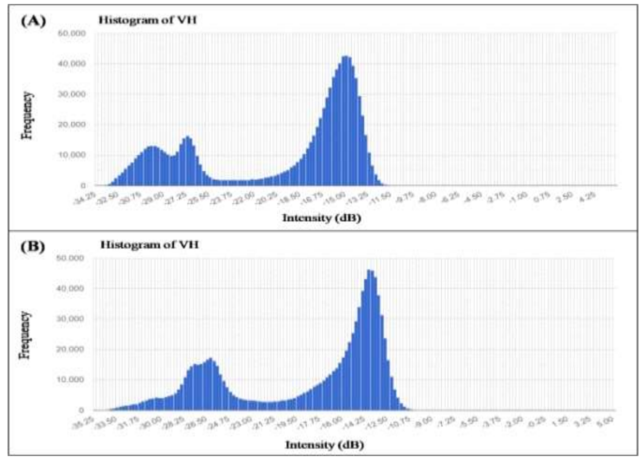

Fig. 5. Biomodal histogram of VH polarization images of (A) pre- Amphan cyclone and (B) post-Amphan cyclone, depicting the distribution of the intensity over SBR generated using the Google Earth Engine

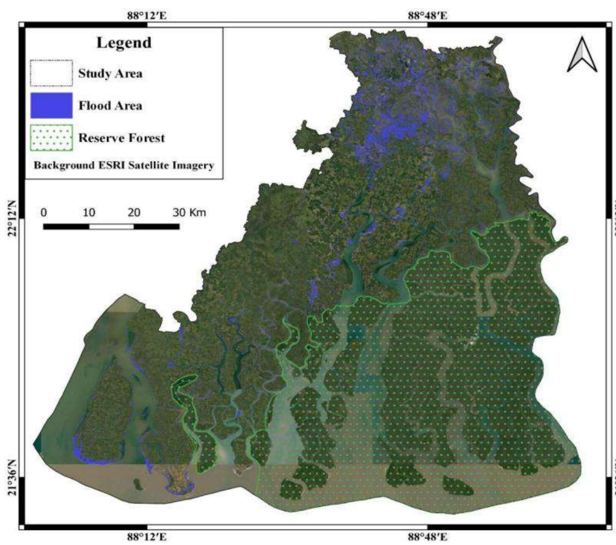

Fig. 6. Water inundation map of Indian Sundarban Biosphere Reserve during the super cyclone Amphan depicting the northern and southern part of the projected area flooded due to the cyclone

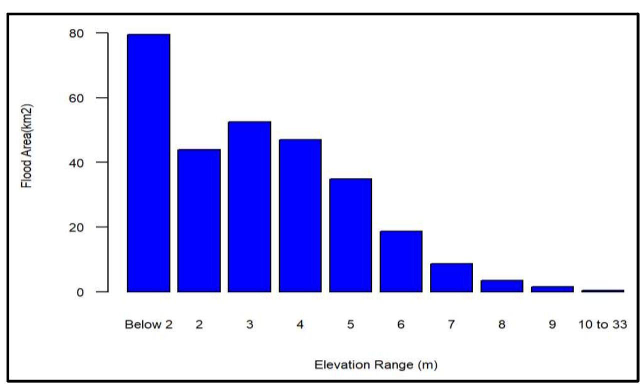

Fig. 7. Graph showing the distribution of flood areas to different elevation ranges. The graph shows the low elevation areas <5m are highly impacted by the flood

the trees (Kumar et al 2021b). Several numerical and physical model-based studies found that mangroves reduce the intensity of cyclones and tsunamis (Darryl and William 2015). Numerous important mangrove species thrive in this region, providing shelter and favourable niches for diverse ocean faunal communities. The extinction of these essential species can have devastating effects on the region's ecological equilibrium and marine biodiversity. The severity of the destruction caused by Cyclone Amphan was greatest within 35 km of the cyclone's trajectory and gradually diminished gradually away from the path. Tropical storm Amphan wreaked havoc on the dense mangrove forest and agricultural crops in the vicinity with varying degrees of severity, as observed during post-Amphan field surveys and validation. The study's outcome revealed expansion in the saturated areas due to damage to farmland and vegetation. In addition, the open vegetation class, including roadside and agricultural bund vegetation, was badly devastated (Fig. 8).

The cyclone Amphan-induced flood caused substantial damage to vast portions of existing agricultural lands (~76 % of agricultural land), constituting ~1.89 % of the Sundarban reserve forests' entire geographical area. The sudden increase in rainfall can be one of the causes of flash floods (Jha et al 2021,Bharath and Venkatesh 2022). In conformity with prior studies, the majority of agricultural and fallow land was inundated in the coastal districts as a result of the Amphan (Behra et al 2021, Kumar et al 2021a) and crops were damaged (~66 %) in Odisha, West Bengal, and the western coast of Bangladesh (Ahammed and Pandey 2021). The damage to vegetation poses severe consequences on the ecosystem and ecosystem services and affects socio-economic composition (Zommers et al 2016). The study demonstrated a comparatively very small built-up area, 0.23% of the total geographical area got impacted by the flood. Few previous studies also reported the flood's comparatively limited influence on urban areas (Dadhich et al 2019; Lal et al 2020). The change in the green urban environment in built-up areas has resulted in a substantial increase in maximum floodwater discharge (Parsasyrat and Jamali 2015). The SAR data perfectly describes all weather conditions and flood mapping (Hassan et al 2020). VH polarisation shows considerable spatial linear association in pre and post-cyclone image histograms, but not VV (Zhang et al 2018). The results indicated that flood severity was greater in low lying areas with an elevation of 5 meters or less (Phiri et al 2020). Consequently, these are the regions where the majority of the population resides, and agriculture is one of the primary means of subsistence for the inhabitants. The flood led to an increase in waterlogged areas, resulting in a diminished agricultural and plant landscape. Due to the flood, particularly in low-elevation areas, flood-induced salinity affected agricultural production (Shrivastava and Kumar 2015) and impacted drinking water quality (Nahian et al 2018). Thus, the promotion of salt-tolerant agricultural crops, particularly the indigenous rice varieties, could be a viable option for enhancing the region's population' food security (Shultanaet al 2020).

In SBR, the rising sea level and the degradation of the ecosystem's terrestrial component are of more concern. Increasing anthropogenic intrusions are also a significant concern, as they impose pressure on the natural resources and threaten the region's ecological equilibrium (Mondal et al 2021). Thus, a well-planned strategy focused on educating the populace, enhancing their skills, and relocating the populace

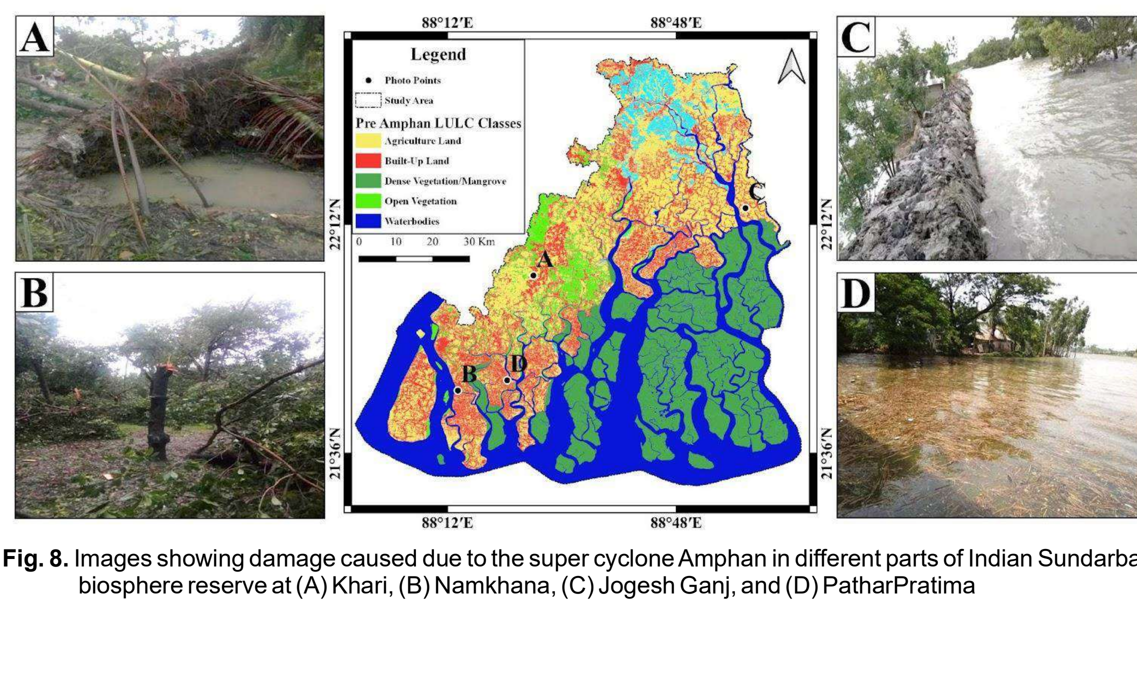

Fig. 8. Images showing damage caused due to the super cyclone Amphan in different parts of Indian Sundarban biosphere reserve at (A) Khari, (B) Namkhana, (C) Jogesh Ganj, and (D) PatharPratima

from extremely vulnerable areas to safer areas with greater employment or work opportunities will be the preferable option. Consequently, a well-planned approach centered on educating the people, enhancing their skills, and relocating the population from extremely vulnerable areas to safer areas with greater employment or work opportunities will be the preferable option, particularly for youth (Danda 2020). The approach will enable more terrestrial space for mangroves to flourish, resulting in an improved ecosystem and protection from natural disasters. A study of the effects of Cyclone Fani on the coastal region of Odisha revealed that non-native species suffered the most and is less resilient to natural disasters than native species (Nandi et al 2020). To encourage the expansion of mangrove forests in the region's natural range, the state's nodal agency must adopt native-based conservation and promotion measures immediately. In total, the findings of the study indicate wide-scale damage to mangroves and agricultural landscapes of the Indian Sundarban Biosphere Reserve due to the cyclone Amphan. This study highlighted the consequences of the cyclone Amphan-induced flood on various classes based on the elevation range and the sabotage of the mangroves. The outcome of the study strengthens our understanding of the impact of cyclones on diverse landscapes and elevation ranges. One major outcome of the study is the elevation-wise understanding of flood impact. It indicates that the lowland areas especially <5m, are at a higher risk of damage due to cyclonic events. These findings are vital for developing strategies to combat such occurrences and urge for greater focus on vulnerable elevation ranges. A key strength of the present study was the comprehensiveness of the adopted methodology to estimate the damage caused by the cyclone and the cyclone-induced flood. The implications and applications of this study pertain to the elevation-based detection of locations susceptible to severe damage from comparable catastrophes. This allows policymakers to prioritise future settlement and support of native flora programmes. Another implication of the study is the replication of the adopted methodology in other areas for similar evaluations. Cloud-free data availability was one of the difficulties. However, the basic composite cloud score technique based on the GEE addresses the post-cyclone cloud analysis. The availability of cloud-free data was one of the issues. This contributes to the scientific merit of the current study and strengthens the usage of the cloud-based GEE platform for simple, accurate, and rapid processing. The study enables for the use of GEE-based analysis to various investigations.

CONCLUSIONS

The present study set out to assess the impact of tropical cyclone Amphan on the Indian Sundarban Biosphere Reserve encompassing the UNESCO world heritage mangrove sites. The study showed wide-scale damage due to the cyclone and notable changes in the LULC of Sundarban Biosphere Reserve. The outcome showed that the severity of damage was excessive within the proximity (~35km) of the trajectory of Amphan. The study exhibits that the low land areas, especially <5m relief are at a greater damage risk to similar events. The flood-induced salinity caused wide-scale damage to agricultural crops. These findings have significant implications in assessing the extent of damage and initiatives to prioritize areas for conservation interventions and combat future threats due to similar cyclonic events. It is recommend native species-based conservation and promotion approach to strengthen and extend the natural distribution of mangroves in the region. Rehabilitation of the population from high-risk sites to safer sites, as well as people skill development programmes for better employment opportunities, should be encouraged in order to ensure socioeconomic security.

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