Indian Journal of Geo Marine Sciences
Vol. 54 (05), May 2025, pp. 225-237
DOI: 10.56042/ijms.v54i05.16954

Review Article

Biological loss under natural disasters and their possible mitigation plans in marine environment along the Bay of Bengal

S Pradhan[a], P Dikshit[b], B Paital*[,c] & S Sahoo[d]

[a]Department of Biotechnology, Indira Gandhi National Tribal University, Amarkantak, Madhya Pradesh – 484 887, India
[b]Department of Zoology, College of Basic Science and Humanities, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha – 751 003, India
[c]Redox Regulation Laboratory, Department of Zoology, College of Basic Science and Humanities, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha – 751 003, India
[d]Department of Zoology, Niali College, Prachiovihar, Cuttack, Odisha – 754 004, India
*[E-mail: biswaranjanpaital@gmail.com, brpaital@ouat.ac.in]

Received 5 February 2025; revised 11 May 2025

Numerable natural disasters, including mass-scale-die-off and cyclonic events, ravaged the east coast of the Indian subcontinent along the Bay of Bengal (BOB). It resulted in the destruction of the critical flora and fauna and human life as well. Over the past 50 years, the tropical cyclones along the BOB coast have resulted in approximately 779,324 casualties and along with staggering economic losses amounting to 1.4 trillion USD. The increasing trend of urbanisation, global warming, overfishing, and critical fluctuation in the climatic conditions has led to the occurrence of more cyclones over the past few decades. Various species such as whales, turtles, finfishes, jellyfishes, dolphins, etc., face the eco-climatic challenges, including a rise in temperature and cyclones, leading to individual or mass-scale-die-off events along the BOB. Hence, various sustainable mitigation strategies are required to reduce the occurrence of these cyclones. This review was undertaken to have a perspective on management and monitoring strategies to save human life, agricultural land, and the rich flora and fauna along the eastern coast of India.

[**Keywords**: Bay of Bengal, Cyclones, Marine life, Mitigation strategy, Natural disaster]

Introduction

The Bay of Bengal (BOB), northeastern part of the Indian Ocean, extends over an area of ~2.17 million sq[2] km and covers about 0.6 % of the total ocean body. This is the largest bay in the world and is fed with nutrient-rich water by around 10 large rivers, including the Ganges, Brahmaputra, and Mahanadi. This oceanic (deep) shore provides habitat for a variety of marine life such as arthropods, molluscs, fishes, etc., that enrich its biodiversity[1-4]. The BOB also has a vital role in controlling the climate and weather patterns, including the South Asian monsoon[5-6]. However, several environmental challenges such as pollution, overfishing, and effects of climatic variation cause rising sea levels, sea surface temperatures, and increasing occurrence of cyclonic storms, which stand as threats to the coastal ecosystem, including the mass mortality events[7-10].

Tropical cyclones over BOB are considered among the disastrous events occurring on the earth. Though it requires a series of activities and dynamic processes to convert pressure depression into a cyclonic storm, it is believed that these cyclonic events are the direct result of the rising sea climatic conditions. The cyclonic events of these regions can be categorised into two distinct types based on the monsoon period, such as pre-monsoon and post-monsoon. Among the BOB cyclones, the deadliest event was Bhola in 1970, which resulted in the death of around 3,00,000 people in Bangladesh. The next severe cyclone was Nargis that resulted in 1,40,000 deaths in Myanmar in 2008[(refs. 11-15)]. In 1999, a super cyclone killed nearly 10,000 people in the Odisha state of India, which has been considered the most catastrophic cyclonic event in the history of Indian cyclones. In the last few years (2011 – 2024), the India Meteorological Department (IMD) has recorded 86 cyclonic events along the Indian coastal region of BoB[(ref. 16)].

The BOB has been going through a number of mass-scale die-off events in the last few decades. Mostly, these events are linked to the advancement in human development and its noxious effects on the

environment. Marine species likely travel long distances in different parts of the sea. These species face die-off events at any point they face natural calamities. However, it draws attention only when there is the presence of a huge number of carcasses on a shore, including at BOB[refs. 17-18]. In the last decades, it has been observed that there is an average number of 5 – 7 die-off events happening per year over BOB. Among these die-off events, the commonly affected species are blue button jellyfish (*Porpita porpita*), olive ridley turtle (*Lepidochelys olivacea*), bottle nose dolphin (*Tursiops aduncus*), disco kokali (*Dussumieria acuta*), and different species of jellyfish, whales, etc., along the BOB[18]. The frequency of viral infection is higher than that of bacteria and other microbiome[19]. On average, a viral explosion causes the death of around 7000 marine lives, whereas a bacterial induction to mass die-offs causes roughly 350 deaths[19-20]. Therefore, it was hypothesised that a comprehensive review of the losses along the Bay of Bengal and associated areas under such natural calamities and designing possible mitigation strategies against them would make a great contribution.

Data and Methodology

The current article emphasises the BOB, the largest Bay in the world, located in the north-eastern region of the Indian Ocean, occupying an area of 2,173,000 sq. km[refs. 21-24]. Authentic sources about the discussion going on the mass-scale die-off events along with the cyclonic events across the coastal region of the BOB are collected. Data were mostly collected from the IMD, and some data were scraped from peer-reviewed research papers, review articles, irrespective of the region, and laboratory. The events on mass-scale die-offs were listed first, and then the data containing the information about the cyclonic events along the BOB were collected from IMD and arranged separately for easy access. As the number of cyclonic events along the BOB is higher across world, it draws attention to the regulations of climate over it. From past decades, it has been observed that the number of cyclonic events was increasing, and there are altogether 86 cyclonic events recorded from 2011 – 2024 along the BOB[refs. 25-28]. These cyclonic events caused huge damage to the resources and directly affect the socio-economic status of the affected region. The details of the deadliest cyclonic events across the BOB were taken for analysis by comparing the intensity of the cyclonic storm and its effect on the environment. The cyclonic events like low pressure and depression, which didn't affect the environment or cause less damage to the resources, were excluded from the analysis. Each mass-scale die-off events across the BOB were documented for analysis[22,29].

Climatic events and mass-scale die-offs

Trends of climatic changes along the BOB

The changing characteristics of the world's oceans are largely due to the integrated factors that have contributed to the indication of climatic variation along the BOB. The 2019 Intergovernmental Panel on Climate Change (IPCC) Third Special Report on The Ocean and Cryosphere in a Changing Climate (SROCC) states that the ocean has absorbed 90 % of the excess heat produced by greenhouse gases (GHG) emissions since 1970[ref. 30-33]. The elements influencing the climate variation along the BOB have been presented holistically with reference to the Indian seas[refs. 26,34-35].

Over the last 45 years, the Sea Surface Temperature (SST) in the Indian seas has increased by 0.2 °C to 0.3 °C[refs. 4,36]. The investigation performed by Anandan *et al.*[37] has suggested the increment of SST by 0.6 °C along the northeastern Indian coast within the period of 40 years from 1976 to 2015. The SST has been increasing at a rate of 0.001 to 0.005 per year along the southeast and northeast coastal regions. A dramatic shift in this rate of temperature rise has been recorded in the last decade[5,15,38-40]. Such an increase in temperature tends to change the composition of the coastal mangroves and lead to an increase in harmful algae. The harmful algal blooms occurred intensely along the Bay of Bengal, resulting in adverse effects on the coastal ecosystem[31].

Recently, in 2023, the Intergovernmental Panel on Climate Change (IPCC) in their 'AR6 Synthesis Report: Climate Change 2023' stated that the global surface temperature increased by 1.1 °C during the years 2011 – 2020 with respect to that of the years 1850 – 1900. This rising surface temperature accelerates the waning of terrestrial ice sheets due to the increased melting. As a result, the melted water adds to the ocean, leading to a rise in ocean volume, and therefore, a rise in a sea level[26]. Moreover, the absorbed heat from GHG emissions promotes the thermal expansion of water, thereby adding to a rise in sea level. With reference to global sea level rise, BOB has also been modelled using the Coupled

Model Intercomparison Project CMIP5-simulations. Results indicate that by 2050, the sea level at the BOB will rise by 37 cm[refs. 35,41-45]. Increase in sea levels has been affecting the coastal agricultural sector, causing loss of fragile habitat at coastal lands and hampering coastal tourism[22,28,46-47].

Cyclones are also among the evident phenomena triggered by climatic disturbances. These cyclonic storms, ocean-air interference events, acts as conduits for heat transfer between the ocean and the atmosphere. These storms serve as a mechanism for releasing solar heat that accumulates above the sea in the humid, foggy conditions of the summer tropics. They form when the surface water temperature reaches a specific threshold of approximately 26 °C, extending to a depth of around 50 – 100 meters. According to IMD's extensive historical data, the highest number of Tropical Cyclones (TC) occurs in October and November. Additionally, the number of depressions has been dropping since 1950, while the occurrence of Severe Cyclonic Storms (SCS) has been increasing since 1960. A study by Girishkumar *et al.*[26] and Pattanaik *et al.*[48] was carried out to review the frequency of cyclone occurrence along the coast of the BOB. They reported a total of 27 storms during 1981 – 1995, while 24 storms during 1996 – 2010 have been developed over BOB. It was found that during the period 1981 – 1995, out of 27 storms observed, 8 were turned into cyclonic storms (30 % conversion) and in the later period *i.e*., during 1996 – 2010, out of 24 storms noticed, 10 were converted into cyclonic storms (42 % conversion). This study reveals that in the recent past, the conversion rate has been increased by 12 %[refs. 25,46,49].

Mujumdar *et al.*[50] found a statistically significant increase (1 flood event per decade) in severe flood events over India from 1985 to 2019 using the Dartmouth Flood Observatory flood database[48,51]. Increase in extreme rainfall events[44,52-54], severe cyclone intensification[44,48,55] and prolonged breaks[56] may have intensified river floods post-1950s. Floods may be rising due to long-term climatic variability[57-58]. Tropical disturbances and cyclones are more likely to flood major rivers and jam drainage systems in Chennai[45,59]. One of the worst floods in the region occurred in December 2015. An unusually extended wet spell from 1 – 17 January 2021 (IMD report of 8 February 2021) was observed in the Tamil Nadu and Puducherry areas. Most dates till 16 January 2021 had above-normal rainfall. This severe rainfall was due to the western disturbance. The east coast, West Bengal, eastern Uttar Pradesh, Gujarat, Konkan, and most urban regions like Mumbai, Kolkata, and Chennai are at higher flood risk[33,53,60]. Under the "Paris Agreement", precipitation extremes under 1.5 and 2.0 °C Global Warming Levels (GWL) increased short-term rainfall extremes and flood risk in urban India[61].

The recent news of a boat carrying fish that capsized has elicited concern from various environmentalists. In the Kendrapara district of Odisha, a boat carrying ~2 tons and 20 kg of fish lost its balance and capsized near the shore, causing a blockage for the rest of the boats. According to the fishermen, the windy weather and the southerly wind led to the catching of such a large number of fish. The fish were not native to the area, and they fetch a high price in the market. The climatic conditions of Gahirmatha marine sanctuary, and the confluence of brackish water and marine water, form the perfect breeding ground for olive ridley turtles, horseshoe crabs, dolphins, sharks, fishes, etc. Climate change and human interventions using trawlers and fishing nets have reduced the breeding tendency of these animals, which may lead to them becoming endangered soon.

List of cyclonic events over the BOB

India is prone to a definite number of tropical cyclones each year. In contrast to the Arabian Sea and the Indian Ocean, the BOB faces the highest number of cyclonic storms. It has been evident that the cyclonic events seen long the Bay of Bengal has been the highest in the year 2022 and lowest in the year 2015 in between years 2015-2023 (Fig. 1). It includes 80 % of the world's cyclones that were caused by the destructive BOB[refs. 44,83]. In addition to all the data, IMD has documented 86 cyclonic events along the BOB coast between 2011 and 2024. Those cyclones are classified as low-pressure, depressions, deep depressions, cyclonic storms, severe cyclonic storms, and super cyclones based on their intensity. Although not all of the cyclonic events were fatal, almost 10 – 15 events were proven as the costliest, among which Bhola in 1970 caused 300,000 deaths in Bangladesh[14,71-72], and Nargis 2008 resulted in the death of around 140,000 people in Myanmar[69,73]. A super cyclone in 1999 killed 10,000 people in Odisha and caused a loss of around ₹20,000 crore properties. In 2019, extremely severe cyclone Fani devastated Odisha and West Bengal by killing 64 people

and destroyed nearly ₹60,000 crore of properties[28]. Extremely severe cyclonic storm Mocha (on May 2023) was the recent deadliest event, which caused the death of 463 people and damaged $2.24 billion in areas like Andaman and Nicobar Island, Sri Lanka, Myanmar, Bangladesh, and India. In 2020[refs. 74-75], cyclonic storm AMPHAN landed in West Bengal and caused the death of 89 people and damaged the coastal area. It is observed that this type of cyclonic event across the BOB caused severe damage, affecting human life, livestock, and the ecosystem, as well as the economic status of the affected area.

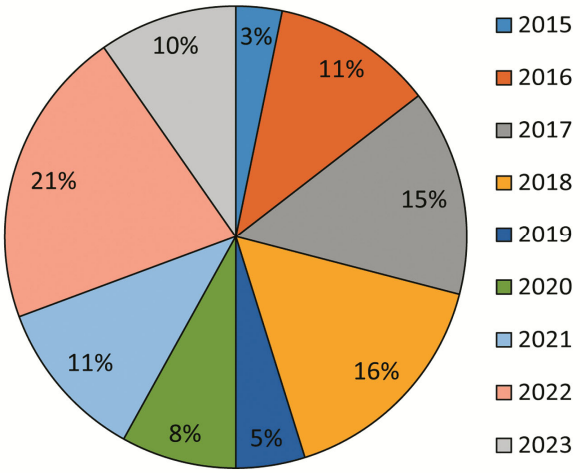

Fig 1 — Number of cyclonic events observed from 2015 – 2023 across Bay of Bengal

List of mass-scale die-off events over BOB

The rate of mass-scale die-off events over the Bay of Bengal is observed, which is assumed to be the result of large-scale infrastructure development, overexploitation, and a rise in environmental insults, including pollution across the coastal belt (Figs. 2, 3 and 4). In 2015, a large-scale die-off was observed across the coastal region of BOB. In March of the same year, three sperm whales (*Physeter marcocephalus*) were found dead along the coast of Puducherry, Alambaraikuppam, and Uyyalikuppam. The body of the whale found in Puducherry was 50 ft long male, weighing 3 tonnes; whereas the body found in Uyyalikuppam was 52 ft long adult male[17,62]. In 2016, the highest number of such die-off events was observed. About 300 olive ridley turtles and bottlenose dolphins were found dead across the Puri beach of Odisha. In the last week of February of the same year, 40 olive ridley turtle carcasses were found on Puri beach. About 80 turtles were found dead at the Jatadhari river mouth on Paradip beach, Odisha. In January 2016, 80 short-finned pilot whales were stranded at Tuticorin along the BOB. Of these,

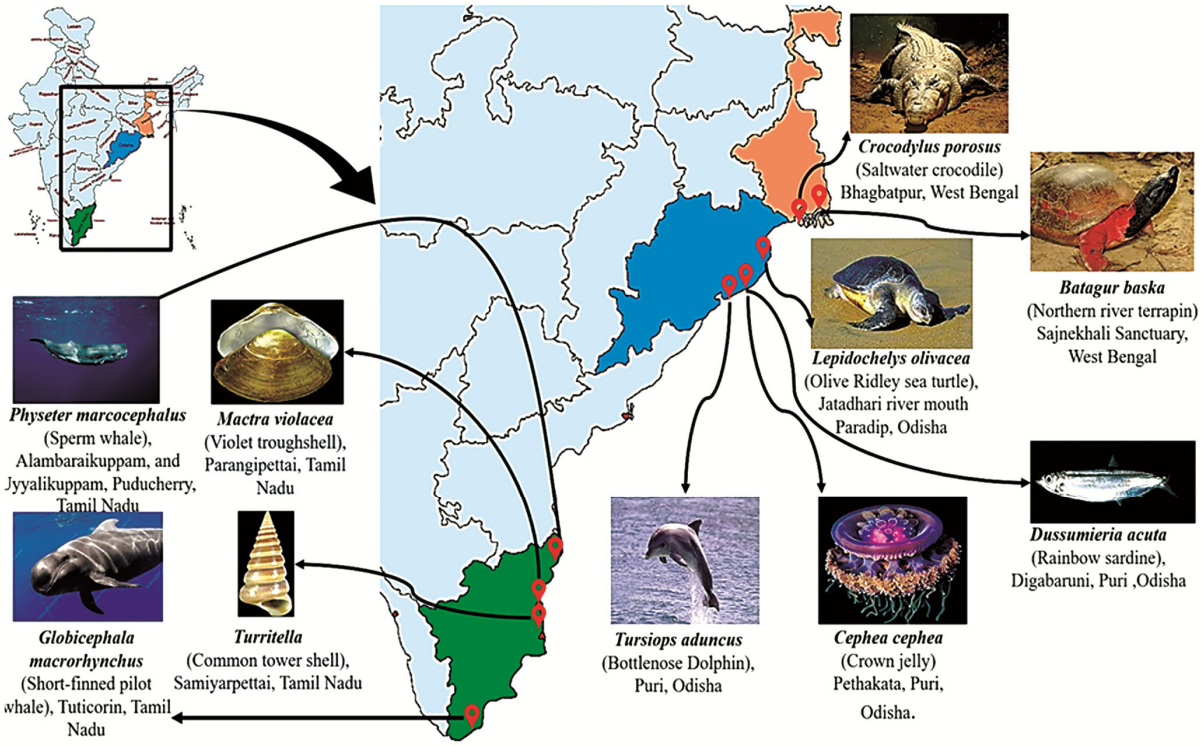

Fig. 2 — Damages incurred to the aquatic fauna along the Indian eastern coast facing Bay of Bengal under the cyclonic events

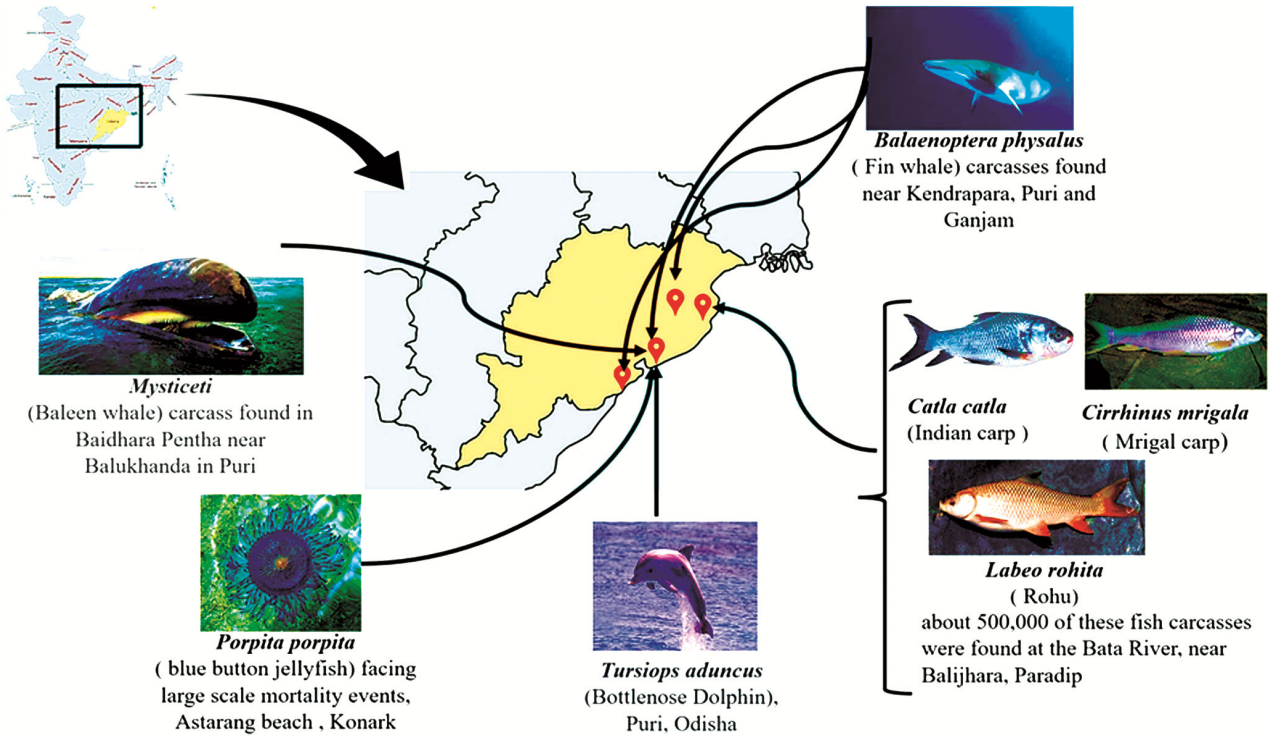

Fig. 3 — Mass scale die-off events of various fish and other species along the Indian eastern coast facing Bay of Bengal under the cyclonic events

45 died, and the remaining were pushed back into the sea by rescue[63].

Recently, some die-off events could be considered for analysis, including those of dolphins and whales along the coast of BOB. According to the Kuakata Dolphin Protection Committee, carcasses of 15 dolphins were found on Kuakata beach, Bangladesh, between January and September 2021. On 28 August of the same year, 2.5 tonnes of blue whale were spotted along the shore at Cox's Bazar, Bangladesh[64]. Between January 2020 and June 2021, 15 dolphins and 2 whales were found dead, which drew attention. A large number of carcasses of Disco Kokali (*Dussumieria acuta*) and jellyfish were found in Digabaruni and Pethakata of Puri district, Odisha. Further, it is concluded that the deaths of this large number of species could be due to the effects of the severe cyclonic storm YAAS. Due to cyclone MOCHA in May 2023, the carcasses of thousands of crown jellyfish were spotted on Puri beach of Odisha state. Experts stated that this could be due to the rising sea surface temperatures and high tides during the cyclonic event. On April 10, 2021, dead Brede's whale was found at Himchhari beach in Bangladesh, which was 16 m in length, 3 m in width, and weighing about 3.5 tonnes. This kind of die-off event is gradually observed across the BOB, which is a matter of great concern and indicates an unfavourable ocean environment for ocean dwellers[27]. It has been noticed that cyclonic events has affected molluscs to the large animals such as whales along the Bay (Fig. 2). Most of the events were noticed along Odisha and Tamil Nadu cost. Large scale fish and blue button die-off have been noticed along the Bay, also during the cyclonic events (Fig. 3).

BOB plays a significant role in the Indian monsoon; however, changes in climatic factors such as SST, Sea Surface Salinity (SSS), humidity, and wind flow adversely affect it. The seawater level of the BOB has increased by 30 % in the last decades compared to the world[31]. These huge changes in climatic factors are the direct results of overexploitation of natural resources, global warming, and human resource development[65].

Effects on socio-economic status

Loss of human life

Human resources were known to be the best in the world for their extraordinary role in global development. This kind of catastrophic event causes

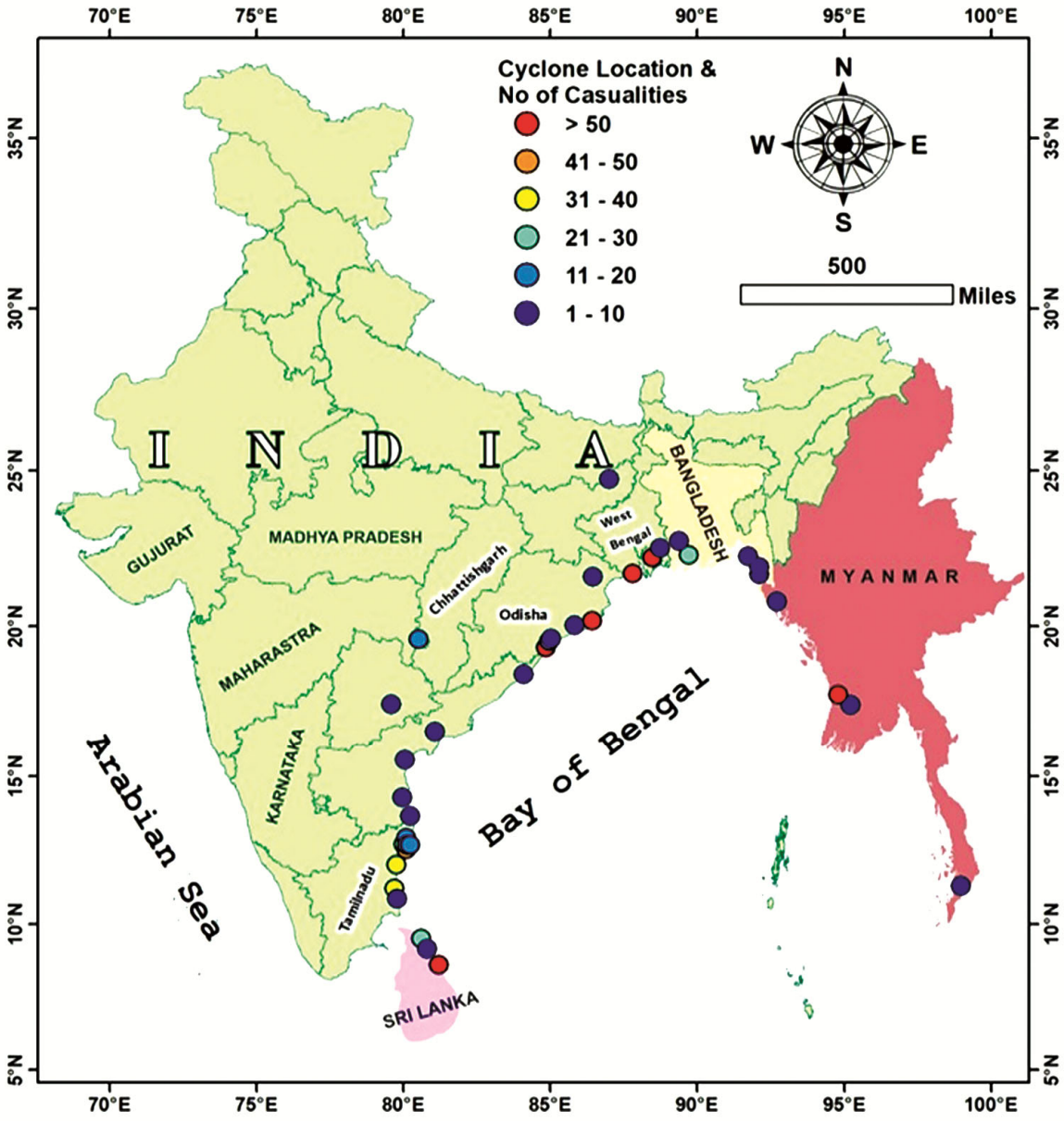

Fig. 4 — Loss of human life during the cyclonic event across the coastal region of the Bay of Bengal

significant damage to human resources; harming economic as well as the social status of a community. Such disastrous cyclonic events have been recorded for decades[14,66] (Fig. 4). The super cyclone in 1999 that struck Odisha, India, caused the loss of nearly 10,000 lives and became the deadliest cyclone. In the twenty-first century, due to advanced forecasting and safety measures, the death rate during cyclonic events is decreasing[25,67]. In 2015, the cyclonic storm KOMEN caused the death of 83 people in West Bengal, 6 people in Bangladesh, and 2 people in Myanmar, whereas, during October of the same year, 31 people were killed in the Tamil Nadu state of India due to a deep depression in BOB. Total 101 people lost their lives during the severe cyclonic storm ROANU in Sri Lanka. VARDAH took the lives of 24 people in Tamil Nadu, India, in 2016.

The cyclonic events named MARUTHA and MORA in 2017 led to the death of 10 people in Bangladesh[66,68,69]. OCKHI caused the death of 35 people in India, and 27 people were killed due to a landslide in Sri Lanka. Among all those cyclonic events between 2015 and 2023, the cyclone TITLI in 2018 killed 77 people in Odisha and 8 people in

Andhra Pradesh of India[43]. An extremely severe cyclonic storm, FANI in 2019, became dangerous by killing 64 people in the Odisha state of India. In 2020, a super cyclonic storm AMPHAN became the deadliest by taking the lives of 93 people in West Bengal, India, whereas during cyclone MOCHA, the death of 143 people was recorded. These large numbers of human lives lost during life-threatening cyclonic events are directed towards the loss of economic and social status of that community, as per IMD(ref. 70).

As this kind of disastrous cyclonic event caused damage to human resources, it was also observed to have a negative effect on the livestock of that area (Table 1). During the cyclonic event, many domestic animals, birds, fish, and other animals also lost their lives. In 2015, 10,088 animals were killed during cyclonic storm KOMEN, whereas in 2019, nearly 7000-8000 livestock lost their lives. In 2020, the cyclonic storm NIVAR caused the death of 88 animals with 8,130 poultry birds[13,43,70-84]. Most of such events are noticed along Odisha and West Bengal costal lines. Early steps including evacuation prior to cyclonic events was found to save human lives leading to even zero casualties in the former case (Fig. 4).

Table 1 — Timeline showing the various cyclones with their characteristic features and life and property loss

Year	Cyclone name	Wind speed	Landfall location	Affected states	Human lives lost	Property loss	References
1970	Cyclone Bhola	185 km/h	Bangladesh	States of Bangladesh and the eastern Indian states of West Bengal	300,000	86.4 million USD	Hossain & Hossain[14]; Hossain[66]; Chadwick *et al.*[71]
1977	Andhra Pradesh Cyclone	~220 km/h	Diviseema	Andhra Pradesh	~10,000	₹1.7 billion	Raghavan *et al.*[76]
1999	Odisha Super Cyclone	~260 km/h	Paradeep	Odisha	9,887	US$1.5 billion	Kalsi[77]
2008	Cyclone Nargis	215 km/h	Myanmar	States of Myanmar, Bangladesh, and Sri Lanka	140,000	15.3 billion USD	Khan *et al.*[69,73]; Westra *et al.*[73]
2013	Cyclone Phailin	215 km/h	Gopalpur, Odisha	Odisha, Andhra Pradesh	45	Estimated $700 million in damages	Srinivasa *et al.*[78]
2018	Cyclone Titli	150 km/h	Palasa, Andhra Pradesh	Andhra Pradesh, Odisha	85	Significant damage to crops and infrastructure	Rao *et al.*[43]; Rao *et al.*[79]
2019	Cyclone Fani	215 km/h	Puri, Odisha	Odisha, West Bengal	64	Estimated $8.1 billion in damages	Panda & Devi[80]
2020	Cyclone Amphan	240 km/h	Near Bakkhali, West Bengal	West Bengal, Odisha	89	Approximately $13.5 billion in damages	Maneesha *et al.*[74]
2021	Cyclone Yaas	130 km/h	North of Dhamra Port, Odisha	Odisha, West Bengal	20	Estimated $2.84 billion in damages	Seo *et al.*[28]
2023	Cyclone Mocha	280 km/h	Myanmar	Andaman and Nicobar Islands, Sri Lanka, Myanmar, Bangladesh, and India	463	$2.24 billion	Rizwan[70]
2024	Cyclone Dana	120 km/h	Odisha coast	Odisha, West Bengal	4 in West Bengal	Significant disruptions and damage to infrastructure	Banerjee *et al.*[81]

Effects on agriculture

Agriculture is the pillar of the Indian economy[54,85]. Cyclonic events always caused damage to the standing crop field, which directly decreased the economic status by declining the yield percentage. Loss of agricultural lands has been recorded along the Bay of Bengal as evident from the decline in trend from 2018 to 2021 (Fig. 5). After cyclone VARDAR blew, ₹35,571 crore of agricultural loss has been recorded, whereas during GAJA in 2018, 88,102 hectares of agricultural land were washed away, and 80 % of coconut trees were rooted out in Tamil Nadu and Andhra Pradesh[46,82]. PEETHAI caused damage to 10.3 lakh hectares of agricultural land and 10,000 hectares of horticultural land in the state of Andhra Pradesh, India. Extremely severe cyclonic storm FANI turned into a nightmare for farmers, washing out 148,663 hectares of crop fields in Odisha, 1,365 hectares in West Bengal, and 1,12,000 hectares of land in Andhra Pradesh. NIVAR in 2020 resulted in damage to 34,000 hectares of crop fields, and ₹50.7 million was lost due to floods in India. The state of West Bengal, India, suffered damage to 2.21 lakh hectares of agricultural land during cyclone YAAS in 2021, which also resulted in damage to properties worth ₹20,000 crore (Table 2). Such agricultural loss after the cyclonic storm decrease business and the economy of the affected area[28,84,86,94].

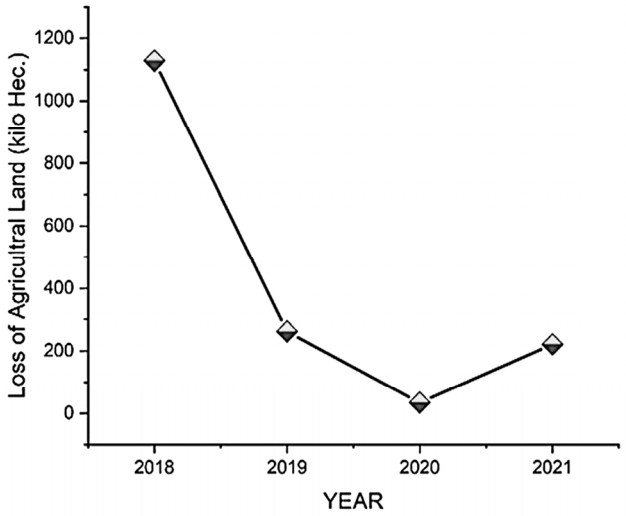

Fig. 5 — Impacts of natural disasters on loss in agricultural lands India

Possible mitigation plans

Natural calamities always cause loss of life, damage the infrastructure, and natural resources, and have deleterious consequences for the economic, social, and environmental status of a community. For cyclonic events, possible mitigation plans should be advanced forecasting, early evacuation, and flood control management, which will reduce their impact[9,87]. The coastal ecosystem is always considered a priority for evaluating the effects of cyclonic storms; however, it is necessary to implement proper coastal zone management to prevent the impacts of cyclonic events[9,66]. Mangroves are found to be the frontline during coastal hazards. The dense aerial roots of mangroves can break waves, dissipating wave energy. As a result, the entrained sediments get deposited on the floor. These sediment blankets, in turn, act as a barrier against erosion in coastal regions. Developing the mangrove ecosystem near coastal zones and river estuaries, cyclone-prone areas, will reduce the impacts of cyclones[88-90].

Forecasting cyclones helps estimate their frequency and intensity. By knowing their intensity, awareness can be created among the communities. Early evacuation of people and domestic animals before landfall of cyclonic storms reduces loss of life. In the case of disaster management, the Indian state Odisha comes first in the world, in 2013 Odisha carried out early evacuation of nearly 1 million people ahead of cyclone Phailin, whereas during the strike of cyclone Fani in 2019, the Odisha government evacuated nearly 1.2 million people based on the forecasting[91-93]. Odisha is the first to take the initiative to develop a warning system for broadcasting disaster-related

Table 2 — Agricultural damage caused by various cyclones

Year	Name of the cyclone	Agricultural damage	References
2016	Varda	₹35,571 crore of agricultural loss	Mondal *et al.*[46]
2018	Gaja	88,102 hectares of agricultural land damaged, 80 % coconut trees rooted	Mondal & Chaudhuri[82]
2018	Peethai	10.3 lakh hectares of agricultural land damaged and 10,000 hectares of horticultural land destroyed	Ali & Aziz[94]
2019	Fani	148,663 hectares of crop fields in Odisha, 1,365 hectares in West Bengal, and 1,12,000 hectares of land in Andhra Pradesh were damaged	Katzenberger *et al.*[84]
2021	Yaas	2.21 lakh hectares of agricultural land loss	Seo *et al.*[28]

information to the ground level. About 1200 villages in the coastal region of the state of Odisha now receive tsunami or cyclone-related information through mass messaging and sirens[94]. Construction of a coastal belt highway can provide easier access to road transport system, and long tree plantations near the coastal belt can help break wind speed and also help maintain the temperature on shore. Similarly, underground wiring for the electrical supply can provide another option to reduce losses in electrical equipment and interruptions in electric power supply in frequently affected areas.

Global climate change events are evident in many studies as associated with increased disaster events. Specifically, the numbers of cyclones at the global and regional scales, for example, in the BOB regions, is noted[95-109]. Along with cyclonic hits, other environmental factors, such as temperature rise, also lead to trouble for the inhabitants along the cost[110]. Such events are not specific to BOB only, but have also been noted along the North Indian ocean[111-116]. Although early forecasting can mitigate most of the loss during such climatic extremity[117], casualties and other losses at the environmental level are still documented. Additionally, infectious diseases are also responsible for mass-scale die-off events that may occur interchangeably between terrestrial and aquatic organisms[118,119]. As viral or bacterial infections spread in populations, such as in schooling fish, research may also focus on mass-scale die-offs in coastal fish and invertebrate populations.

Conclusion

Large-scale die-offs of human lives, flora and fauna in the BOB due to natural disasters, including cyclones, highlight the devastating consequences of extreme weather events intensified by climate change. Storm surges, high winds, and flooding contribute significantly to habitat destruction, biodiversity loss and human casualties. It underscores the need for improved early warning systems, disaster preparedness and ecological conservation strategies to mitigate future impacts. Strengthening coastal defences, restoring mangroves, and implementing sustainable land-use can enhance resilience. Addressing these challenges requires collaborative approaches among governments, environmental agencies, and local communities to ensure human safety and the preservation of the ecosystem near BOB.

Acknowledgements

We are thankful to the anonymous reviewers for their insightful comments and constructive suggestions to make the article more robust.

Funding

Funding by Department of Biotechnology, Government of India, New Delhi under DBT Star College Scheme (Grant number HRD-11011/33/2022-HRD-DBT) is duly acknowledged.

Conflicts of Interest

Authors declare no conflict of interest.

Ethical Statement

No ethical permission was required for this review work.

Author Contributions

BP: Conceptualization and formal analysis, writing-original draft, review editing, and supervision. SP: Software, formal analysis, writing-original draft, review & editing, and drawing original figures. PD: Software, writing-original draft, editing, drawing figures and preparation of tables. SN: Writing-original draft, editing.

References

1 Akter S, Rahman M S, Ali H, Minch B, Mehzabin K, *et al.*, Phylogenetic diversity and functional potential of the microbial communities along the Bay of Bengal coast, *Sci Rep*, 13 (2023) 1-18, Art No 15976. https://doi.org/10.1038/s41598-023-43306-4

2 Rayner N A, Parker D E, Horton E B, Folland C K, Alexander L V, *et al*., Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, *J Geophys Res*, 108 (2003) p. 4407. https://doi.org/10.1029/2002jd002670

3 Varkey M J, Murty V S N & Suryanarayana A, Physical oceanography of the Bay of Bengal and Andaman Sea, *Oceanograph Mar Biol Ann Rew*, 34 (1996) 1-70. http://drs.nio.org/drs/handle/2264/2276

4 Vivekanandan E, Climate change : Challenging the sustainability of marine fisheries and ecosystems, *J Aquat Biol Fish*, 1 (1&2) (2013) 54-67. http://eprints.cmfri.org.in/id/eprint/12255

5 Alam E, Momtaz S, Bhuiyan H U & Baby S N, Climate Change Impacts on the Coastal Zones of Bangladesh: Perspectives on Tropical Cyclones, Sea Level Rise, and Social Vulnerability, In: *Bangladesh I: Climate Change Impacts, Mitigation and Adaptation in Developing Countries*, edited by Islam M N & Amstel A, (Springer, Cham), 2018, pp. 145-166. https://doi.org/10.1007/978-3-319-26357-1_6

6 Devare S T, An Overview of the Energy Scene in the Bay of Bengal Region, In: *A New Energy Frontier*, edited by Devare S T, (ISEAS Publishing, Singapore), 2008, pp. 1-15. https://doi.org/10.1355/9789812307828-005

7 Akter N, An Overview of Tropical Cyclone Formation over the Bay of Bengal, *Bangladesh Maritime J*, 1 (1) (2017) 99-111.

8 Halder B, Das S, Bandyopadhyay J & Banik P, The deadliest tropical cyclone 'Amphan': investigate the natural flood inundation over south 24 Parganas using google earth engine, *Safet Extrem Environ*, 3 (2021) 63-73. https://doi.org/10.1007/s42797-021-00035-z

9 Swain D, Tropical Cyclones and Coastal Vulnerability: Assessment and Mitigation, In: *Geospatial Technologies for Land and Water Resources Management*, edited by Pandey A, Chowdary V M, Behera M D & Singh V P, (Springer, Cham), 2021, pp. 587-621. https://doi.org/10.1007/978-3-030-90479-1_30

10 Wahiduzzaman M, Yeasmin A, Luo J-J, Quadir D A, van Amstel A, *et al*., Markov Chain Monte Carlo simulation and regression approach guided by El Niño–Southern Oscillation to model the tropical cyclone occurrence over the Bay of Bengal, *Clim Dyn*, 56 (2021) 2693–2713. https://doi.org/10.1007/s00382-020-05610-x

11 Alam E & Dominey-Howes D, A new catalogue of tropical cyclones of the northern Bay of Bengal and the distribution and effects of selected landfalling events in Bangladesh, *Int J Climatol*, 35 (5) (2015) 801-835. https://doi.org/10.1002/joc.4035

12 Frank N L & Husain S A, The Deadliest Tropical Cyclone in History, *Bull Am Meteorol Soc*, 52 (6) (1971) 438-444. https://doi.org/10.1175/1520-0477(1971)052<0438:tdtcih>2.0.co;2

13 Gayathri R, Murty P L N, Bhaskaran P K & Kumar T S, A numerical study of hypothetical storm surge and coastal inundation for AILA cyclone in the Bay of Bengal, *Environ Fluid Mechan*, 16 (2) (2016) 429-452. https://doi.org/10.1007/s10652-015-9434-z

14 Hossain N, The 1970 Bhola cyclone, nationalist politics, and the subsistence crisis contract in Bangladesh, *Disasters*, 42 (1) (2018) 187-203. https://doi.org/10.1111/disa.12235

15 Reale F, Testa P, Klimchuk J A & Parenti S, Evidence of widespread hot plasma in a non-flaring coronal active region from Hinode/XRT, *Astrophys J*, 698 (1) (2009) p. 756. https://doi.org/10.1088/0004-637x/698/1/756

16 Das Y, Mohanty U C, Indu J & Jain I, Development of tropical cyclone wind field for simulation of storm surge/ sea surface height using numerical ocean model, *Model Earth System Environ*, 2 (1) (2016) 1-12. https://doi.org/10.1007/s40808-015-0067-5

17 Paital B & Chainy G B N, Seasonal variability of antioxidant biomarkers in mud crabs (*Scylla serrata*), *Ecotoxicol Environ Saf*, 87 (2013) 33-41. https://doi.org/10.1016/j.ecoenv.2012.10.006

18 Paital B, Bal A, Rivera-Ingraham G A & Lignot J H, Increasing frequency of large-scale die-off events in the Bay of Bengal: reasoning, perspectives and future approaches, *Indian J Geo-Mar Sci*, 47 (2018) 2135-2146.

19 Islam M d S, Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh, *Ocean Coast Manag*, 46 (8) (2003) 763-796. https://doi.org/10.1016/s0964-5691(03)00064-4

20 Ray A, Das S & Sil S, Role of Anomalous Ocean Warming on the Intensification of Pre-Monsoon Tropical Cyclones Over the Northern Bay of Bengal, *J Geophys Res Oceans*, 129 (4) (2024) p. e2023JC020527. https://doi.org/10.1029/2023jc020527

21 Bhattacharya J, The Sea of Changes: Shifting Trajectories Across the Bay of Bengal, *Asian Politics Policy*, 9 (2) (2017) 245-267. https://doi.org/10.1111/aspp.12321

22 Dube S K, Indu J, Jain I, Rao A D & Murty T S, Storm surge modelling for the Bay of Bengal and Arabian Sea, *Nat Hazards*, 51 (1) (2009) 3-27. https://doi.org/10.1007/s11069-009-9397-9

23 Singh O, Khan T A & Rahman Md S, Changes in the frequency of tropical cyclones over the North Indian Ocean, *Meteorol Atmos Phys*, 75 (1-2) (2000) 11-20. https://doi.org/10.1007/s007030070011

24 Singh O P, Recent Trends in Tropical Cyclone Activity in the North Indian Ocean, In: *Indian Ocean Tropical Cyclones and Climate Change*, edited by Charabi Y, (Springer, Dordrecht), 2010, pp. 247-263. https://doi.org/10.1007/978-90-481-3109-9_8

25 Bandyopadhyay S, Dasgupta S, Khan Z H, Wheeler D & Wheeler D, Spatiotemporal Analysis of Tropical Cyclone Landfalls in Northern Bay of Bengal, India and Bangladesh, *Asia-Pac J Atmos Sci*, 57 (4) (2021) 767-780. https://doi.org/10.1007/s13143-021-00227-4

26 Girishkumar M S & Ravichandran M, The influences of ENSO on tropical cyclone activity in the Bay of Bengal during October–December, *J Geophys Res Oceans*, 117 (C2) (2012) p. C02033. https://doi.org/10.1029/2011jc007417

27 Sadhuram Y, Maneesha K & Murty T V R, Intensification of Aila (May 2009) due to a warm core eddy in the north Bay of Bengal, *Nat Hazards*, 63 (3) (2012) 1515-1525. https://doi.org/10.1007/s11069-011-9837-1

28 Seo S N, A Refuge from Oceans and Hurricanes: A Story of Cyclone Shelters in Bangladesh Abutting the Bay of Bengal, *Nat Hazards*, 6 (1) (1992) 11-24. https://doi.org/10.1007/978-3-030-66680-4_5

29 Khalil G M, Cyclones and storm surges in Bangladesh: Some mitigative measures, *Nat Hazards*, 6 (1) (1992) 11-24. https://doi.org/10.1007/bf00162096

30 Allen M R & Ingram W J, Constraints on future changes in climate and the hydrologic cycle, *Nature*, 419 (6903) (2002) 224-232. https://doi.org/10.1038/nature01092

31 Biswas H, Mukhopadhyay S, De T K, Sen S & Jana T K, Biogenic controls on the air—water carbon dioxide exchange in the Sundarban mangrove environment, northeast coast of Bay of Bengal, India, *Limnol Oceanogr*, 49 (1) (2004) 95-101. https://doi.org/10.4319/lo.2004.49.1.0095

32 Groisman P Y, Knight R W, Roisman G, Easterling D R, Knight RW, *et al*., Trends in Intense Precipitation in the Climate Record, *J Climate*, 18 (9) (2005) 1326–1350. https://doi.org/10.1175/jcli3339.1

33 Vinodan C & Kurian A L, Energy Security and Climate Change: India's Responses to the Challenges, *J Int Stud*, 11 (2015) 79-96. https://doi.org/10.32890/jis.11.2015.7962

34 Mishra S P, Sethi K C, Mishra D P & Siddique M, Pre-Monsoon Cyclogenesis Over Bay of Bengal, *Int J Recent Technol Eng*, 8 (2) (2019) 4895-4980. https://doi.org/10.35940/ijrte.b3694.078219

35 Wahiduzzaman M, Oliver E C J, Wotherspoon S & Holbrook N J, A climatological model of North Indian Ocean tropical cyclone genesis, tracks and landfall, *Clim Dyn*, 49 (7-8) (2017) 2549–2564. https://doi.org/10.1007/s00382-016-3461-4

36 Vivekanandan E, Hermes R & O'Brien C, Climate change effects in the Bay of Bengal Large Marine Ecosystem, *Environ Develop*, 17 (2016) 46-56. https://doi.org/10.1016/j.envdev.2015.09.005

37 Anandan V, Babu M N, Muthukrishnan N & Babu M D, Performance of silver nanofluids with minimum quantity lubrication in turning on titanium: a phase to green manufacturing, *J Brazil Soc Mech Sci Eng*, 42 (2) (2020) 1-14. https://doi.org/10.1007/s40430-020-02277-7

38 Balaguru K, Taraphdar S, Leung L R & Foltz G R, Increase in the intensity of post monsoon Bay of Bengal tropical cyclones, *Geophys Res Lett*, 41 (10) (2014) 3594-3601. https://doi.org/10.1002/2014gl060197

39 Chaudhuri D, Sengupta D, D'Asaro E A, Venkatesan R & Ravichandran M, Response of the Salinity-Stratified Bay of Bengal to Cyclone Phailin, *J Phys Oceanogr*, 49 (5) (2019) 1121–1140. https://doi.org/10.1175/jpo-d-18-0051.1

40 Rajeevan M, Bhate J & Jaswal A K, Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data, *Geophys Res Lett*, 35 (L18707) (2008) 1-6. https://doi.org/10.1029/2008gl035143

41 Bezdan J, Blagojević B, Antić, S, Greksa A, Milić D, *et al.*, Impact of Climate Change on Extreme Rainfall Events and Pluvial Flooding Risk in the Vojvodina Region (North Serbia), *Atmosphere*, 15 (4) (2024) p. 488. https://doi.org/10.3390/atmos15040488

42 Kusche J, Uebbing B, Rietbroek R, Shum C K & Khan Z H, Sea level budget in the Bay of Bengal (2002–2014) from GRACE and altimetry, *J Geophys Res*, 121 (2) (2016) 1194-1217. https://doi.org/10.1002/2015jc011471

43 Rao G V, Reddy K V & Sridhar V, Sensitivity of Microphysical Schemes on the Simulation of Post-Monsoon Tropical Cyclones over the North Indian Ocean, *Atmosphere*, 11 (12) (2020) p. 1297. https://doi.org/10.3390/atmos11121297

44 Sahoo B & Bhaskaran P K, Assessment on historical cyclone tracks in the Bay of Bengal, east coast of India, *Int J Climatol*, 36 (1) (2016) 95-190 https://doi.org/10.1002/joc.4331

45 Sahu L K, Tripathi N, Sheel V, Kajino M, Deushi M, *et al*., Impact of the tropical cyclone Nilam on the vertical distribution of carbon monoxide over Chennai on the Indian peninsula, *Quart J Royal Meteorol Soc*, 144 (713) (2018) 1091-1105. https://doi.org/10.1002/qj.3276

46 Mondal M, Sabatier P, Paul S, Bhattacharya S & Biswas A, Micro-level Assessment of Rural Societal Vulnerability of Coastal Regions: An Insight into Sagar Island, West Bengal, India, *Asia-Pac J Rural Develop*, 30 (1-2) (2020) 1-34. https://doi.org/10.1177/1018529120946230

47 Needham H F, Keim B D & Sathiaraj D, A review of tropical cyclone-generated storm surges: Global data sources, observations, and impacts, *Rev Geophys*, 53 (2) (2015) 545-591. https://doi.org/10.1002/2014rg000477

48 Pattanaik D R, Sreejith O P, Pai D S & Musale M, Seasonal Forecast of Tropical Cyclogenesis Over Bay of Bengal During Post-Monsoon Season, In: *Tropical Cyclone Activity over the North Indian Ocean*, edited by Mohapatra M, Bandyopadhyay B & Rathore L, (Springer, Cham), 2017, pp. 183-197. https://doi.org/10.1007/978-3-319-40576-6_13

49 Reynolds R W, Rayner N, Smith T M, Smith T M, Stokes D C, *et al.*, An Improved In Situ and Satellite SST Analysis for Climate, *J Clim*, 15 (13) (2002) 1609–1625. https://doi.org/10.1175/1520-0442(2002)015<1609:aiisas>2.0.co;2

50 Misra V, Droughts and Floods, Assessment of Climate Change Over the Indian Region, In: *Regionalizing Global Climate Variations*, (Elsevier), 2020, pp. 229-259. https://doi.org/10.1016/b978-0-12-821826-6.00009-6

51 Sahana M & Sajjad H, Vulnerability to storm surge flood using remote sensing and GIS techniques: A study on Sundarban Biosphere Reserve, India, *Remote Sens Appl: Soc Environ*, 13 (2019) 106-120. https://doi.org/10.1016/j.rsase.2018.10.008

52 Goswami B N, Venugopal V, Sengupta D, Madhusoodanan M S & Xavier P K, Increasing Trend of Extreme Rain Events Over India in a Warming Environment, *Science*, 314 (2006) 1442–1445. https://doi.org/10.1126/science.1132027

53 Guhathakurta P, Rajeevan M, Sikka D R & Tyagi A, Observed changes in southwest monsoon rainfall over India during 1901–2011, *Int J Climatol*, 35 (8) (2015) 1881-1898. https://doi.org/10.1002/joc.4095

54 Krishnan R, Gnanaseelan C, Sanjay J, Swapna P, Dhara C, *et al*., Introduction to Climate Change Over the Indian Region, In: *Assessment of Climate Change over the Indian Region*, edited by Krishnan R, Sanjay J, Gnanaseelan C, Mujumdar M, Kulkarni A, *et al*., (Springer Nature), 2020, pp. 1-20. https://doi.org/10.1007/978-981-15-4327-2_1

55 Kishtawal C M, Jaiswal N, Singh R & Niyogi D, Tropical cyclone intensification trends during satellite era (1986–2010), *Geophys Res Lett*, 39 (10) (2012) 1-6 (Art No L10810). https://doi.org/10.1029/2012gl051700

56 Molnár P, Fatichi S, Gaál L, Szolgay J & Burlando P, Storm type effects on super Clausius–Clapeyron scaling of intense rainstorm properties with air temperature, *Hydrol Earth Sys Sci*, 19 (4) (2015) 1753–1766. https://doi.org/10.5194/hess-19-1753-2015

57 Islam T & Peterson R E, Climatology of landfalling tropical cyclones in Bangladesh 1877–2003, *Nat Hazards*, 48 (1) (2009) 115-135. https://doi.org/10.1007/s11069-008-9252-4

58 Najibi N & Devineni N, Recent trends in the frequency and duration of global floods, *Earth Sys Dynam Discuss*, 9 (2) (2017) 757–783. https://doi.org/10.5194/esd-9-757-2018

59 Boyaj A, Ashok K, Ghosh S, Devanand A, Govardhan D, *et al*., The Chennai extreme rainfall event in 2015: The Bay of Bengal connection, *Clim Dyn*, 52 (3-4) (2019) 2431-2441. https://doi.org/10.1007/s00382-017-3778-7

60 Ali H & Mishra V, Increase in Subdaily Precipitation Extremes in India Under 1.5 and 2.0 °C Warming Worlds, *Geophys Res Lett*, 45 (13) (2018) 6972-6982. https://doi.org/10.1029/2018gl078689

61 Chaudhuri R R & Sharma P, An integrated stochastic approach for extreme rainfall analysis in the National Capital Region of India, *J Earth Sys Sci*, 130 (1) (2021) 1-15. https://doi.org/10.1007/s12040-020-01510-0

62 Balaguru K, Leung L R, Lu J & Foltz G R, A meridional dipole in pre monsoon Bay of Bengal tropical cyclone activity induced by ENSO, *J Geophys Res*, 121 (12) (2016) 6954–6968. https://doi.org/10.1002/2016jd024936

63 Subbaramayya I & Rao S R M, Frequency of Bay of Bengal Cyclones in the Post-Monsoon Season, *Mon Weather Rev*, 112 (8) (1984) 799-815. https://doi.org/10.1175/1520-0493(1984)112<1640:fobobc>2.0.co;2

64 Lenderink G & van Meijgaard E, Linking increases in hourly precipitation extremes to atmospheric temperature and moisture changes, *Environ Res Lett*, 5 (2) (2010) p. e2022GL099727. https://doi.org/10.1088/1748-9326/5/2/025208

65 Rastogi N, Agnihotri R, Sawlani R, Patel A, Babu S S, *et al*., Chemical and isotopic characteristics of PM10 over the Bay of Bengal: Effects of continental outflow on a marine environment, *Sci Total Environ*, 726 (2020) p. 138438. https://doi.org/10.1016/j.scitotenv.2020.138438

66 Hossain N, Analysis of human vulnerability to cyclones and storm surges based on influencing physical and socioeconomic factors: Evidences from coastal Bangladesh, *Int J Disaster Risk Reduct*, 13 (2015) 66-75. https://doi.org/10.1016/j.ijdrr.2015.04.003

67 Bandyopadhyay D & Biswas H, Impacts of variable nutrient stoichiometry (N, Si and P) on a coastal phytoplankton community from the SW Bay of Bengal, India, *European J Phycol*, 56 (3) (2020) 273–288. https://doi.org/10.1080/09670262.2020.1834146

68 Alam Md S, Chakraborty T, Hossain Z & Rahaman K R, Evacuation dilemmas of coastal households during cyclone Amphan and amidst the COVID-19 pandemic: a study of the Southwestern region of Bangladesh, *Nat Hazards*, 115 (1) (2022) 507-537. https://doi.org/10.1007/s11069-022-05564-9

69 Khan J U, Durand F, Bertin X, Testut L, Krien Y, *et al*., Towards an efficient storm surge and inundation forecasting system over the Bengal delta: chasing the Supercyclone Amphan, *Nat Hazard Earth Sys Sci*, 21 (8) (2020) 2523–2541. https://doi.org/10.5194/nhess-2020-340

70 Rizwan M, Development of Tropical Cyclone over the Bay of Bengal during South West Monsoon, *Dhaka Uni J Earth Environ Sci*, 10 (1) (2021) 57-65. https://doi.org/10.3329/dujees.v10i1.56280

71 Chadwick M, Miller F & Thomalla F, Cyclone Nargis: what are the lessons from the 2004 tsunami for Myanmar's recovery? *Int J Environ Stud*, 66 (6) (2009) 747–760.

72 Hossain N, Analysis of human vulnerability to cyclones and storm surges based on influencing physical and socioeconomic factors: Evidences from coastal Bangladesh, *Int J Disaster Risk Reduct*, 13 (2015) 66-75. https://doi.org/10.1016/j.ijdrr.2015.04.003

73 Westra S, Fowler H J, Evans J P, Alexander L V, Berg P, *et al*., Future changes to the intensity and frequency of short-duration extreme rainfall, *Rev Geophys*, 52 (3) (2014) 522-555. https://doi.org/10.1002/2014rg000464

74 Maneesha K, Ratheesh S & Bhaskar T V S U, Impact of the Upper Ocean Processes on Intensification of Cyclone Amphan, *J Indian Soc Remote Sens*, 50 (11) (2022) 3955-3963. https://doi.org/10.1007/s12524-022-01592-x

75 Rathaur N R, Singh A & Patel P K, Analysis of major cyclone storms 'mocha 2023', 'Mandous 2022' of recent years over India, *World J Adv Res Rev*, 19 (3) (2023) 1801-1810. https://doi.org/10.30574/wjarr.2023.19.3.1929

76 Raghavan S, Rengarajan S & Varadarajan V M, Radar Study of the Bay of Bengal cyclone of 19 November 1977, *Mausam*, 31 (2) (1980) 229-240.

77 Kalsi S R, Orissa super cyclone – A Synopsis, *Mausam*, 579 (1) (2006) 1–20.

78 Srinivasa K, Murty T, Pradeep K P L N, Krishna K M, Padmanabham M, *et al*., Modeling Storm Surge and its Associated Inland Inundation Extent Due to Very Severe Cyclonic Storm Phailin, *Mar Geod*, 38 (4) (2015) 345–360. https://doi.org/10.1080/01490419.2015.1053640

79 Rao G V, Reddy K V & Sridhar V, Sensitivity of Microphysical Schemes on the Simulation of Post-Monsoon Tropical Cyclones over the North Indian Ocean, *Atmosphere*, 11 (12) (2020) p. 1297. https://doi.org/10.3390/atmos11121297

80 Panda D & Devi M, Management of the Impact of Extremely Severe Cyclonic Storm "Fani" of 2019 in Odisha, In: *International Handbook of Disaster Research*, edited by Singh A, (Springer, Singapore), 2023, pp. 395–412. https://doi.org/10.1007/978-981-19-8388-7_43

81 Banerjee A, Pattnaik S, Chakraborty S, Chakraborty S & Vishwakarma V, Investigation of unique landfall attributes of cyclone DANA over the Eastern Coast of India: role of large-scale environment and dry-air intrusion, *Meteorol Atmos Phys*, 138 (2026) 1-17. https://doi.org/10.1007/s00703-026-01118-x

82 Mondal P & Chaudhuri S, Temporal variability in the withdrawal phase of southwest monsoon over India and related consequences in northeast monsoon: a climatological perspective, *Theor Appl Climatol*, 149 (2022) 1099-1115. https://doi.org/10.1007/s00704-022-03979-9

83 Balaguru K, Leung L R, Lu J & Foltz G R, A meridional dipole in pre monsoon Bay of Bengal tropical cyclone activity induced by ENSO, *J Geophys Res*, 121 (12) (2016) 6954-6968. https://doi.org/10.1002/2016jd024936

84 Katzenberger A, Schewe J, Pongratz J & Levemann A, Robust increase of Indian monsoon rainfall and its variability under future warming in CMIP-6 models, *Earth Syst Dyn*, 12 (2) (2021) 367–386. https://doi.org/10.5194/esd-2020-80

85 McPhaden M J, Foltz G R, Lee T, Murty V S N, Ravichandran M, *et al*., Ocean- Atmosphere Interactions During Cyclone Nargis, *Eos Trans Am Geophys Union*, 90 (7) (2009) 53-60. https://doi.org/10.1029/2009eo070001

86 Mallick B, Ahmed B & Vogt J, Living with the Risks of Cyclone Disasters in the South-Western Coastal Region of Bangladesh, *Environments*, 4 (1) (2017) p. 13. https://doi.org/10.3390/environments4010013

87 Haque C E, Climatic hazards warning process in Bangladesh: Experience of, and lessons from, the 1991 April cyclone, *Environ Manag*, 19 (5) (1995) 719-734. https://doi.org/10.1007/bf02471954

88 Anandh T S, Das B N, Das B K, Kumar B P, Kumar B, *et al*., Analyses of the oceanic heat content during 1980-2014 and satellite-era cyclones over Bay of Bengal, *Int J Climatol*, 38 (2) (2018) 121-139. https://doi.org/10.1002/joc.5767

89 Das T, Shahfahad & Rahman A, Assessing tropical cyclone risk for improving mitigation strategies in Coastal Odisha, India, *Environ Sci Pollut Res*, 31 (2024) 15067-15086. https://doi.org/10.1007/s11356-024-33017-2

90 Lakshani W A E, Zhou W & Cheung P K Y, Impacts of El Niño Diversity on Tropical Cyclone Activity in the Bay of Bengal, *Front Earth Sci*, 10 (2022) p. 824769. https://doi.org/10.3389/feart.2022.824769

91 Ghosh S & Mistri B, Cyclone-induced coastal vulnerability, livelihood challenges and mitigation measures of Matla–Bidya inter-estuarine area, Indian Sundarban, *Nat Hazards*, 117 (2023) 1709-1736. https://doi.org/10.1007/s11069-023-05840-2

92 Mohapatra M, Bandyopadhyay B K & Tyagi A, Best track parameters of tropical cyclones over the North Indian Ocean: a review, *Nat Hazards*, 63 (3) (2012) 1285-1317. https://doi.org/10.1007/s11069-011-9935-0

93 Swain M, Sinha P, Mohanty U C & Pattnaik S, Dominant large-scale parameters responsible for diverse extreme rainfall events over vulnerable Odisha state in India, *Clim Dyn*, 53 (11-12) (2019) 6629-6644. https://doi.org/10.1007/s00382-019-04949-0

94 Ali A A & Aziz A A, The Impact of Early Warning System of Food Security Program: On the Decision Making Process at the Red Sea State-Sudan, *Int J Sci Res*, 2 (2013) 189–194.

95 Klotzbach P J, Trends in global tropical cyclone activity over the past twenty years (1986–2005), *Geophys Res Lett*, 33 (10) (2006) 1-4 (Art No L10805). https://doi.org/10.1029/2006gl025881

96 Singh O & Khan T M A, Has the frequency of intense tropical cyclones increased in the north Indian Ocean, *Curr Sci*, 80 (4) (2001) 575-580.

97 Boyaj A, Dasari H P, Hoteit I & Ashok K, Increasing heavy rainfall events in south India due to changing land use and land cover, *Quart J Royal Meteorol Soc*, 146 (731) (2020) 3064-3085. https://doi.org/10.1002/qj.3826

98 Antony C, Unnikrishnan A S, Krien Y, Murty P L N, Samiksha S V, *et al*., Tide–surge interaction at the head of the Bay of Bengal during Cyclone Aila, *Reg Stud Mar Sci*, 135 (2020) p. 101133. https://doi.org/10.1016/j.rsma.2020.101133

99 Chatterjee S, Interactive comment on Analytical Study of North Indian Oceanic Cyclonic Disturbances with Special Reference to Extremely Severe Cyclonic Storm Fani: Meteorological Variability, India's Preparedness with Terrible Aftermath, *Nat Hazards Earth Syst Sci Discuss*, (2020) 1-4. https://doi.org/10.5194/nhess-2020-287-RC2

100 Singh K, Panda J, Osuri K K & Vissa N K, Progress in Tropical Cyclone Predictability and Present Status in the North Indian Ocean Region, *Intech Open*, (2016) 1-24. https://doi.org/10.5772/64333

101 Sharma T, Ratna S, Pai D S, Bandgar A B, Rajeevan M, *et al*., Indian summer monsoon rainfall response to two distinct evolutions of La Niña events, *Int J Climatol*, 44 (13) (2024) 4405-4427. https://doi.org/10.1002/joc.8588

102 Sarkar A, Prasad S, Mamgain A, Dube A, Chakraborty P, *et al*., Probabilistic forecasting of Super Cyclone 'Amphan' using NCMRWF global and regional ensemble prediction systems, *Proc Indian Acad Sci: Earth Planet Sci*, 131 (1) (2022) p. 260. https://doi.org/10.1007/s12040-022-01985-z

103 Tasnim K M, Ohira K, Koichiro O, Shibayama T, Esteban M, *et al*., Numerical simulation of cyclonic storm surges over the Bay of Bengal using a meteorology-wave-surge-tide coupled model, *Proc Coast Eng Conf*, 1 (2014) p. 26. https://doi.org/10.9753/icce.v34.currents.26

104 Sudharsan N, Karmakar S, Fowler H J, Vittal H & Hari V, Large-scale dynamics have greater role than thermodynamics in driving precipitation extremes over India, *Clim Dyn*, 55 (9-10) (2020) 2603–2614. https://doi.org/10.1007/s00382-020-05410-3

105 Singh O, Khan T M A & Rahman S H, Probable reasons for enhanced cyclogenesis in the Bay of Bengal during July–August of ENSO years, *Glob Planet Change*, 26 (1-3) (2001) 139-144. https://doi.org/10.1016/s0921-8181(00)00090-4

106 Murty T S, Flather R A & Henry R F, The storm surge problem in the Bay of Bengal, *Prog Oceanogr*, 16 (3) (1986) 195-233. https://doi.org/10.1016/0079-6611(86)90039-x

107 Moron V, Barbero R, Fowler H J & Mishra V, Storm types in India: linking rainfall duration, spatial extent and intensity, *Philos Trans R Soc A: Math Phys Eng Sci*, 379 (2021) p. 2195. https://doi.org/10.1098/rsta.2020.0137

108 Ali M M, Jagadeesh P S V & Jain S, Effects of eddies on Bay of Bengal cyclone intensity, *Eos Trans Am Geophys Union*, 88 (8) (2007) 93-95. https://doi.org/10.1029/2007eo080001

109 Alam Md M, Hossain Md A & Shafee S, Frequency of Bay of Bengal cyclonic storms and depressions crossing different coastal zones, *Int J Climatol*, 23 (9) (2003) 1119-1125. https://doi.org/10.1002/joc.927

110 Yaduvanshi A, Nkemelang T, Bendapudi R & New M, Temperature and rainfall extremes change under current and future global warming levels across Indian climate zones, *Weather Clim Extrem*, 31 (2020) 1-21. https://doi.org/10.1016/j.wace.2020.100291

111 Webster P J, Holland G J, Curry J A & Chang H R, Changes in tropical cyclone number, duration, and intensity in a warming environment, *Science*, 309 (5742) (2005) 1119-1125. https://doi.org/10.1126/science.1116448

112 Wahiduzzaman M & Yeasmin A, Statistical forecasting of tropical cyclone landfall activities over the North Indian Ocean rim countries, *Atmos Res*, 35 (2019) 2549–2564. https://doi.org/10.1016/j.atmosres.2019.04.034

113 Wahiduzzaman M & Yeasmin A, A kernel density estimation approach of North Indian Ocean tropical cyclone formation and the association with convective available potential energy and equivalent potential temperature, *Meteorol Atmos Phys*, 132 (5) (2019) 1-10. https://doi.org/10.1007/s00703-019-00711-7

114 Paital B, Pati S G, Panda F, Jally S K & Agrawal P K, Changes in physicochemical, heavy metals and air quality linked to spot *Aplocheilus panchax* along Mahanadi industrial belt of India under COVID-19-induced lockdowns, *Environ Geochem Health*, 45 (3) (2023) 751-770. https://doi.org/10.1007/s10653-022-01247-3

115 Rath S, Bal A & Paital B, Heavy metal and organic load in Haripur creek of Gopalpur along the Bay of Bengal, east coast of India, *Environ Sci Pollut Res*, 28 (22) (2021) 28275-28288. https://doi.org/10.1007/s11356-021-12601-w

116 Tyagi A, Bandyopadhyay B K & Mohapatra M, Monitoring and Prediction of Cyclonic Disturbances Over North Indian Ocean by Regional Specialised Meteorological Centre, New Delhi (India): Problems and Prospective, In: *Indian Ocean Tropical Cyclones and Climate Change*, edited by Charabi Y, (Springer Dordrecht), 2010, pp. 149-166. https://doi.org/10.1007/978-90-481-3109-9_13

117 Yu L, Variability of the depth of the 20°C isotherm along 6°N in the Bay of Bengal: its response to remote and local forcing and its relation to satellite SSH variability, *Deep-Sea Res Part II-Top Stud Oceanogr*, 50 (12-13) (2003) 2285-2304. https://doi.org/10.1016/s0967-0645(03)00057-2

118 Kumar A, Middha S K, Menon S V, Paital B, Gokarn S, *et al.*, Current Challenges of Vaccination in Fish Health Management, *Animal*, 14 (18) (2024) p. 2692. https://doi.org/10.3390/ani14182692

119 Mugunthan S P, Kannan G, Chandra H M & Paital B, Infection, Transmission, Pathogenesis and Vaccine development against *Mycoplasma gallisepticum*, *Vaccine*, 11 (2) (2023) p. 469. https://doi.org/10.3390/vaccines11020469