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Characteristics of Cyclonic Disturbance on India and their Impact Analysis on Human and Economic Losses

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Abstract

This paper explores the features of cyclonic disturbances in the North Indian Ocean (NIO) by utilizing data from 1990 to 2022. It investigates the occurrence rate of these disturbances and their effects on human and economic losses throughout the mentioned period. The analysis demonstrates a rising trend in cyclonic disturbances in the NIO. While there has been a slight decline in cyclonic disturbance-related fatalities since 2015, there has been a considerable increase in economic losses. These findings can be attributed to enhanced government initiatives in disaster prevention and mitigation in recent years and rapid economic growth in regions prone to CDs. The study sheds light on the significance of addressing the impact of CDs on both human lives and economic stability in the NIO region.

Keywords: *Cyclonic disturbance, North Indian Ocean, Impact, Characteristics.*

Resumen

En este artículo se analizan las características de los ciclones tropicales en el océano Índico septentrional (OIN) utilizando datos de 1990 a 2022. Se investiga la tasa de ocurrencia de estos ciclones tropicales y sus efectos en las pérdidas humanas y económicas durante el período mencionado. El análisis demuestra una tendencia al alza de los ciclones tropicales en el OIN. Si bien ha habido una ligera disminución de las muertes relacionadas con los ciclones tropicales desde 2015, ha habido un aumento considerable de las pérdidas económicas. Estos hallazgos pueden atribuirse a las iniciativas gubernamentales mejoradas en materia de prevención y mitigación de desastres en los últimos años y al rápido crecimiento económico en las regiones propensas a los ciclones tropicales. El estudio arroja luz sobre la importancia de abordar el impacto de los ciclones tropicales tanto en las vidas humanas como en la estabilidad económica en la región del OIN.

Palabras claves: *Perturbación ciclónica, Océano Índico del Norte, Impacto, Características.*

1 Introduction

In the past years, the occurrence of natural disasters has been increasingly frequent globally, leading to substantial loss of life and property. Due to its position in the context of global climate change and its varying levels of economic development, India is significantly affected by many natural disasters. Consequently, the significance of effectively preventing and responding to these disasters has heightened. India experiences diverse natural disasters, widely dispersed throughout the country, occurring frequently and resulting in significant losses. The impacts of these disasters vary in severity across all provinces, with over 13 states and Union Territories and 33% of the population residing in regions susceptible to severe natural disasters. Therefore, accurate Cyclonic disturbances' intensity, path, and size forecasting is paramount.

The key natural disasters affecting India encompass Cyclonic disturbances (when the cyclonic disturbances exceed the minimum threshold of 34 knots (18 ms-1), they are universally known as "Tropical cyclones" or simply "Cyclone," as defined by the World Meteorological Organization (WMO) Programme, W.M.O.T.C. 1999), droughts, rainstorms, gales and hailstorms, thunderstorms, heat waves, extremely low temperatures, and snowstorms. Among these, cyclonic disturbances (CDs) are devastating, leading to substantial loss of life and economic ramifications. With the projected global warming trends, the duration and intensity of CDs are expected to escalate, exacerbating their impact (Wu, L. et al 2005, Changnon, S.A. 2009). India Meteorological Department (IMD) classifies CDs into eight categories based on the wind speed of the CD. Table 1 (adapted from Table 1 of the referenced paper (Yadav, M., Das, L. 2023) presents the specifications for each category.

Table 1: Different phases of CDs according to the IMD classification.

Phases	T Number	Maximum Wind Speed
Low-pressure area (WML)	T1.0	< 17 kts
Depression (D)	T1.5	17-27 kts
Deep Depression (DD)	T2.0	28-33 kts
Cyclonic Storm (CS)	T2.5-T3.0	34-47 kts
Severe CS (SCS)	T3.5	48-63 kts
Very Severe CS (VSCS)	T4.0-T4.5	64-89 kts
Extremely Severe CS (ESCS)	T5.0-T6.0	90-119 kts
Super CS	T6.5 -T8.0	> 120 kts

The hazards posed by CDs stem from four primary factors: wind, storm surges, intensity, and rainfall (Yadav, M., Das, L. 2024). While storm surges primarily affect low- lying coastal areas, high winds, and heavy rainfall can extend well inland (Zandbergen, P.A. 2009). The main CD season in India is from October to December. While there is no observational evidence suggesting an increase in the frequency or intensity of CDs, the impact of these events has amplified due to population growth, coastal infrastructure development, and societal vulnerabilities in the tropical Atlantic and Indian Oceans (Changnon, S.A. 2009, Chittibabu, P. et al 2004). However, limited knowledge exists regarding CDs and their damage to India. This research aimed to analyze the occurrence rate of CDs impacting India and assess their impacts on the country. This was achieved by investigating the occurrences of CD-related disasters and the resultant damage using recent statistical and meteorological data. Additionally, an investigation into the temporal and spatial patterns of economic losses and casualties were conducted to identify potential trends in CD generation within the NIO region.

The structure of this paper includes Section 2, which describes the data and methods used, and Section 3, which presents discussions on various aspects, such as annual and seasonal variations on the generation of CDs. Section 4 discusses the impact of CDs on India's socio-economic conditions, and Section 5 concludes the paper.

2 Data and Methods

2.1 Data

The IMD compiles an annual report (IMD) through its Regional Specialized Meteorological Centre (RSMC) over the NIO region. This report contains crucial data regarding CD and serves as a valuable resource. It includes information such as the timing and location of CD generation and landfall, the tracks followed by the CD, the air pressure at the CD's center, the intensity and duration of the CD, landing sites, associated wind, rainfall intensities, Casualty, infrastructure losses, and agriculture losses. The IMD collects comprehensive monitoring data on CDs in the NIO region annually. Furthermore, they meticulously record the extent of damage caused by these CDs, allowing for a comprehensive understanding of their impact on various aspects.

Since 1990, the IMD has consistently prepared and published an annual report through its RSMC over NIO. This report provides comprehensive documentation on various aspects, including the affected population, impacted areas and agricultural regions, casualties, damaged and destroyed houses, impaired infrastructure, direct economic losses, and agricultural economic losses resulting from meteorological disasters. These valuable datasets cover the period from 1990 to 2022, offering a wealth of information for researchers and policymakers who aim to analyze and mitigate the impact of cyclonic disturbances in the NIO region (IMD).

2.2 Methods

This study aims to thoroughly investigate the societal impacts caused by natural disasters originating from NIOs. The primary objective is to assess the direct economic losses (which include house damage and agricultural losses) and human casualties resulting from these events. Utilizing statistical methods, namely correlation, R-squared value, and linearly fitted equation, the study analyzes a dataset covering 32 years, allowing for a comprehensive approach that compares observations across different years. This approach leads to a deeper understanding of the patterns and trends concerning the social consequences of natural disasters over the studied time frame. In summary, through this in-depth investigation, the study aims to assess the societal impacts of CDs arising from NIOs and gain valuable insights into their long-term effects.

3 Results

3.1 Changes in the generation of Cyclonic Disturbances over the NIO over 32 years

The NIO basin, known for its dynamic nature among the seven global basins, has exhibited significant activity, as shown in Table 2. From 1990 to 2022, 297 CDs were formed in this region, producing an average of 9 yearly CDs. The year 2022 witnessed the highest number of CDs, with 15 occurrences, while 2012 had the lowest number, with only four instances. Figure 1 visually represents the variations in CD numbers in the NIO from 1990 to 2022.

The average annual CD count in the NIO in the past few decades was 7 in the 1990s, 8 in the 2000s and 2010s. However, in the 2020s, there was a slightly higher average of 11 CDs. This suggests an upward trend in the number of CDs generated in the NIO, emphasizing the notable changes observed in recent years.

The numbers have shown fluctuations over time, and the current decade indicates an increase in CD occurrence compared to previous decades.

Table 2: From 1990 to 2022, many CDs were formed over the NIO. BB stands for Bay of Bengal, AS for Arabian Sea, LD for Land.

Year	Basin	D	DD	CS	SCS	VSCS	ESCS	SuCS	Total
1990	BB	6	2	0	2	0	0	0	10
	AS	0	0	0	0	0	0	0	0
	LD	0	0	0	0	0	0	0	0
	Total								10
1991	BB	4	1	1	0	0	0	1	7
	AS	0	1	0	0	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								8
1992	BB	0	3	3	1	0	0	0	7
	AS	0	1	3	0	0	0	0	4
	LD	0	0	0	0	0	0	0	0
	Total								11
1993	BB	0	2	1	0	0	0	0	3
	AS	1	0	0	1	0	0	0	2
	LD	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	5
1994	BB	1	2	0	1	0	0	0	4
	AS	0	0	0	1	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								5
1995	BB	1	4	0	2	0	0	0	7
	AS	0	0	1	0	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								8

Year	Basin	D	DD	CS	SCS	VSCS	ESCS	SuCS	Total
1997	BB	1	4	1	1	1	0	0	8
	AS	1	0	0	0	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								9
1998	BB	0	3	0	1	2	0	0	6
	AS	0	1	1	1	1	0	0	4
	LD	1	0	0	0	0	0	0	1
	Total								11
1999	BB	2	2	1	0	1	0	1	7
	AS	0	0	0	0	1	0	0	1
	LD	1	0	0	0	0	0	0	1
	Total								9
2000	BB	1	1	2	0	2	0	0	6
	AS	0	0	0	0	0	0	0	0
	LD	1	0	0	0	0	0	0	1
	Total								7
2001	BB	2	0	1	0	0	0	0	3
	AS	0	0	2	0	1	0	0	3
	LD	0	0	0	0	0	0	0	0
	Total								6
2002	BB	1	1	2	1	0	0	0	5
	AS	0	0	0	0	0	0	0	0
	LD	0	0	0	0	0	0	0	0
	Total								5
2003	BB	2	2	0	1	1	0	0	6
	AS	0	0	0	1	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								7
2004	BB	2	0	0	0	1	0	0	3
	AS	0	2	0	3	0	0	0	5
	LD	2	0	0	0	0	0	0	2
	Total								10
2005	BB	2	3	4	0	0	0	0	9
	AS	2	0	0	0	0	0	0	2
	LD	1	0	0	0	0	0	0	1
	Total								12
2006	BB	5	2	1	0	1	0	0	9
	AS	0	1	0	1	0	0	0	2
	LD	1	0	0	0	0	0	0	1
	Total								12
2007	BB	0	3	4	1	0	1	0	9
	AS	0	1	1	0	0	0	1	3
	LD	0	0	0	0	0	0	0	0
	Total								12
2008	BB	1	2	3	0	1	0	0	7
	AS	1	1	0	0	0	0	0	2
	LD	1	0	0	0	0	0	0	1
	Total								10
2009	BB	0	2	2	1	0	0	0	5
	AS	2	0	1	0	0	0	0	3
	LD	0	0	0	0	0	0	0	0
	Total								8

Year	**Basin**	**D**	**DD**	**CS**	**SCS**	**VSCS**	**ESCS**	**SuCS**	**Total**
2010	BB	2	1	0	2	1	0	0	6
	AS	0	0	1	0	1	0	0	2
	LD	0	0	0	0	0	0	0	0
	Total								8
2011	BB	2	2	0	0	1	0	0	5
	AS	1	2	1	0	0	0	0	4
	LD	1	0	0	0	0	0	0	1
	Total								10
2012	BB	0	2	1	0	0	0	0	3
	AS	0	0	1	0	0	0	0	1
	LD	0	0	0	0	0	0	0	0
	Total								4
2013	BB	3	0	1	1	3	0	0	8
	AS	0	1	0	0	0	0	0	1
	LD	1	0	0	0	0	0	0	1
	Total								10
2014	BB	2	2	0	0	1	0	0	5
	AS	0	0	1	0	1	0	0	2
	LD1	0	0	0	0	0	0	0	1
	Total								8
2015	BB	1	1	1	0	0	0	0	3
	AS	0	2	1	0	0	2	0	5
	LD	2	2	0	0	0	0	0	4
	Total								12
2016	BB	1	2	3	0	1	0	0	7
	AS	2	0	0	0	0	0	0	2
	LD	1	0	0	0	0	0	0	0
	Total								10
2017	BB	4	1	1	1	1	0	0	8
	AS	0	0	0	0	0	0	0	0
	LD	2	0	0	0	0	0	0	2
	Total								10
2018	BB	3	2	1	2	1	0	0	9
	AS	1	0	0	0	1	2	0	4
	LD	1	0	0	0	0	0	0	1
	Total								14
2019	BB	0	1	1	0	1	1	0	4
	AS	2	1	1	0	2	1	1	8
	LD	0	0	0	0	0	0	0	0
	Total								12
2020	BB	1	1	1	0	1	0	1	5
	AS	2	0	0	1	1	0	0	4
	LD	0	0	0	0	0	0	0	0
	Total								9
2021	BB	3	1	2	0	1	0	0	7
	AS	1	0	0	1	0	1	0	3
	LD	0	0	0	0	0	0	0	0
	Total								10
2022	BB	4	3	1	2	0	0	0	10
	AS	2	1	0	0	0	0	0	3
	LD	2	0	0	0	0	0	0	2
	Total								15

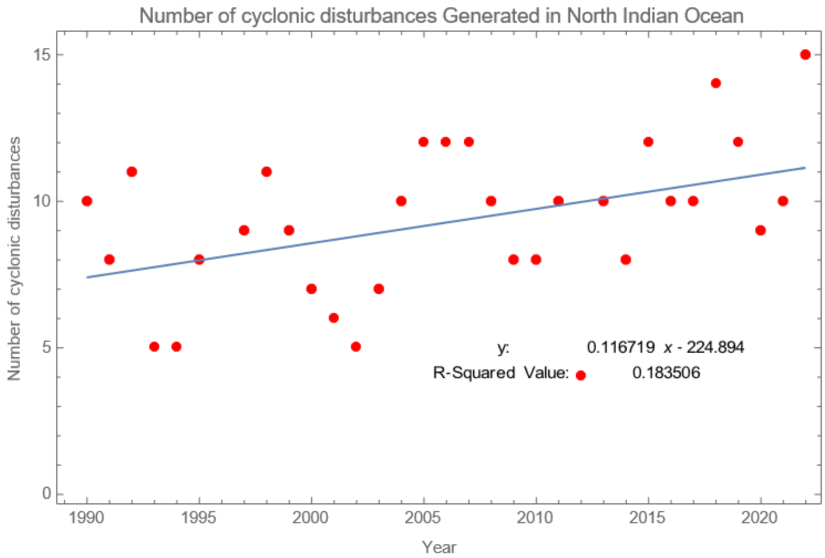

Figure 1: The occurrence frequency of CDs generated in the NIO between 1990 and 2022 is depicted by the red dots, while the solid blue line represents the trend

3.2 Seasonally trend in the generation of Cyclonic Disturbance over the NIO

Table 3 presents insights on the average distribution of CDs generated during different months. The peak month for CD generation is November, with an average of 18.28 occurrences. Following closely behind is October, with an average of 16.79 CDs. May and June both exhibit an average of 11.56 CDs. On the other hand, February and March have the lowest average numbers of generated CDs, with a value of 0.7.

Of notable significance are October, November, and December, which contributed to nearly half of all CDs formed in the NIO. Weather conditions in these months play a crucial role in CD generation, emphasizing the need for heightened vigilance and preparedness measures to mitigate potential impacts. In contrast, January, February, and March experience infrequent occurrences of CDs.

Table 3: The average count of CDs generated in various months.

Month	Generated CD (%)
January	1.11
February	0.7
March	0.7
April	1.49
May	11.56
June	11.56
July	7.46
August	11.19
September	7.83
October	16.79
November	18.28
December	11.19

3.3 Spatial characteristics of Cyclonic Disturbances making landfall

CDs primarily make landfall along the eastern coast of India, especially in states like Odisha, Andhra Pradesh, and West Bengal, which are situated along the Bay of Bengal. However, although less frequently impacted, the western coast of India, encompassing states such as Gujarat, Maharashtra, and Goa, also experiences the landfall of CDs originating from the Arabian Sea. The Bay of Bengal is acknowledged as one of the six major global regions susceptible to CDs, with a considerable occurrence of destructive CDs emanating from this specific area (Knapp, et al 2010, Jangir et al 2020). Throughout history, these CDs have primarily manifested between October and November. A notable issue within the Bay of Bengal is the escalating sea temperatures and concurrent occurrences of marine heat waves (Gupta et al 2023, Rathore, S. et al 2022). These factors play a pivotal role in enhancing the intensity of CDs as they near coastal zones, thereby exacerbating the potential risks and repercussions associated with these events.

4 Discussion

4.1 Losses due to Cyclonic Disturbance

CDs, being frequent natural calamities, inflict significant damage. The extent of the destruction resulting from typhoon disasters is contingent not only on the strength of the typhoon system and its mechanisms but also on the economic advancement of the impacted regions and the density of their populations.

India ranks among the nations most severely impacted by tropical cyclones. The coastal region of India holds paramount economic significance, marked by a high level of economic activity and densely concentrated human population. India's maritime sector, constituting 95% of its commerce via transportation, is pivotal, contributing an estimated 4% to the nation's Gross Domestic Product (GDP). The coastal areas have become exceedingly susceptible to natural calamities due to the low-lying terrain, extensive construction, infrastructure development, and population density. In the context of global climate change and rapid urban expansion, the escalating incidence of natural disasters, coupled with the growing vulnerability of coastal regions, is poised to amplify both the frequency and intensity of potentially colossal socio-economic losses.

4.2 Casualty analysis

By utilizing historical data from 1990 to 2022, we can examine the cumulative number of casualties caused by CD disasters over a 32-year span, which totaled 101,021 individuals. This equates to around 3,157 casualties per year attributed to these events. The data reveals a slight decrease in CD casualties since 2015, as shown in Figure 2. However, it is crucial to acknowledge the existence of data gaps between 1990 and 2022, which may affect the accuracy and comprehensive understanding of the situation. A negative correlation exists between the occurrence of CDs in the NIO and the resulting casualties. The decline in casualties can be attributed to the government's prioritization of people's well-being and their intensified disaster prevention and mitigation efforts since the 2010s. These efforts aim to minimize the loss of human life during natural disasters, emphasizing the significance of reducing such casualties.

The year 2008 witnessed the highest number of casualties, with 84,113 fatalities, followed by 10,539 deaths in 1999 and 1,290 deaths in 1998. Particularly, 2008 is the deadliest since 1990, with 10 CDs occurring in the NIO. Among these incidents, the Very Severe Cyclonic Storm "NARGIS" had the most devastating impact, claiming the lives of 84,000 individuals. NARGIS formed over the Bay of Bengal from April 27 to May 3, 2008, causing extensive destruction, including the sinking of vessels and destruction of houses, bridges, roads, and other infrastructure. Severe flooding, landslides, and mudslides were also triggered. Remarkably, NARGIS maintained its Very Severe Cyclonic Storm intensity for approximately 12 hours even after making landfall. Table 4 summarizes the top five deadliest CDs recorded between 1990 and 2022. These five events account for approximately 95% of the total casualties associated with CDs during the specified period.

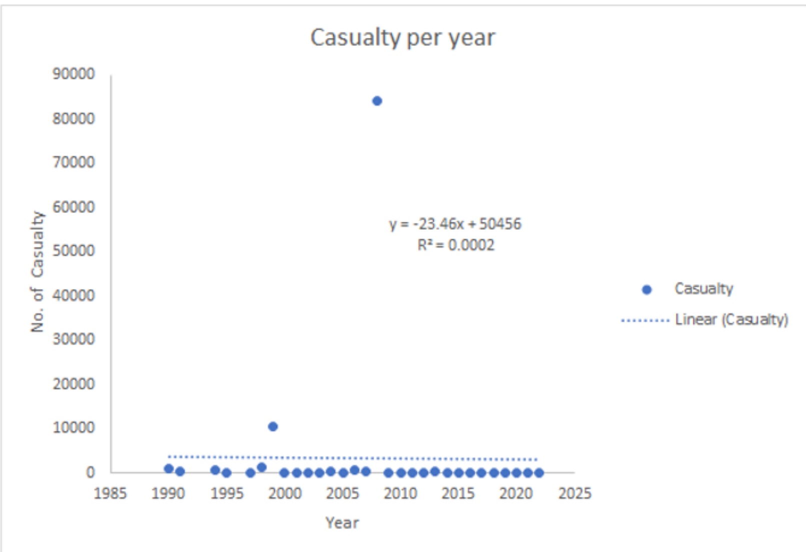

Figure 2: The casualties caused by CDs in India from 1990 to 2022 are represented by data points (dot), and a dashed line depicts the trend

Table 4: Five most catastrophic CDs between 1990 and 2022.

Rank	Name	Year	Category	Casualty
1	Nargis	2008	VSCS	84,000
2	October	1999	SuCS	9887
3	June 1998	1998	VSCS	1173
4	May 1990	1990	SuCS	928
5	May	1999	VSCS	454

4.3 Analysis of Economic Loss

Economic losses from CDs in India can be broadly categorized into direct and indirect losses.

1. Direct Economic loss:

• Infrastructure Damage: CDs can cause severe damage to critical infrastructure such as roads, bridges, power grids, and communication networks. The cost of repairing and rebuilding infrastructure can be substantial.

• Property Damage: Cyclonic winds and storm surges can destroy or severely damage residential, commercial, and industrial buildings. The financial burden of rebuilding or repairing properties contributes to economic losses.

• Human Casualties: Cyclonic rainfall, cyclonic floods, and storm surges can cause human casualties, resulting in profound sorrow and suffering for affected communities while triggering significant economic ramifications. The consequences of lost human lives extend beyond a CD's immediate aftermath, impacting various economic aspects. This includes reduced investment, diminished tourism, and decreased business activities in the affected regions. As a result, the overall economic growth of the area may be hindered, necessitating substantial resources for long-term recovery and reconstruction efforts. The loss of human lives not only has a devastating emotional impact but also carries long-lasting economic implications for the affected region.

• Disrupted Economic Activities: CDs can disrupt economic activities, particularly in sectors such as agriculture, fisheries, tourism, and transportation. Crop and livestock losses, disruption of supply chains, reduced tourist arrivals, and halted trade can all have significant economic consequences.

2. Indirect Economic loss:

• Loss of Productivity: Disrupted economic activities and damaged infrastructure can lead to a loss of productivity in various sectors. Businesses may struggle to operate, reducing production, employment, and income generation.

• Income Loss: CD-related disruptions can result in job losses, reduced working hours, and income reduction for individuals and businesses. This loss of income can have long-term implications for individuals and the overall economy.

• Increased Expenditure: Governments often bear the financial burden of CD response and recovery efforts. Increased expenditure on emergency response, relief measures, and infrastructure rehabilitation can strain public finances and divert resources from other development priorities.

This study's primary objective is to analyze direct economic losses, specifically those incurred in agriculture, and the damage caused to infrastructure, such as houses. We solely focus on these aspects, investigating the extent of their economic impact. Our analysis aims to comprehensively understand the direct economic losses (agriculture and infrastructure damage), shedding light on the overall consequences.

4.3.1 Demographical Analysis of Damaged House

Over 32 years, from 1990 to 2022, a thorough examination of historical data highlights a significant finding: the total count of houses damaged due to CD disasters has reached an astonishing figure of 5,098,257. On an annual average, approximately 159,320 houses experienced the consequences of these disasters. Data analysis reveals a gradual increase in the number of damaged houses, indicating the escalating impact of these disturbances (refer to Figure 3). How- ever, it is important to note that data gaps between 1990 and 2022 might influence our overall accuracy and comprehensive understanding of the situation. Moreover, a positive correlation between CD disasters over the NIO and the number of houses affected is observed. Notably, the highest occurrence of damaged houses was recorded in 1999 (1,659,356), followed by 2008 (745,764) and 2019 (621,732).

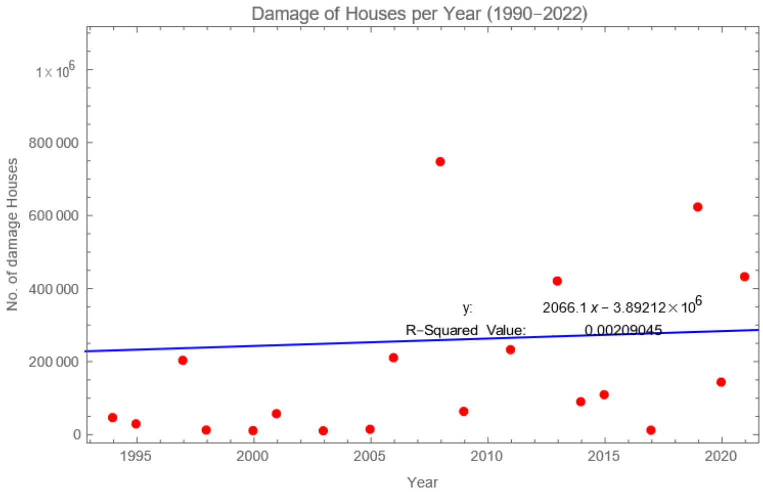

Figure 3: Number of damaged houses due to CD between 1990 and 2022 is depicted by the red dots, while the solid blue line represents the trend

4.3.2 Demographical Analysis of Agriculture Loss

Based on a thorough analysis of historical data from 1990 to 2022, it is evident that disasters caused by CDs have had a significant and detrimental effect on agriculture, resulting in substantial losses within the sector. The cumulative data over 32 years reveals that these disturbances have affected a staggering 8,886,447 hectares of agricultural land, averaging approximately 277,701 hectares per year. A noteworthy observation is the downward trend in agri-cultural losses, indicating a progressive increase in the magnitude of these disruptions (see Fig. 4).

However, it is important to acknowledge the presence of data gaps within the 1990-2022 timeframe, which may impact the overall accuracy and our comprehensive understanding of the situation. Despite this limitation, it is apparent that the incidence of CDs in the North Indian Ocean (NIO) region correlates negatively with agricultural loss. The highest agricultural losses were recorded in 1990, affecting 1,843,000 hectares, followed by 1995 with 1,253,653 hectares, and 2008 with 771,458 hectares.

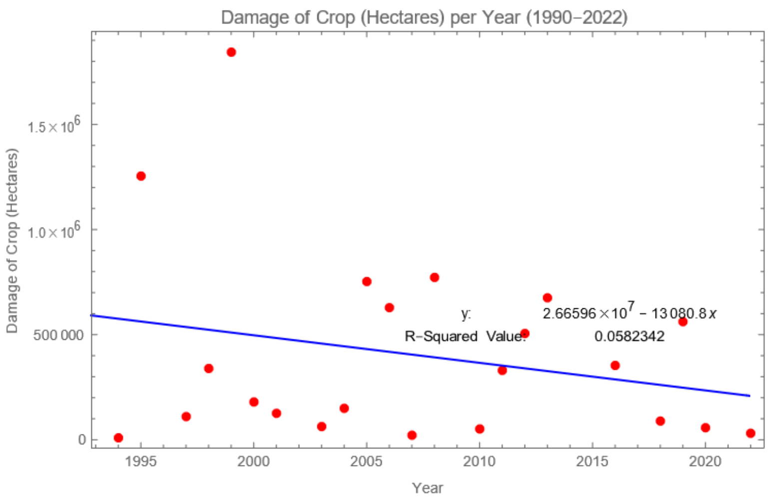

Figure 4: Damage of Crop (Hectares) due to CD between 1990 and 2022 is depicted by the red dots, while the solid blue line represents the trend

As mentioned earlier, it is crucial to recognize that factors such as agriculture loss and infrastructure damage play a pivotal role in influencing the economic consequences of CDs. Notably, the trends observed in agricultural and infrastructure losses suggest an overall upward economic trend from 1990 to 2022. Nevertheless, it is imperative to note the existence of data gaps within the available economic records during this period, which restricts our ability to obtain a complete and accurate understanding of the situation. These data gaps challenge our comprehensive assessment of the overall economic impact caused by the CDs.

5 Conclusions

The IMD has published the annual report (IMD) from 1990 to 2022, providing valuable data on CDs in the NIO. This data encompasses important details such as the timing and location of CD generation and landfall, the tracks followed by the CD, the air pressure at the CD's center, the intensity and duration of the CD, landing sites, associated wind, rainfall intensities, casualty, infrastructure losses, and agriculture losses. It serves as a crucial foundation for analyzing various characteristics associated with CDs. For 32 years, 297 CDs have been documented, averaging around nine disturbances per year. Notably, there has been a significant increase in the number of CDs generated during this period. However, it is important to acknowledge that there are data gaps within the timeframe of 1990 to 2022, which may impact the overall accuracy and comprehension of the situation. To assess the impacts of CDs, this study specifically focuses on the direct economic losses, including agriculture and infrastructure loss (specifically houses), and casualties recorded between 1990 and 2022. Historical data reveals that there were a total of 101,021 casualties recorded for 32 years, averaging approximately 3,157 casualties per year from CDs making landfall. Interestingly, there appears to be a slight decrease in casualties since 2015. Among the CDs analyzed, the five most devastating ones accounted for approximately 95% of the total casualties during the studied period. Furthermore, the data analysis shows a slight upward trend in economic losses during the study period. These findings can be attributed to the proactive measures taken by the countries' governments surrounding the NIO in recent years, as they have focused on enhancing natural disaster prevention and mitigation efforts.

6 References

Changnon, S.A.: Characteristics of severe atlantic hurricanes in the united states: 1949–2006. Natural Hazards 48(3), 329–337 (2009).

Chittibabu, P., Dube, S., Macnabb, J., Murty, T., Rao, A., Mohanty, U., Sinha, P.: Mitigation of flooding and cyclone hazard in orissa, india. Natural Hazards 31, 455–485 (2004).

Gupta, H., Sil, S., Gangopadhyay, A., Gawarkiewicz, G.: Observed surface and subsurface marine heat waves in the bay of bengal from in-situ and high-resolution satellite data. Climate Dynamics (2023).

IMD: Report on cyclonic disturbances over the north indian ocean. RSMC-Tropical Cyclones, New Delhi (Accessed: 10 May 2023).

Jangir, B., Swain, D., Ghose, S.: Influence of eddies and tropical cyclone heat potential on intensity changes of tropical cyclones in the north indian ocean. Advances in Space Research 68(2), 773–786 (2021).

Jangir, B., Swain, D., Ghose, S.K., Goyal, R., Bhaskar, T.U.: Inter- comparison of model, satellite and in situ tropical cyclone heat potential in the north indian ocean. Natural Hazards 102, 557–574 (2020).

Knapp, K.R., Kruk, M.C., Levinson, D.H., Diamond, H.J., Neumann, C.J.: The international best track archive for climate stewardship (ibtracs) unifying tropical cyclone data. Bulletin of the American Meteorological Society 91(3), 363–376 (2010).

Neetu, S., Lengaigne, M., Vincent, E.M., Vialard, J., Madec, G., Samson, G., Ramesh Kumar, M., Durand, F.: Influence of upper-ocean stratifi- cation on tropical cyclone-induced surface cooling in the bay of bengal. Journal of Geophysical Research: Oceans 117(C12) (2012).

Programme, W.M.O.T.C.: Tropical Cyclone Operational Plan for the Bay of Bengal and the Arabian Sea. Secretariat of the World Meteorological Organization, ??? (1999).

Rathore, S., Goyal, R., Jangir, B., Ummenhofer, C.C., Feng, M., Mishra, M.: Interactions between a marine heatwave and tropical cyclone amphan in the bay of bengal in 2020. Frontiers in Climate 4, 861477 (2022).

Wu, L., Wang, B., Geng, S.: Growing typhoon influence on east asia. Geophysical Research Letters 32(18) (2005).

Yadav, M., Das, L.: Analyze the satcon algorithm's capability to estimate tropical storm intensity across the west pacific basin. Journal of Earth System Science 133(2), 79 (2024).

Yadav, M., Das, L.: Detecting tropical cyclone from the basic overview of life cycle of extremely severe cyclonic storm, tauktae. Revista de Climatologıa 23, 150 (2023).

Yadav, M., Das, L.: Formulation and evaluation of the radius of max- imum wind of the tropical cyclones over the north indian ocean basin. Theoretical and Applied Climatology, 1–14 (2024).

Zandbergen, P.A.: Exposure of us counties to atlantic tropical storms and hurricanes, 1851–2003. Natural Hazards 48, 83–99 (2009)