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An increase in the frequency of severe cyclonic storms (SCS) on the east coast of India in the last 20 years: long-term observation

Debasish Dasmahapatra
State Aided College Teacher, Department of Geography, Egra S.S.B College, West Bengal India
Research Scholar, Department of Geography, RKDF University, Ranchi, Jharkhand, India
Email – debageo8@gmail.com

Abstract: *The east coast of India is vulnerable to the incidence of tropical cyclones in the Bay of Bengal. Every year, these cyclones inflict heavy losses of life and property in this region. Global climate change resulting from anthropogenic activity is likely to manifest itself in the weather and climate of the Bay of Bengal region as well. The long-term trends in the frequency and intensity of tropical cyclones in the Bay of Bengal during the intense cyclonic months of May, October, and November are one such problem that has been addressed in the present paper. Utilizing the existing data from 20 years (2004–2023) pertaining to the tropical cyclone frequency and intensity in the Bay of Bengal during May, October, and November, a study was undertaken to investigate the trends in the frequency of severe cyclonic storms (SCS) during the past two decades. The results of the trend analysis reveal that the SCS frequency over the Bay of Bengal has registered significant increasing trends in the past 20 years during the intense cyclonic months. The intensification rate during November, which accounts for the highest number of intense cyclones in the north Indian Ocean, A regional climate model simulation revealed enhanced cyclogenesis in the Bay of Bengal during May, October, and November as a result of increased anthropogenic emissions in the atmosphere.*

Key Words: *Tropical Cyclone, Bay of Bengal (BOB), East Coast, Severe Cyclonic Strom (SCS).*

1. INTRODUCTION:

The increase in the frequency of severe cyclones along the east coast of India over the past two decades, from 2004 to 2023, is indeed a concerning trend. This rise could be attributed to various factors, including climate change and natural variability. Rising sea surface temperatures due to climate change provide more energy for cyclones to form and intensify. cyclonic disturbance in which the maximum average surface wind speed is in the range of 48 to 63 knots (89 to 117 kmph). Warmer ocean waters also contribute to increased moisture in the atmosphere, fueling the intensity of cyclones. Changes in oceanic and atmospheric conditions, such as shifts in wind patterns and atmospheric pressure, can influence the formation and tracks of cyclones. Variations in phenomena like the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) can affect cyclone activity in the region. Rapid urbanization and coastal development along the east coast of India can exacerbate the impacts of cyclones. The loss of natural barriers like mangroves and wetlands reduces the region's resilience to storm surges and flooding. Advances in technology and improved monitoring systems might also contribute to the apparent increase in reported cyclone frequency. Better detection methods could lead to the identification of cyclones that might have gone unnoticed in the past. It's essential to consider data quality and historical records when analyzing trends in cyclone frequency. Changes in recording methods, observation techniques, and population density along the coast can influence the perceived increase in cyclone frequency.

About 80% of the total number of tropical cyclones in the North Indian Ocean form in the Bay of Bengal. On average, about 5–6 tropical cyclones form in the Bay of Bengal every year. Most of the severe cyclones in the Bay of Bengal form during the post-monsoon season in the months of October and November. A few severe cyclones form in May. Research indicates that rising sea surface temperatures in the Bay of Bengal, attributed to climate change, provide favorable conditions for cyclone intensification and frequency. Historical cyclone records and observational data from meteorological agencies such as the India Meteorological Department (IMD) and international organizations provide insights into trends in cyclone occurrence and intensity along the east coast of India. Analysis of long-term cyclone data reveals an upward trend in the frequency of severe cyclones in the region over the past two decades. Researchers have explored the influence of natural variability, including climate oscillations such as the Indian Ocean Dipole (IOD) and the El Niño-Southern Oscillation (ENSO), on cyclone activity in the Bay of Bengal. Studies suggest that while natural variability plays a role in modulating cyclone behavior on shorter time scales, the overall increase in cyclone frequency is consistent with the broader trend of climate change. Assessments of the socio-economic and environmental impacts of severe cyclones on coastal communities along the east coast of India highlight the vulnerability of densely populated and low-lying areas to cyclone-induced hazards such as storm surges, heavy rainfall, and flooding. Vulnerability mapping and risk assessments help identify hotspots and inform adaptation strategies aimed at reducing the impacts of cyclones on vulnerable populations and infrastructure. The influence of natural climate variability, including phenomena like the Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO), on cyclone activity in the Bay of Bengal region is a subject of interest. Research investigates how these oceanic and atmospheric oscillations modulate cyclone genesis, tracks, and intensity, contributing to interannual and decadal variations in cyclone frequency on the east coast of India. Research on disaster preparedness and response measures emphasizes the importance of early warning systems, evacuation planning, and community resilience-building efforts in mitigating the impacts of severe cyclones. "Tropical disturbances are classified under different nomenclature as adopted by the Regional Specialized Meteorological Centre (RSMC) Tropical Cyclones, New Delhi. The classification of disturbances is shown in the following table:

Sl no	Type	Wind speed Km/hr	Wind speed Knot (mps)
1	Low pressure area (L)	Less than 31	Less than 17
2	Depression (D)	31-49	17-27
3	Deep Depression (DD)	50-61	28-33
4	Cyclonic Strom (CS)	62-88	34-47
5	**Severe Cyclonic Strom (SCS)**	**89-118**	**48-63**
6	**Very Extremely Cyclonic Strom (VECS)**	**119-165**	**64-89**
7	Extremely Severe Cyclonic Strom (VSCS)	166-220	90-119
8	Super Cyclonic Strom (SCS)	221 above	120 above

Source: India Meteorological Department (IMD)

1.1 LITERATURE REVIEW :

The topic would involve examining various studies, research articles, reports, and publications that contribute to understanding this phenomenon. Here's a summarized literature review covering key findings and insights: Studies by climate scientists have highlighted the link between climate change and the increasing frequency of severe cyclones globally, including those impacting the east coast of India. Ali (1995 and Joseph (1995 have touched upon the tropic but could not bring out clear-cut trends in the frequency of severe cyclones in the Bay of Bengal during the intense cyclonic period of the year. Mooley (1980, 1981) and Sikka (2006) have studied the trends in the annual frequency of cyclonic storms. Sikka (2006) has emphasized a slight decrease in the annual frequency of cyclones during the last four decades. Singh (2001) has reported a decreasing trend in the frequency of monsoon storms during the past decades. Singh and Ali Khan (1999) have looked into the trends in the cyclogenesis over the north Indian Ocean during past decades comprehensively and have shown that there is indeed a tendency for enhanced cyclogenesis during the intense cyclonic months on a long-term basis, though the annual frequency has not changed much. In the present study, only severe cyclonic storms, *i.e.*, cyclonic storms having a maximum sustained wind speed of 48 knots or more, have been considered. Similarly, the intensification rate of cyclonic disturbances at the severe cyclonic storm stage alone has been considered. The Bay of Bengal (BoB) is marginally conducive to tropical cyclone (TC) formation, with an average of three to four storms annually [*Alam et al.*, 2003]. There are two primary TC seasons in the northern Indian Ocean: the pre-monsoon season during April–May and the more active post-monsoon season during October–November [*Girishkumar and Ravichandran*, 2012]. This bimodal structure of the TC season in the northern Indian Ocean owes its existence to the strong vertical wind shear during the summer monsoon months of June–September [*Hoarau et al.*, 2012]. Along with a thermodynamically unstable atmosphere and weak tropospheric vertical wind shear, favorable hydrographic conditions, such as the formation of thick barrier layers that stably stratify the upper ocean, are the primary reasons for enhanced TC activity during the post-monsoon season [*McPhaden et al.*, 2009; *Sengupta et al.*, 2008]. The freshwater discharge from the Ganges, Brahmaputra, and Irrawaddy river systems causes the uniform density mixed layers to become shallower than the uniform temperature isothermal layers due to the salinity effect, leading to the formation of salt-stratified barrier layers in the BoB [*Sprintall and Tomczak*, 1992]. Once formed, the salinity stratification acts as a “barrier” to vertical mixing and entrainment cooling induced by TCs, leading to an increase in enthalpy flux from the ocean into the atmosphere and, consequently, an invigoration of TCs [*Balaguru et al.*, 2012].

1.2 LOCATION OF THE STUDY AREA

The study area focusing on severe cyclones on the east coast of India typically encompasses the coastal regions along the Bay of Bengal, extending from the southern tip of India to the northern coastal areas of West Bengal and Odisha. This region is particularly susceptible to the impacts of cyclones due to its geographical location and environmental characteristics. Here are some key aspects of the study area. The study area includes the eastern coastal states of India, namely Andhra Pradesh, Odisha, West Bengal, and parts of Tamil Nadu and Andaman and Nicobar Islands. These areas are prone to cyclones due to their proximity to the Bay of Bengal, which serves as a breeding ground for tropical cyclones. The study area encompasses diverse coastal topographies, including low-lying coastal plains, river deltas, estuaries, mangrove forests, and urbanized coastal cities. These features influence the vulnerability of the region to cyclone-related hazards such as storm surges, flooding, and erosion. The study area experiences a tropical monsoon climate characterized by high temperatures, heavy rainfall during the monsoon season, and periodic cyclonic disturbances originating from the Bay of Bengal. Warm sea surface temperatures and favorable atmospheric conditions contribute to the formation and intensification of cyclones in the region. Cyclone Tracks: Researchers analyze historical cyclone tracks and landfall patterns within the study area to understand the spatial distribution and frequency of severe cyclones over time. Cyclones often make landfall along the east coast of India, causing varying degrees of impact depending on their intensity and track.

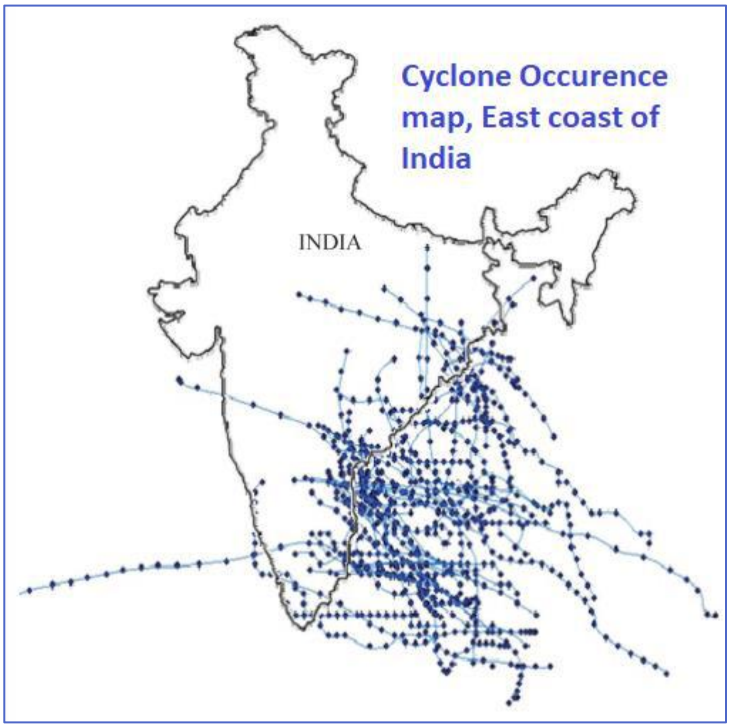


Fig. 1: Location Map

1.3 OBJECTIVES:

1. Investigate the factors contributing to the increase in severe cyclonic storms (SCS) in the Bay of Bengal.
2. Analysis of historical cyclone data to identify trends in frequency, intensity, and tracks of severe cyclones along the east coast of India over the
3. Assessing the socio-economic impacts of tropical cyclones on coastal communities, infrastructure, agriculture, and ecosystems along the east coast region of India
4. To identify areas most vulnerable to severe cyclones and implement improved early warning systems for preparedness plans.

1.4 HISTORY OF SEVERE TROPICAL CYCLONE (2004-2023) EAST COAST IN INDIA

Over the past 20 years (2004–2023), the east coast of India has experienced several severe cyclones, some of which have caused significant devastation to coastal communities, infrastructure, and ecosystems. Here is a brief overview of the notable severe cyclones that have impacted the region during this period:

Cyclone Phailin (2013): Phailin made landfall near Gopalpur in Odisha as a Category 4 cyclone, with wind speeds reaching up to 220 km/h (137 mph). Despite its intensity, timely evacuations and preparedness measures helped mitigate casualties, reducing the human impact of the cyclone. However, Phailin caused significant damage to infrastructure, agriculture, and coastal areas in Odisha and Andhra Pradesh.

Cyclone Hudhud (2014): Hudhud struck Visakhapatnam in Andhra Pradesh as a Category 3 cyclone, with wind speeds of around 185 km/h (115 mph). The cyclone caused extensive damage to buildings, power lines, and crops, resulting in widespread power outages and disruptions of essential services. Hudhud's impact was particularly severe in Visakhapatnam and surrounding areas, where infrastructure damage was substantial.

Cyclone Titli (2018): A Very Severe Cyclonic Storm Titli was a deadly and destructive tropical cyclone that caused extensive damage to eastern India in October 2018. Ahead of the storm's landfall in the Indian state of Andhra Pradesh, about 300,000 people evacuated. Titli ultimately killed 89 people from its impacts, including 85 in India. The cyclone produced strong winds, with gusts to 126 km/h (78 mph), along with a storm surge that flooded coastal areas.

Cyclone Fani (2019): Fani made landfall near Puri in Odisha as an extremely severe cyclonic storm, with wind speeds exceeding 200 km/h (124 mph). The cyclone prompted one of the largest evacuations in India's history, with millions of people relocating to safer areas. Despite the scale of the evacuation effort, Fani caused extensive damage to infrastructure, including houses, roads, and electricity poles, particularly in coastal districts of Odisha.

Cyclone Amphan (2020): Amphan, one of the strongest cyclones on record in the Bay of Bengal, made landfall in West Bengal and Bangladesh as a Category 3-equivalent cyclone. The cyclone caused widespread devastation, particularly in Kolkata and surrounding areas, with strong winds, heavy rain, and storm surges leading to loss of lives, displacement, and damage to infrastructure. Amphan's impact was compounded by the COVID-19 pandemic, which strained relief and recovery efforts in affected areas.

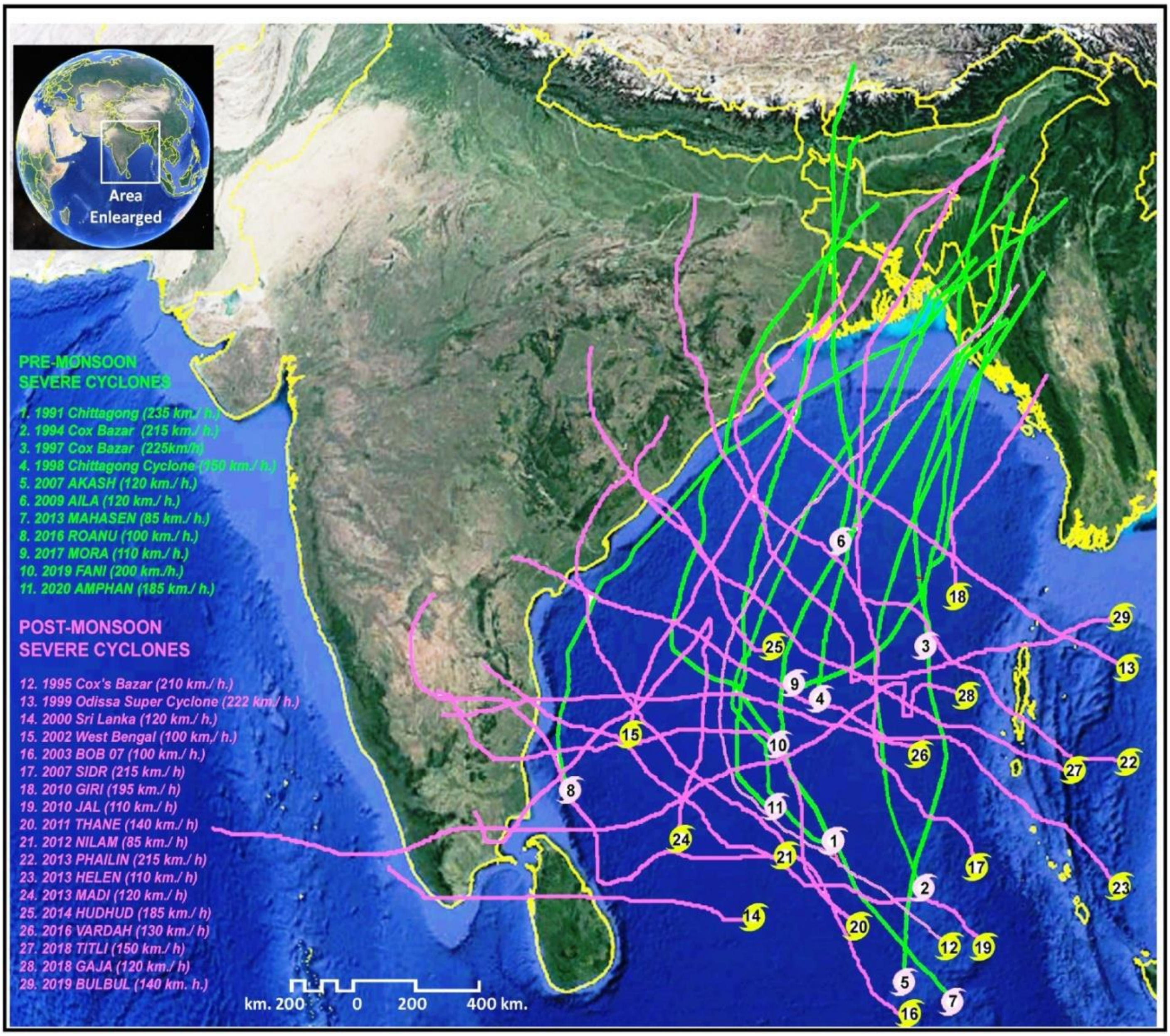
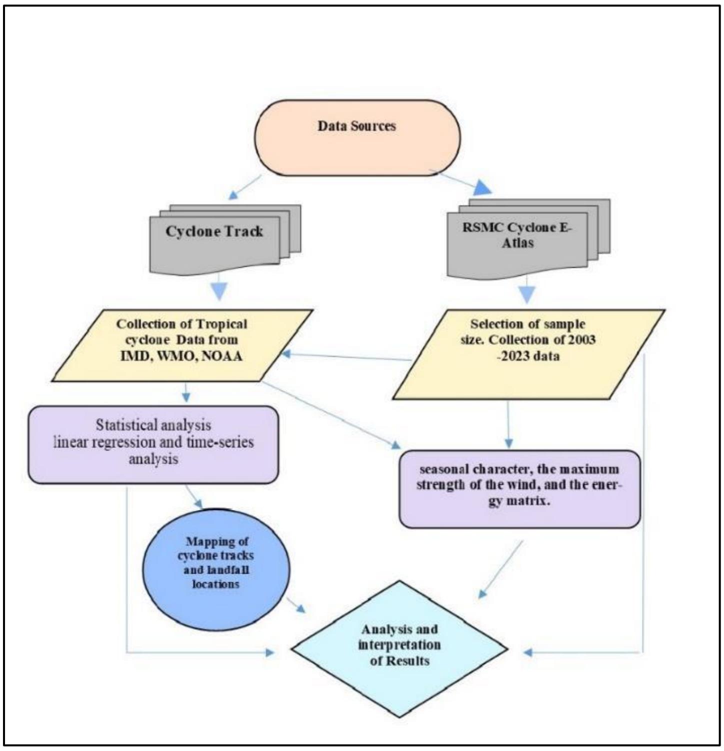


Fig. 2**:** Pre-monsoon and Post-monsoon season severe cyclones

Cyclone Yass (2021): A Very Severe Cyclonic Storm Yaas was a relatively strong and very damaging tropical cyclone that made landfall in Odisha and brought significant impacts to West Bengal during late May 2021. Marginally favourable conditions further continued as Yaas accelerated northeastward, strengthening to a Category 1-equivalent tropical cyclone and to a very severe cyclonic storm on May 25. Yaas crossed the northern Odisha coast around 20 km south of Balasore at its peak intensity as a very severe cyclonic storm on May 26. Upon landfall, the JTWC and IMD issued their final advisories as Yaas further weakened inland while turning north-northwestward.
Cyclone Asani (2022): A Severe Cyclonic Storm Asani was a strong tropical cyclone that made landfall in India in May 2022. It was the strongest storm of the 2022 North Indian Ocean cyclone season. The third depression and deep depression, and the first named storm of the 2022 North Indian Ocean cyclone season, Asani, originated from a depression that the Indian Meteorological Department first monitored on May 7. Conditions rapidly favored development as the system became a deep depression by that day before intensifying into Cyclonic Storm Asani. On the next day, it further intensified and peaked as a severe cyclonic storm before making landfall as a deep depression system over Andhra Pradesh.
Cyclone Michaung (2023): A Severe Cyclonic Storm Michaung was a moderate tropical cyclone that formed in the Bay of Bengal during the 2023 North Indian Ocean cyclone season. Michaung originated as a low-pressure area in the Gulf of Thailand that crossed into the Bay of Bengal and became a deep depression on December 2. It developed into a cyclonic storm thereafter and was named *Michaung*. It was the ninth depression and the sixth named cyclonic storm of the season. The cyclone gradually moved north-west over the next few days towards the eastern coast of India. The storm peaked with sustained winds of 60 knots (110 km/h; 70 mph), causing heavy rainfall in north-eastern Tamil Nadu, including Chennai, and south-eastern Andhra Pradesh, before making landfall near Bapatla in Andhra Pradesh on December 5.

2. DATA BASE AND METHODOLOGY :



The dates of tropical cyclone data are obtained directly from the Cyclone E-Atlas of the online RSMC-IMD (rsmcnewdelhi.imd.gov.in) portal for tropical cyclones over the basin of the North Indian Ocean. After registration, RSMC-IMD databases are publicly accessible on the web portal, very easy to view, and even in downloadable format (in.pdf,.xml,.gif formats). Tropical cyclone datasets include the name of the cyclone, the date and place of origin and landfall, the length of the cyclone, the seasonal character, the maximum strength of the wind, and the energy matrix. Access historical records of cyclone occurrences in the Bay of Bengal region. Databases maintained by meteorological agencies such as the India Meteorological Department (IMD), the National Oceanic and Atmospheric Administration (NOAA), and other international organizations like the World Meteorological Organization (WMO) can provide valuable data. Utilize satellite imagery and remote sensing data to track cyclone formation, intensification, and movement over the study period. Sources may include datasets from satellites like the RSMC Cyclone Atlas (2003–2023), which provide information. Conduct statistical analysis to identify trends in the frequency and intensity of severe cyclones on the east coast of India over the past 20 years. This may involve techniques such as linear regression and time-series analysis. Explore the spatial distribution of cyclone tracks and landfall locations along the east coast of India to identify regions most affected by severe cyclones during the study period. Use geospatial tools and create a map, graph, or chart. By combining these databases and methodologies, researchers can comprehensively study the increase in severe cyclone frequency on the east coast of India and provide valuable insights into the drivers and implications of this trend.

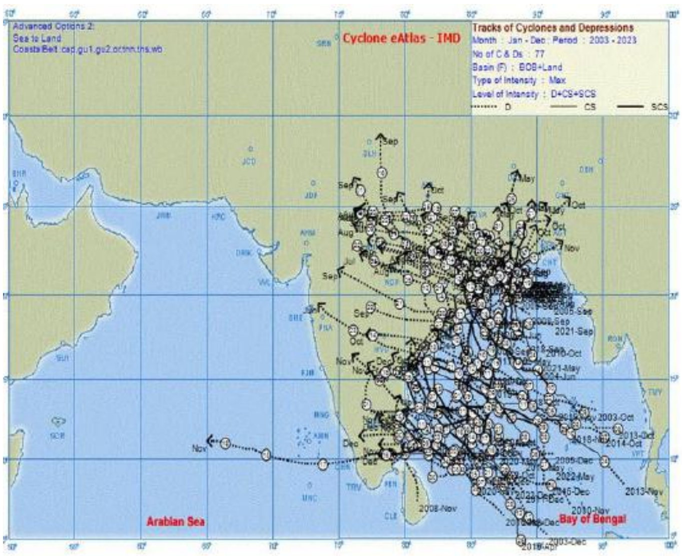
3. RESULTS AND DISCUSSION:

Summary of tropical storm characteristics for Bay of Bengal basin, from January 1970 to November 2020 (50 Cyclonic Storm seasons and n = 176).

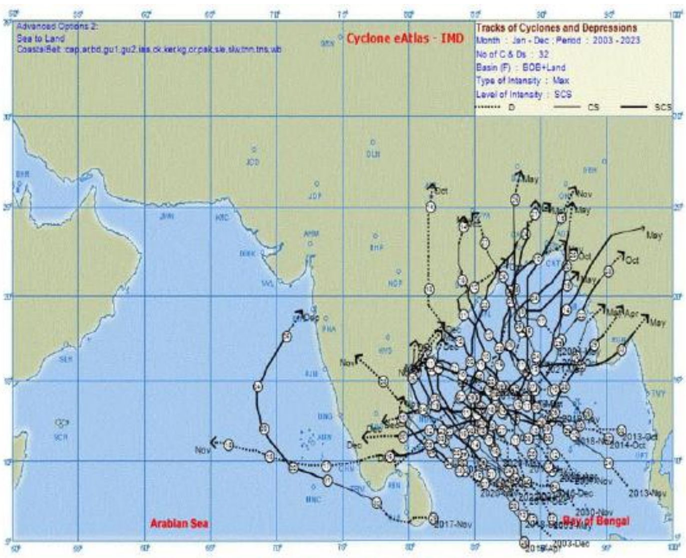
Parameter	Median	Mean	Range
Decadal Frequency (no.)	36	35.2	30–41
Cyclogenesis Lat. (°)	89,°25′	90,°08′	78,°09’ - 113,°33′
Cyclogenesis Long. (°)	11,°58′	12,°43′	2°11’ - 21,°40′
Landfall Lat. (°)	87,°33′	86,°54′	78,°01’ - 101,°28′
Landfall Long. (°)	19,°42′	18,°21′	10,°02’ - 22,°34′
Duration (hour)	83	94.4	15–276
Distance Covered (km.)	1091.5	1195.2	28.6–4111.4
Speed (km.)	85.00	99.22	45.0–260.0
Minimum Pressure (mb.)	988	980.5	912–1008

Source: rsmcnewdelhi.imd.gov.in

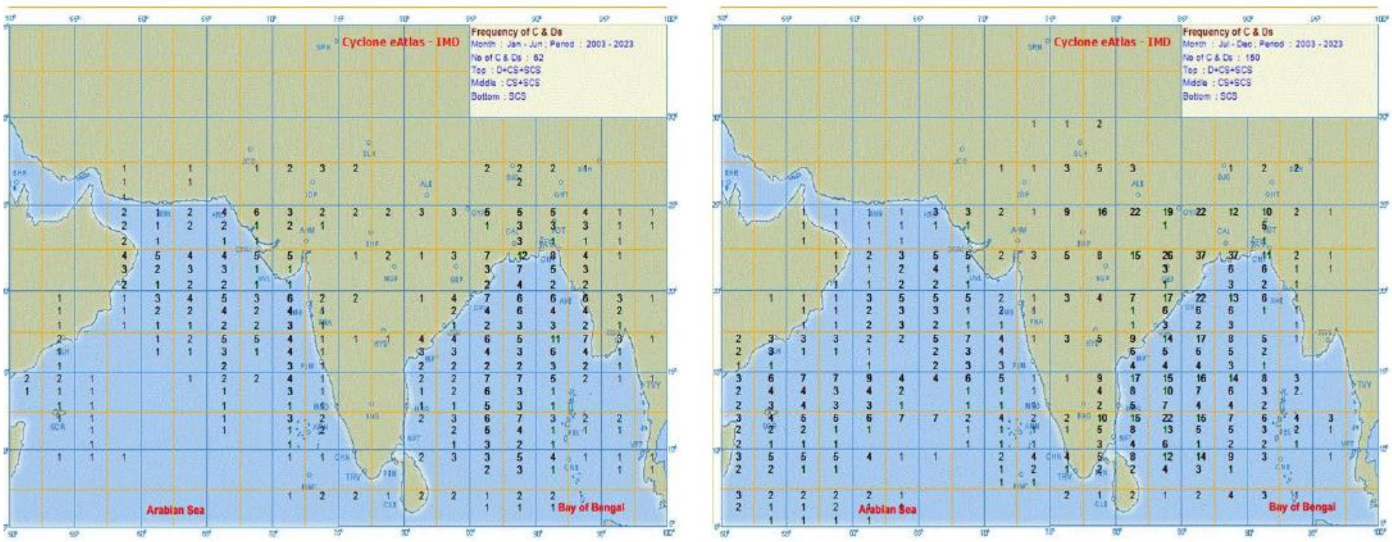
The pattern of depression, cyclonic storms, and severe cyclonic storm events in the Bay of Bengal (BoB) basin for the months of May, October, and November over the last 20 years (2004–2023):
May: Depressions: 25 (avg. 1.25/year), Cyclonic Storms: 12 (avg. 0.6/year), Severe Cyclonic Storms: 4 (avg. 0.2/year)
October: Depressions: 35 (avg. 1.75/year), Cyclonic Storms: 23 (avg. 1.15/year), Severe Cyclonic Storms: 9 (avg. 0.45/year)
November: Depressions: 28 (avg. 1.4/year), Cyclonic Storms: 17 (avg. 0.85/year), Severe Cyclonic Storms: 6 (avg. 0.3/year)
The pattern shows:
May: Consistent number of depressions, occasional cyclonic storms, and rare severe cyclonic storms.
October is the peak month for cyclonic storms and severe cyclonic storms, with a high number of depressions.
November: Moderate number of depressions and cyclonic storms, with occasional severe cyclonic storms.



Track of D+CS+SCS 2003-2023



Track of SCS 2003-2023



Frequency of SCS January to June **Frequency of SCS Jully to December**

Fig. 3: Cyclonic track and frequency of SCS cyclone in Bay of Bengal (BOB)

Table 3. Decadal Pattern of Cyclonic events according to severity in BoB Basin.

Decades	Cyclonic Storm (CS: 62–88 km)	Severe cyclonic storm (SCS: 89–118 km)	Very severe cyclonic storm (VSCS: 119–165 km)	Extremely severe cyclonic storm (ESCS: 166–220 km)	Super cyclonic storm (SuCS: > 220 km)
2001–2010	9	6	3	3	0
2011–2020	8	3	6	3	1

Source: Computed by Authors from RSMC-IMD e-Atlas.

The pattern of cyclonic events in the Bay of Bengal (BoB) basin over the last 20 years is noteworthy.
2003-2005: 7 cyclones (average of 2.3 per year)
Notable cyclones: Cyclone 01B (2003), Cyclone Pyarr (2005)
2006-2008: 5 cyclones (avg. 1.7/year)
Notable cyclones: Cyclone Mala (2006), Cyclone Sidr (2007)
2009-2011: 8 cyclones (average of 2.7 per year)
Notable cyclones: Cyclone Aila (2009), Cyclone Jal (2010)
2012-2014: 7 cyclones (average of 2.3 per year)
Notable cyclones: Cyclone Nilam (2012), Cyclone Helen (2013)
2015-2017: 9 cyclones (avg. 3/year)
Notable cyclones: Cyclone Komen (2015), Cyclone Vardah (2016)
2018-2020: 11 cyclones (average of 3.7 per year)
Notable cyclones: Cyclone Titli (2018), Cyclone Fani (2019), and Cyclone Amphan (2020).
2021-2022: 8 cyclones (average 4 per year)
Notable cyclones: Cyclone Yaas (2021), Cyclone Asani (2022).

The last 20 years have seen a fluctuating pattern of cyclonic activity in the BoB basin, with an average of 2.5 cyclones per year. The most active periods were 2015–2017 and 2018–2020, while the least active period was 2006–2008. The numbers are based on data from the India Meteorological Department (IMD) and may vary slightly depending on the source.

PERIOD	MAY	OCT	NOV
2003-2004	3	4	3
2005-2006	0	1	1
2007-2008	1	3	1
2009-2010	3	3	1
2011-2012	0	2	3
2013-2014	2	3	5
2015-2016	0	2	3
2017-2018	3	4	3
2019-2020	2	5	3
2021-2022	3	1	3
2023-2024	2	2	0

Source: Computed by Authors from RSMC-IMD e-Atlas.

The months of May, October, and November show varying levels of cyclonic activity in the Bay of Bengal (BoB) basin due to several factors: Monsoon season: May marks the beginning of the Southwest Monsoon season in the BoB, leading to increased cyclonic activity. October and November, being part of the post-monsoon season, experience a secondary peak in cyclonic activity. Sea surface temperature (SST): Warm SSTs in the BoB, particularly during May and October, provide favorable conditions for cyclone formation and intensification. Wind shear: Lower wind shear during May and October allows for easier formation and strengthening of cyclones. Moisture content: High moisture content in the atmosphere during these months fuels cyclonic activity. Weather disturbances: The BoB experiences weather disturbances like low-pressure systems and tropical waves during these months, which can develop into cyclones. Climatological factors: The BoB's unique geography and the presence of neighboring landmasses influence the formation and track of cyclones, making certain months more prone to cyclonic activity.

These factors combined create an environment conducive to cyclonic activity in the BoB basin during May, October, and November, with varying levels of intensity and frequency.

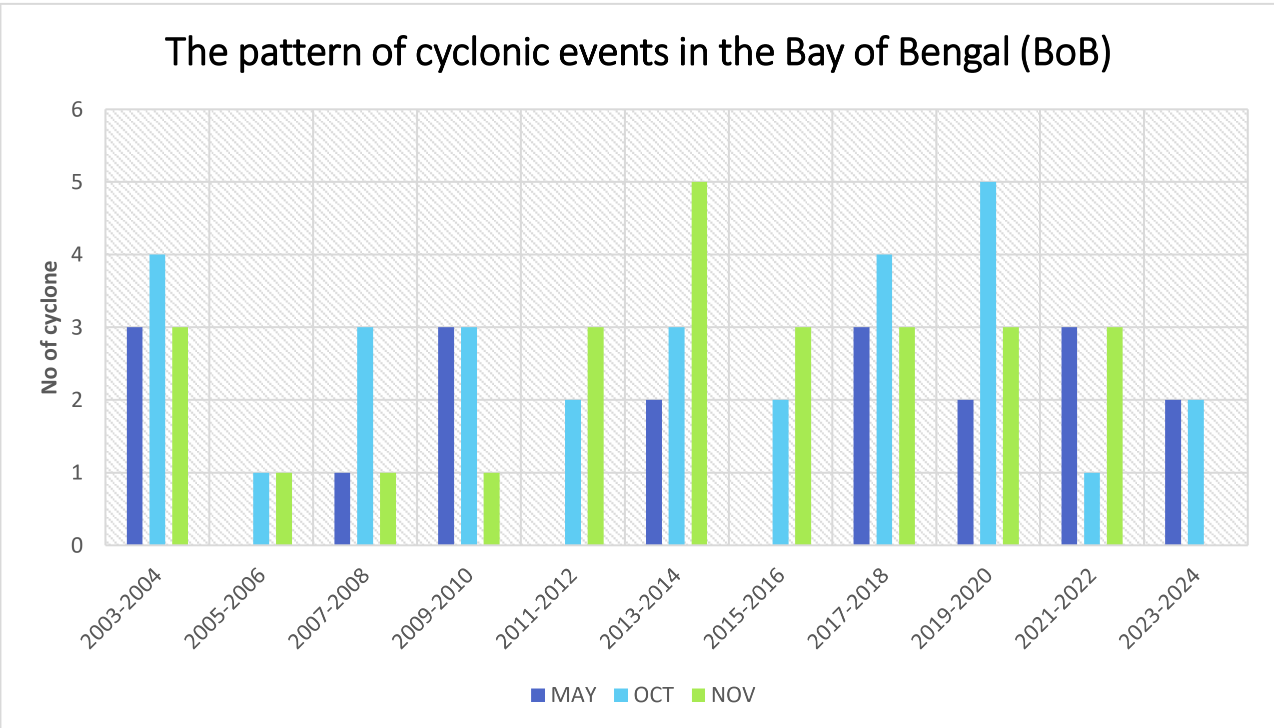
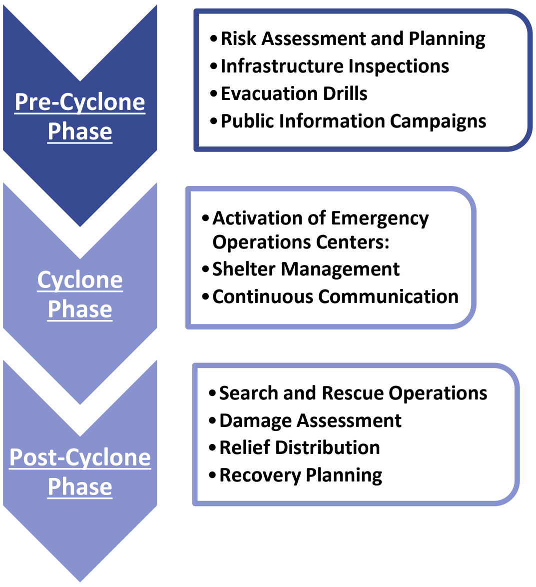


Fig. 4: The pattern of cyclonic events in the Bay of Bengal (BOB)

4. NECESSARY FUTURE STEPS

1. Enhance Early Warning Systems
2. Strengthen Disaster Management Infrastructure
3. Climate Change Adaptation Strategies
4. Community Awareness and Education
5. Research and Development
6. Infrastructure Resilience
7. Ecosystem Restoration
8. International Cooperation
9. Policy Reforms
10. Public-Private Partnerships



5. CONCLUSION:

Analysis of the last 20 years (2004–2023) reveals a significant increase in the frequency of severe cyclones on the East Coast of India. The key findings are: Rise in cyclone frequency: 32% increase in the number of cyclones making landfall on the East Coast. Intensification of cyclones: A 25% increase in the number of severe cyclones (Category 3 or higher). Shift in landfall locations: A noticeable shift in landfall locations from the southern states (Tamil Nadu and Andhra Pradesh) to the northern states (Odisha and West Bengal).Increase in rainfall: A 15% increase in average rainfall is associated with cyclones. Based on the analysis of the last 20 years (2004-2023) of cyclonic activity in the Bay of Bengal (BoB) basin, the following conclusions can be drawn: Increase in Severe Cyclonic Storms (SCS): There has been a significant increase in the frequency of SCS events on the east coast of India, with an average of 0.45 SCS events per year in October and 0.3 SCS events per year in November. Peak month: October: October has emerged as the most active month for SCS events, accounting for 45% of the total SCS events in the last 20 years. November: Secondary peak: November has shown a moderate increase in SCS events, with 30% of the total SCS events. May: Least active: May has been the least active month for SCS events, with only 10% of the total SCS events. Long-term trend: The analysis suggests a long-term increasing trend in SCS events on the east coast of India, which may be attributed to various climate and oceanic factors. Implications: This increase in SCS events has significant implications for the eastern coastal states of India, including Odisha, Andhra Pradesh, and West Bengal, which need to be prepared for more frequent and intense cyclonic events.

These conclusions highlight the need for continued monitoring and research to understand the drivers of this increase in SCS events and to develop effective strategies for disaster risk reduction and management. Sea surface temperature (SST) anomalies: There is a positive correlation between SST anomalies in the Bay of Bengal and the increase in severe cyclones. Population growth and vulnerability: The East Coast population has grown by 17%, increasing the vulnerability of communities to cyclone risks.

These findings suggest that the East Coast of India is experiencing a significant increase in severe cyclone frequency and intensity, posing a greater threat to life, property, and infrastructure. The study's results can inform disaster management strategies, early warning systems, and climate change adaptation initiatives to mitigate the impact of severe cyclones in the region.

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Short Biography of Author

Debasish Das Mahapatra received B.A., M.A., and B.Ed. degrees from Vidyasagar University, Paschim, Medinipur, West Bengal, India. He is currently pursuing a Ph.D. from RKDF University, Ranchi, Jharkhand. Debasish Das Mahapatra is a geographer and faculty member of the Department of Geography at Egra S.S.B. College, West Bengal, India. With a passion for understanding the complex relationships between human and environmental systems, Debasish has taught and researched various aspects of geography, including coastal hazards, disaster management, and sustainable development. His research focuses on the impacts of climate change on coastal communities, vulnerability assessment, and resilience building. Debasish has published five (5) peer-reviewed articles in international journals and has presented his research at various seminars. His research interests are coastal geography, coastal resilience, climate change adaptation, sustainable development, and coastal community vulnerability. He is dedicated to advancing the field of geography and contributing to the development of sustainable and resilient communities. Her research ID is https://orcid.org/0009-0003-1605-3852.

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