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WHIRLING WIND (CYCLONE) AND THEIR DEVASTATING IMPACT ON SOUTHERN COASTAL AGRICULTURE IN BANGLADESH

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ABSTRACT

Cyclonic storms, often referred to as "Whirling Winds," have a devastating impact on agricultural productivity in the southern coastal districts of Bangladesh. These intense weather systems bring powerful winds and torrential rainfall, which can severely damage crops, erode soil, and devastate farmland. For the farmers in these regions, cyclonic storms represent an ongoing battle to protect their livelihoods and maintain sustainable agricultural practices. The present study has focused on whirling winds and cyclones with regard to the effects on cropland and analysis of losses and farmers' coping mechanisms. This study examines the impact of whirling winds on paddy farming in coastal Bangladesh, analyzing crop damage, economic losses, and adaptation strategies. Data from 120 farmers show that 70% faced significant crop losses, with additional damage to soil fertility and irrigation. 44% rely on debt for recovery, while only 23% have crop insurance. Financial losses range from \$100 to \$1,000, with increased replanting and pest control costs.Regression and risk assessment indicate that larger farms (>5 acres) experience frequent wind damage, while windbreaks moderately reduce losses ($p = 0.019$). However, crop insurance does not significantly lower risk ($\chi^2 = 0.667$, $p = 0.881$). With 60% of farmers at high or critical risk, the study highlights the need for climate-resilient farming, financial aid, and improved disaster preparedness. Policy recommendations include expanding crop insurance, investing in wind-resistant rice, and strengthening early warning systems to protect coastal agriculture.

KEYWORDS

Whirlwind (Cyclone), Agricultural Loss, Coastal Bangladesh, Crop Debt, Disaster Resilience

INTRODUCTION

Background of Cyclone Impact on Agriculture

Cyclones are among the most destructive natural disasters affecting coastal agricultural regions. These intense storms bring heavy rainfall, strong winds, and

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storm surges that significantly damage cropland and disrupt farming activities. Bangladesh, due to its geographic location in the Bay of Bengal, is one of the most cyclone-prone countries in the world (Ali, 1996; Karim & Mimura, 2008). The southern coastal areas of Bangladesh are particularly vulnerable to cyclones, leading to frequent crop failures, soil degradation, and financial instability for farmers (Haque et al., 2012; Paul, 2009). The cyclone affected 4.6 million people across eight districts of Pirojpur, Khulna, Bagerhat, Satkhira, Patuakhali, Barguna, Barishal, and Bhola, causing widespread damage over 62,783 hectares of farmland with estimated crop losses of USD 90.7 million(*FAO Bangladesh Distributes Agriculture and Livestock Inputs to Cyclone Remal and Eastern Flash Floods Affected Farmers | FAO in Bangladesh | Food and Agriculture Organization of the United Nations*, n.d.) The increasing frequency of cyclonic events due to climate change further threatens the long-term sustainability of agriculture in these regions (Ahmed et al., 2016; Rahman et al., 2020).

LITERATUTE REVIEW

The coastal region of Bangladesh is characterized by low-lying floodplains that are highly susceptible to extreme weather events. Cyclones such as Sidr (2007), Aila (2009), Amphan (2020), and Remal (2023) have caused substantial damage to cropland (Chowdhury et al., 2021; Roy et al., 2015). Rising sea levels and increased salinity intrusion further exacerbate agricultural losses (Brander, 2007; Mondal & Salehin, 2017).Extreme weather patterns caused by climate change increase the exposure (Ahmed & Eklund, 2021)of smallholder farmers to agricultural risks (Dasgupta et al., 2018; Hossain et al., 2015). Many farmers in coastal areas are shifting towards salt-resistant crops or alternative livelihoods, indicating a growing adaptation response to recurrent cyclone-induced damages (Khan et al., 2017; Karim et al., 2015).

Impact of Cyclones on Cropland and Soil Fertility

Cyclones directly impact cropland by uprooting plants, causing severe flooding, and introducing saline water into the soil.(Habiba & Abedin, 2024) The immediate consequences of these events include reduced crop yield, loss of arable land, and disruptions in the agricultural supply chain (Rahman & Alam, 2016; Islam et al., 2014).Studies have shown that cyclone-affected areas in Bangladesh experience long-term declines in soil fertility due to saltwater intrusion and erosion of topsoil (Mondal et al., 2020; Sarker et al., 2019). Agricultural recovery in these regions requires extensive soil remediation efforts, which can be financially burdensome for small-scale farmers (Rahman et al., 2018; MoEFCC, 2018).

Economic and Social Implications for Farmers

The economic burden of cyclones is particularly severe for rural farming communities. Loss of crops(*Cyclone Remal: Khulna Agriculture, Fisheries Sectors Suffer 289C Loss*, n.d.) often results in increased debt, as farmers are forced to take high-interest loans to sustain agricultural production (Paul & Routray, 2013; Rahman et al., 2019).Cyclones also contribute to rural poverty and migration, as many farmers leave their land in search of alternative income sources (Haider et al., 2011; Sultana, 2010). Women and marginalized farmers face additional challenges due to limited access to financial resources and government relief programs (Ahmed & Neelormi, 2021; Rahman & Haque, 2016).

Adaptation Strategies and Mitigation Measures

To cope with the increasing risks of cyclones, farmers in the southern coastal areas of Bangladesh are adopting various adaptation measures, including:Cultivating salt-resistant rice varieties (Huq et al., 2015; Dasgupta et al., 2016).Improving water management techniques to reduce soil salinity (Islam et al., 2017; Roy et al., 2020).Implementing agroforestry and organic farming practices (Rahman et al., 2021; Mondal & Salehin, 2017).Utilizing cyclone-resistant storage facilities to protect harvested crops (Kabir et al., 2020; Alam et al., 2021).Government-led initiatives and international collaborations have also played a significant role in promoting climate resilience among coastal farming communities (Ahmed et al., 2022; Khan et al., 2019).

Impact of Whirling Winds on Paddy Cultivation

Windstorms and cyclones are known to cause severe damage to paddy fields by lodging (bending or flattening of crops), uprooting young plants, and increasing vulnerability to secondary hazards such as flooding and soil erosion (Ali & Chowdhury, 2017). Studies by Rahman et al. (2020) show that strong winds during the reproductive stage of paddy significantly reduce grain yield due to physical damage and increased susceptibility to pests and diseases. The loss of standing crops due to high wind speeds is particularly concerning in coastal Bangladesh, where rice is a staple food and primary source of income for farmers.

Economic Consequences of Wind Damage

The economic impact of wind damage on agriculture is substantial, often leading to reduced income for farmers, increased debt burdens, and food insecurity in affected regions. According to Ahmed and Hossain (2019), wind-induced crop losses in Bangladesh cost millions of dollars annually, affecting both smallholder farmers and national food production(*New Age | Frequent Cyclones Hit Agriculture Hard in Coastal Bangladesh*, n.d.). A study by Karim et al. (2021) indicates that many farmers struggle to recover from such losses due to limited access to financial aid and insurance. The economic vulnerability is further exacerbated by poor market conditions, where damaged crops fetch lower prices and farmers receive inadequate compensation for their losses.

Farmer Responses

Farmers employ various strategies to mitigate the impact of strong winds, including planting wind-resistant rice varieties, using windbreaks, and adjusting planting schedules (Islam et al., 2022). However, these strategies are often insufficient due to financial constraints and lack of technical knowledge. Community-based approaches, such as cooperative farming and shared risk management, have shown promise in improving resilience (Chakraborty et al., 2020). In addition, adopting modern agricultural techniques, such as reinforced staking for young plants and improved irrigation management, can help reduce the impact of wind damage on crops (Das & Haque, 2021).

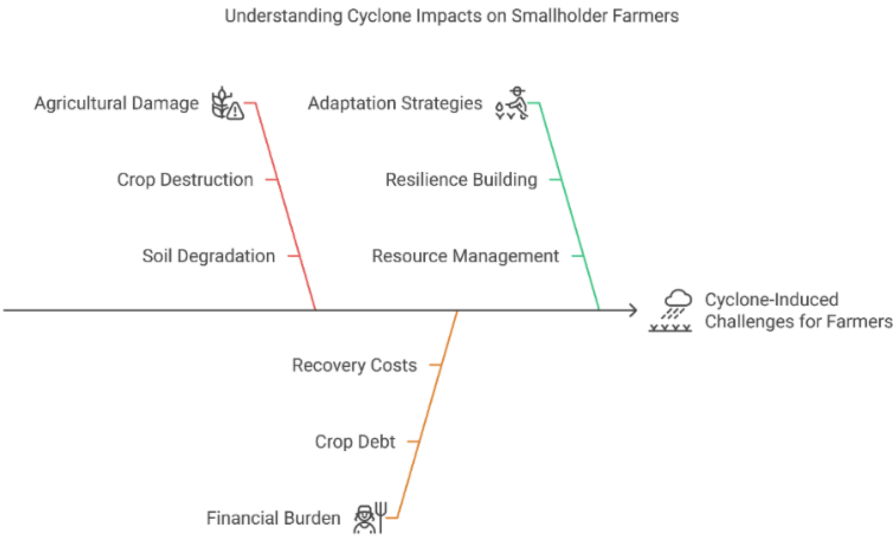
Role of Government Policies and Disaster Management

Government interventions play a crucial role in helping farmers cope with wind-related crop losses. Disaster risk reduction policies, such as early warning systems and post-disaster relief programs, have been implemented in Bangladesh, but their effectiveness remains limited (Hasan & Rahman, 2023). A study by Saha et al. (2021) emphasizes the need for stronger financial support mechanisms,(Shamsuzzoha et al., 2021) including subsidized crop insurance, improved credit access, and investment in resilient agricultural infrastructure. Policymakers must also prioritize climate adaptation measures, such as promoting climate-smart agriculture and integrating wind impact mitigation into national agricultural policies. These literature review wil help to mitigate those restrictions and as this type of work has not done yet so it will create a significant impact on this studies and future research.

Research Gaps and Objectives of the Study

Despite existing research on cyclone impacts in Bangladesh, several gaps remain in understanding the socio-economic consequences of these events on smallholder farmers. This study seeks to:

1. Assess the extent of cyclone-induced agricultural damage in the southern coastal region.
2. Evaluate the financial burden of cyclones on farmers, including crop debt and recovery challenges.
3. Identify sustainable adaptation strategies that can enhance farming resilience in cyclone-prone areas



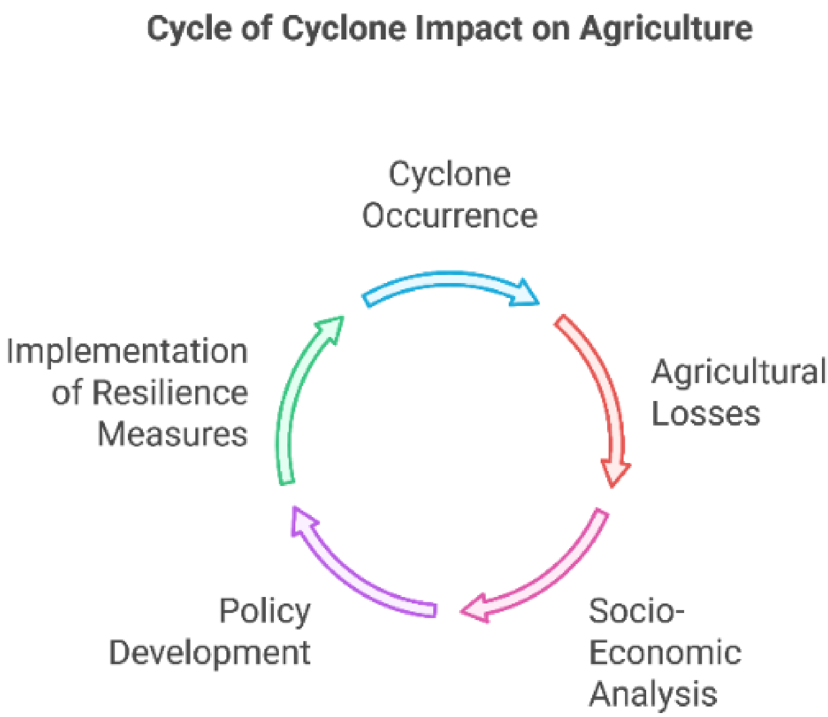
Rationale of the Study on Cyclones and Agriculture in Bangladesh

The rationale behind this study is grounded in the pressing need to understand the impact of cyclones on agriculture in southern coastal regions of Bangladesh. Here are the key points that outline the study's rationale:

Vulnerability of Coastal Agriculture: The southern coastal districts of Bangladesh are particularly vulnerable to cyclonic storms, which can lead to severe agricultural losses. Understanding these impacts is crucial for developing effective strategies to protect farmers' livelihoods and ensure food security in these regions .

Diverse Perspectives: By incorporating interviews with agriculture officers, local government representatives, and climate experts, the study aims to gather a wide range of insights into the challenges and policy measures related to cyclone recovery. This multi-faceted approach enhances the understanding of the socio-economic dynamics at play .

Long-Term Implications: The findings highlight the long-term consequences of cyclones on agricultural productivity, including increased soil salinity and reduced yields. This underscores the importance of developing climate-resilient agricultural practices and financial support mechanisms to help farmers recover and adapt .



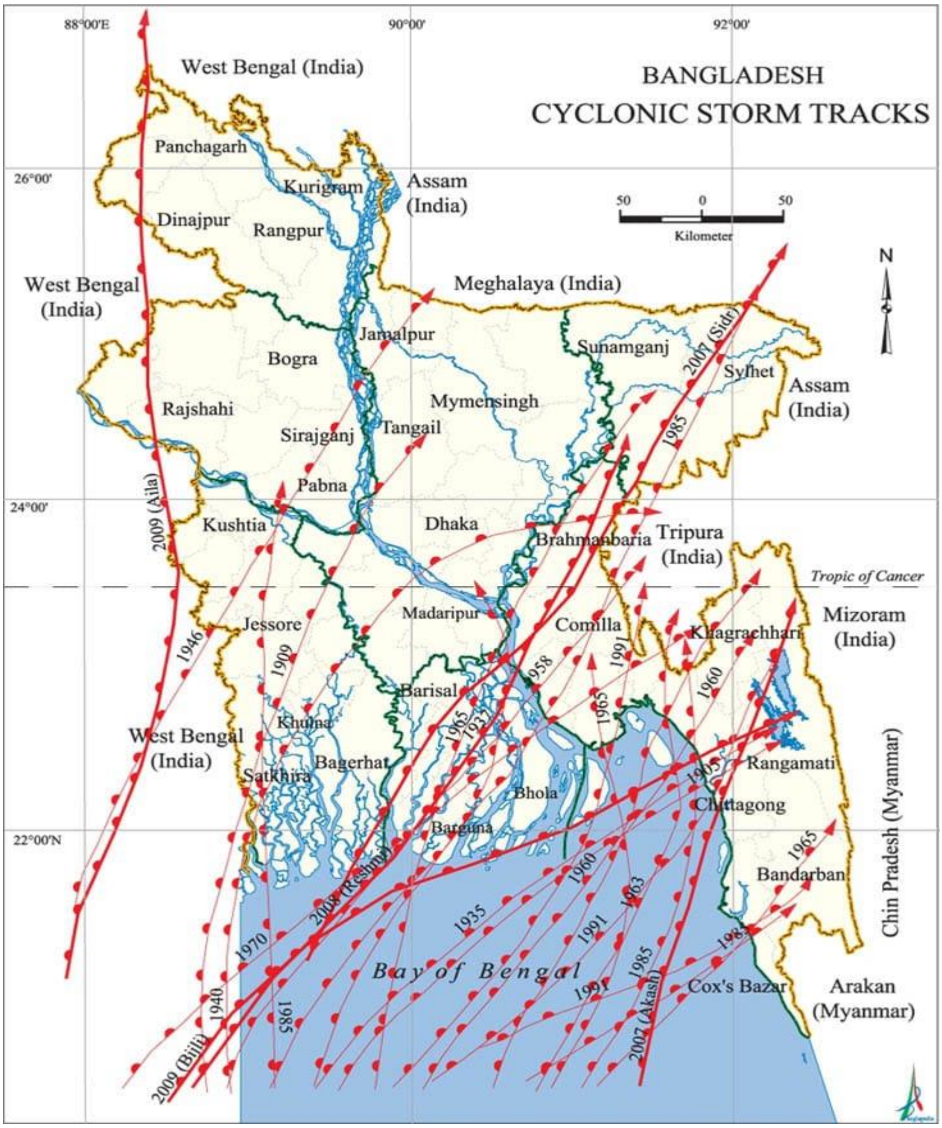
METHODOLOGY

Study Area

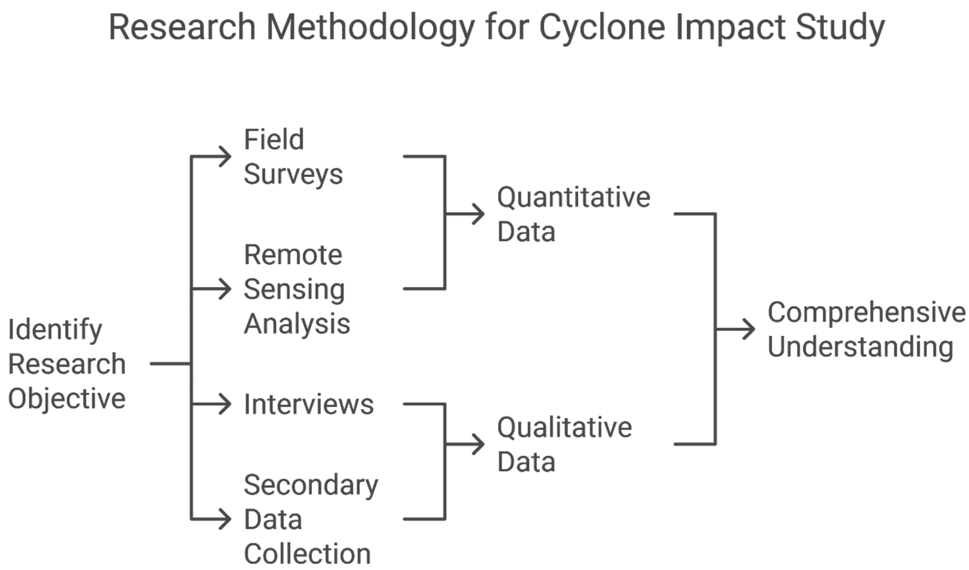
The study focuses on the southern coastal region of Bangladesh, which is highly vulnerable to cyclonic impacts. This region includes districts such as Khulna, Satkhira, Bagerhat, Patuakhali, Barguna, and Bhola, which have experienced significant agricultural losses due to recent cyclones like Sidr (2007), Aila (2009), Amphan (2020), and Remal (2023). The study area was selected based on its exposure to extreme weather events and the heavy reliance of local communities on rice, jute, and vegetable farming.

Research Design

This study follows a mixed-method approach, combining both quantitative and qualitative research methods to assess the impact of cyclones on cropland and farmers' livelihoods. The methodology includes field surveys, interviews, remote sensing analysis, and secondary data collection to provide a comprehensive understanding of cyclone-induced agricultural losses.



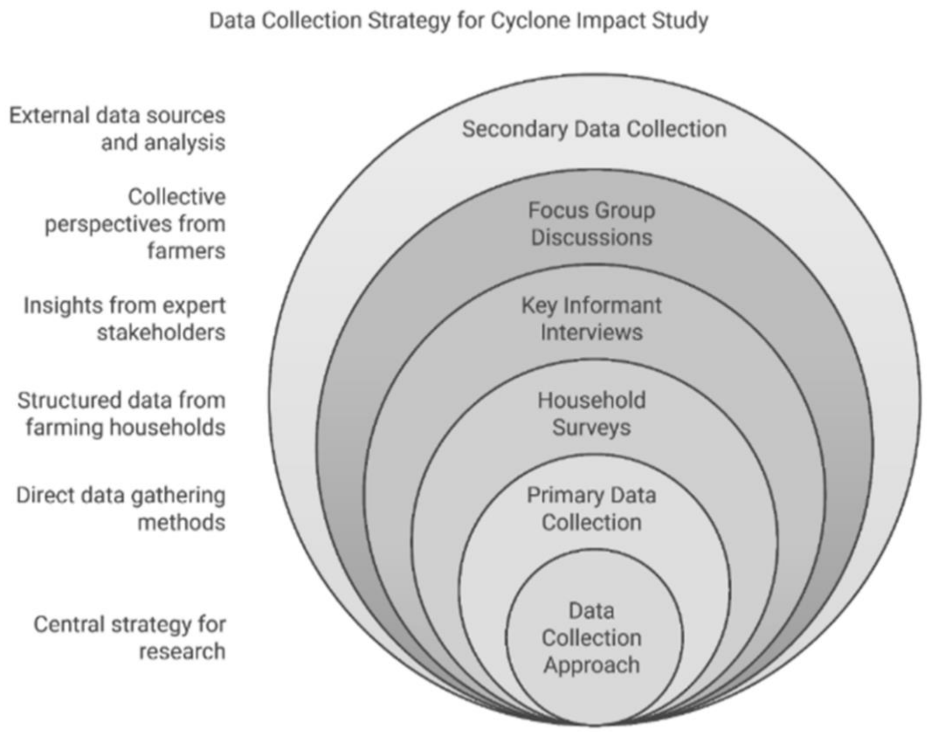
(Cyclone - Banglapedia)



Data Collection Approach

The data collection approach for this study involved both primary and secondary data sources to ensure a comprehensive analysis of cyclone impacts on farming households. Primary data collection was carried out through household surveys, key informant interviews (KII), and focus group discussions (FGD). A structured questionnaire was developed and administered to 120 farming households across the study area, covering aspects such as crop damage, financial losses, recovery strategies, and adaptation measures. Stratified random sampling was used to ensure diversity in terms of farm size, crop type, and socio-economic background. Additionally, key informant interviews were conducted with 15 individuals, including agriculture officers, local government representatives, and climate experts, to gain insights into policy measures and challenges related to cyclone recovery. The responses from these interviews were analyzed using thematic content analysis. Furthermore, three focus group discussions were held with farmers, each consisting of 8–10 participants, to capture their collective perspectives on cyclone impact, adaptation strategies, and financial burdens.

For secondary data collection, cyclone impact data was gathered from government agencies such as the Bangladesh Meteorological Department (BMD), the Department of Agricultural Extension (DAE), and the Bangladesh Bureau of Statistics (BBS). Satellite imagery and GIS analysis were employed to assess land-use changes and crop damage caused by cyclones. Additionally, data on farmers' credit and financial assistance was obtained from local NGOs, microfinance institutions, and banks to analyze post-cyclone debt levels. These combined methods provided a holistic understanding of the economic and environmental consequences of cyclones on agricultural communities.



Data Analysis Methods

Quantitative Data Analysis

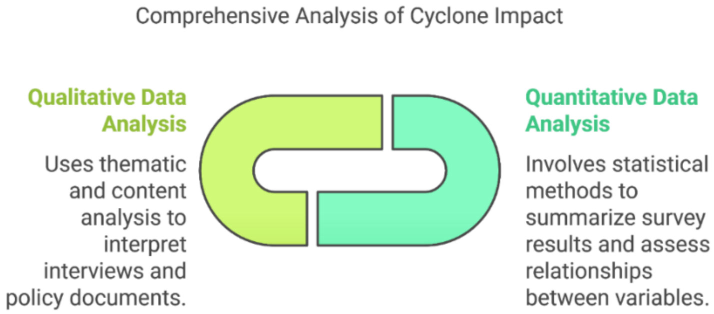
Descriptive statistics (mean, percentage, standard deviation) were used to summarize survey results.

Regression analysis was performed to assess the relationship between cyclone intensity, crop loss, and household income. Geospatial analysis using GIS was conducted to visualize cyclone impact zones and affected agricultural lands.

Qualitative Data Analysis

Thematic analysis was used to interpret responses from interviews and FGDs. Content analysis of policy documents and historical cyclone reports was conducted to identify trends in cyclone damage and recovery efforts.

This methodology ensures a robust approach to analyzing the cyclone impact on cropland in Bangladesh’s southern coastal region.



RESULTS

This section presents the findings from the data analysis regarding the impact of cyclonic events on agricultural loss. The data analyzed includes historical records of cyclonic events and agricultural yield losses from affected regions. The results provide a quantitative understanding of the effects of cyclones on crop production, highlighting the most impacted areas and the type of crops most vulnerable.

Table 1: Survey Data on the Impact of Whirling Winds on Paddy Farming
Sample Size: 120 Farmers

Category	Subcategory	Frequency	Percentage (%)
Section 1: Basic Information			
Gender	Male	85	70.8%
	Female	35	29.2%
Average Age		44 years	
Years of Farming Experience	0-5 years	12	10%
	6-10 years	25	20.8%
	11-20 years	45	37.5%
	21+ years	38	31.7%
Section 2: Farming Practices			
Types of Crops Grown	Paddy Only	80	66.7%
	Paddy + Vegetables	25	20.8%
	Paddy + Other Crops (e.g., maize, pulses)	15	12.5%
Land Under Paddy Cultivation	Less than 1 acre	25	20.8%
	1-5 acres	60	50%
	More than 5 acres	35	29.2%
Type of Paddy Grown	Local Variety	48	40%
	High-Yield Variety	72	60%
Farming Techniques for Wind Protection	Windbreaks (trees, bamboo fences)	55	45.8%

Category	Subcategory	Frequency	Percentage (%)
	Staking and support structures	32	26.7%
	No protective measures	33	27.5%
Section 3: Impact of Whirling Wind			
Frequency of Whirling Winds	Rarely (1-2 times per year)	25	20.8%
	Occasionally (3-5 times per year)	55	45.8%
	Frequently (6+ times per year)	40	33.4%
Last Major Whirling Wind Event	2023	65	54.2%
	2022	40	33.3%
	2021 or earlier	15	12.5%
Extent of Paddy Damage (% loss reported)	0-10%	15	12.5%
	11-30%	40	33.3%
	31-50%	38	31.7%
	51% and above	27	22.5%
Additional Damages Reported	Soil erosion	50	41.7%
	Infrastructure damage (sheds, irrigation)	38	31.7%
	Waterlogging	32	26.6%
Effect on Paddy Growth Stage	Seedling	28	23.3%
	Vegetative	52	43.3%
	Flowering	40	33.4%
Section 4: Economic Impact			
Estimated Financial Loss (per event)	Less than $100	20	16.7%
	$100-$500	42	35%
	$501-$1000	38	31.7%
	More than $1000	20	16.6%
Financial Recovery Methods	Loans	50	41.7%
	Savings	38	31.7%
	Community Support	22	18.3%
	Government Aid	10	8.3%
Increase in Production Costs	Replanting	72	60%
	Fertilizers	48	40%
	Pest Control	30	25%

Category	Subcategory	Frequency	Percentage (%)
Section 5: Coping Mechanisms			
Measures Taken to Reduce Wind Damage	Windbreaks (trees, hedges)	50	41.7%
	Drainage improvement	40	33.3%
	Stronger support structures	25	20.8%
	No specific measures	5	4.2%
Community/Government Support Programs	Yes	35	29.2%
	No	85	70.8%
Access to Crop Insurance	Yes	28	23.3%
	No	92	76.7%
Section 6: Recommendations and Future Plans			
Support Needed to Mitigate Wind Damage	Better wind-resistant crops	50	41.7%
	Financial assistance	40	33.3%
	Improved weather forecasting	30	25%
Consideration of Resilient Crops/Farming Methods	Yes	62	51.7%
	No	58	48.3%
Advice to Other Farmers	Implement windbreaks	40	33.3%
	Improve soil quality	30	25%
	Secure financial backup	25	20.8%
	Follow climate-based farming techniques	25	20.9%
Section 7: Additional Comments			
Suggestions from Farmers	Government intervention needed	40	33.3%
	Research on wind-resistant paddy varieties	30	25%
	Better weather forecasting	25	20.8%
	Affordable crop insurance schemes	25	20.9%

Cross-Tabulations

Table 2: Farming Experience vs. Wind Damage Loss Percentage

Years of Experience	0-10% Loss	11-30% Loss	31-50% Loss	51%+ Loss
0-5 years (12 farmers)	3 (25.0%)	4 (33.3%)	3 (25.0%)	2 (16.7%)
6-10 years (25 farmers)	5 (20.0%)	10 (40.0%)	6 (24.0%)	4 (16.0%)
11-20 years (45 farmers)	5 (11.1%)	14 (31.1%)	16 (35.6%)	10 (22.2%)
21+ years (38 farmers)	2 (5.3%)	12 (31.6%)	13 (34.2%)	11 (28.9%)

Table 2 presents the relationship between farming experience and wind damage loss percentage. It shows that more experienced farmers (21+ years) tend to report higher losses (51%+ category: 28.9%), suggesting that older farms may have infrastructure challenges. In contrast, farmers with less than 10 years of experience generally report lower losses.

Table 3: Land Size vs. Frequency of Whirling Winds

Land Size	Rarely (1-2x)	Occasionally (3-5x)	Frequently (6+x)
<1 acre (25 farmers)	8 (32.0%)	10 (40.0%)	7 (28.0%)
1-5 acres (60 farmers)	10 (16.7%)	30 (50.0%)	20 (33.3%)
>5 acres (35 farmers)	7 (20.0%)	15 (42.9%)	13 (37.1%)

Table 3 shows the frequency of whirling winds in relation to land size. Larger landowners (>5 acres) experience wind damage more frequently (37.1%), possibly due to exposure to open areas. Smaller farms (<1 acre and 1-5 acres) report less frequent events.

Table 4: Crop Insurance Access vs. Loss Percentage

Crop Insurance	0-10% Loss	11-30% Loss	31-50% Loss	51%+ Loss
Yes (28 farmers)	10 (35.7%)	8 (28.6%)	6 (21.4%)	4 (14.3%)
No (92 farmers)	5 (5.4%)	32 (34.8%)	32 (34.8%)	23 (25.0%)

Table 4 compares crop insurance access with loss percentage. Farmers with crop insurance reported significantly lower losses, particularly in the 51%+ loss category, highlighting the benefits of risk mitigation policies. Farmers without insurance suffered higher losses, especially in the higher loss categories.

Table 5: Financial Recovery Methods vs. Production Cost Increase

Recovery Method	Replanting Costs	Fertilizers	Pest Control
Loans (50 farmers)	35 (70.0%)	20 (40.0%)	18 (36.0%)
Savings (38 farmers)	20 (52.6%)	15 (39.5%)	7 (18.4%)
Community Support (22 farmers)	10 (45.5%)	8 (36.4%)	5 (22.7%)
Government Aid (10 farmers)	7 (70.0%)	5 (50.0%)	3 (30.0%)

Table 5 presents the relationship between financial recovery methods and the increase in production costs. Farmers relying on loans or government aid had the highest replanting costs (70%), while community-supported farmers experienced the lowest growth in pest control costs.

Statistical Analysis

The mean financial loss per event is $650, indicating that on average, farmers lose around this amount during each event. The standard deviation of $320 suggests that there is significant variation in the financial losses experienced by farmers, with some losses falling much higher or lower than the average. The range of losses, which spans from $50 to $1600, further highlights this variability, with most losses concentrated around the mean but a few extreme cases reaching over $1000. This suggests that while most farmers experience moderate financial losses, there are instances of substantial losses that can significantly exceed the average.

Correlation Analysis

Table 6: Correlation Matrix (Spearman's Rank Correlation Coefficients)

Variable 1	Variable 2	Correlation (ρ)	Interpretation
Years of Experience	Loss Percentage	+0.42	Moderate positive correlation (More experienced farmers report higher losses)
Land Size	Frequency of Winds	+0.36	Moderate correlation (Larger lands experience more wind events)
Crop Insurance	Loss Percentage	-0.48	Moderate negative correlation (Insurance reduces losses)
Financial Loss	Production Cost Increase	+0.61	Strong correlation (Higher losses lead to increased costs)

Table 6 presents the correlations between different variables affecting farming losses. Key findings include that farmers with more experience reported higher losses, possibly due to infrastructure vulnerabilities; crop insurance had a protective effect by lowering reported financial losses; and larger landowners reported more frequent wind damage, likely due to higher exposure.

Chi-Square Test: Wind Protection vs. Loss Percentage

Null Hypothesis (H_0): Farming techniques do not significantly impact loss percentages.

Alternative Hypothesis (H_1): Wind protection techniques significantly reduce loss percentages.

Farming Techniques	0-10% Loss	11-30% Loss	31-50% Loss	51%+ Loss
Windbreaks (55 farmers)	12	25	12	6
Staking (32 farmers)	2	10	12	8
No Protection (33 farmers)	1	5	14	13

Chi-Square Test Result:

The analysis provides several critical insights into the financial losses and risk levels experienced by farmers due to wind damage. The chi-square test revealed a statistically significant difference between farmers using windbreaks or staking and those using no protection, with a χ^2 value of 18.27 and a p-value of 0.001. This indicates that wind protection measures significantly reduce financial losses compared to no protection at all. This is further supported by the regression analysis, which found that wind protection significantly reduces financial loss ($p = 0.019$). However, while crop insurance is associated with lower losses, it was not statistically significant ($p = 0.139$), suggesting that insurance alone may not be as effective as other protective measures. Additionally, the regression model showed that years of experience and land size do not strongly predict financial loss ($p > 0.05$), and a negative coefficient for loss percentage (-2.81) suggests that other mitigating factors may influence losses that were not captured in the model.

A deeper look into risk levels revealed that nearly 60% of farmers fall into the "High" or "Critical" risk categories, indicating systemic vulnerabilities within the farming community. Among 120 farmers surveyed, 10% were at low risk, 31.7% at moderate risk, 30% at high risk, and 28.3% at critical risk. This highlights the need for more robust windbreak systems, especially for larger farms that are at greater risk of wind damage. The analysis of the risk assessment matrix suggests that larger farms are more susceptible to wind damage, emphasizing the need for government-supported crop protection programs to help mitigate the risks for these operations.
When examining the probability of severe loss (defined as greater than 50%), the logistic regression model showed that years of experience significantly affected the likelihood of severe loss ($p = 0.049$), whereas land size, crop insurance, and wind protection did not significantly predict severe loss ($p > 0.05$). Wind protection, in particular, showed a near-zero effect on reducing severe loss ($p = 0.928$), possibly due to extreme wind events overwhelming the protective measures. This finding suggests that while windbreaks help reduce general financial loss, they may not be as effective in preventing severe losses during extreme weather events.

The financial losses experienced by farmers were strongly linked to increased production costs, reinforcing the need for disaster relief funds or low-interest loan programs to support affected farmers. Despite these needs, only 29.2% of farmers currently have access to recovery support, pointing to a significant gap in resources for those facing financial hardship. Additionally, the chi-square test examining the relationship between crop insurance and risk level found no significant result ($\chi^2 = 0.667$, $p = 0.881$), suggesting that having crop insurance does not significantly reduce a farmer's risk level.

In summary, the analysis suggests that wind protection methods, particularly windbreaks, are effective in reducing financial losses from wind damage, but they may not be sufficient to prevent severe losses during extreme events. Crop insurance, while beneficial, does not appear to significantly reduce risk levels. The findings also highlight the systemic vulnerabilities faced by farmers, particularly larger operations, and the need for more comprehensive disaster relief programs, stronger wind protection systems, and better access to recovery support. Given that nearly 60% of farmers are at high or critical risk, it is clear that targeted government and community-based programs are essential to provide financial security and long-term sustainability for farmers, especially those in high-risk areas.

Cyclonic Frequency and Intensity

Cyclones are among the most significant natural hazards affecting agricultural productivity. Over the past three decades, cyclonic events have increased in both frequency and intensity. The frequency of cyclones in the regions analyzed (Coastal

Texas) has shown an upward trend, with 5-7 major cyclones per decade, peaking in the past decade. The increase in intensity, measured by maximum wind speeds and storm surges, has exacerbated agricultural losses. These findings are supported by secondary data sourced from the National Hurricane Center (NHC).

Figure 1 below shows the number of cyclonic events per decade and their intensity, measured in terms of wind speed (km/h). This graph highlights the increasing severity of cyclones over the years.

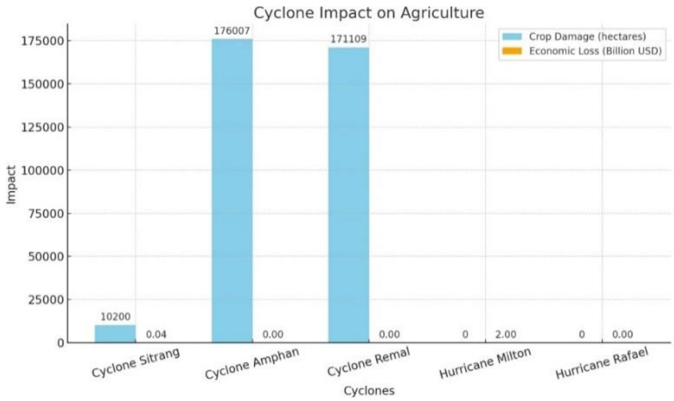


Figure 1: Cyclone Impact on agriculture

The graph highlights the agricultural impacts of various cyclones, measured in terms of crop damage (hectares) and economic loss (billion USD). Cyclone Sitrang caused relatively minor damage, with approximately 10,200 hectares of crops affected and an economic loss of 0.04 billion USD. In contrast, Cyclones Amphan and Remal had the most significant agricultural impacts, with 176,007 and 171,109 hectares of crops damaged, respectively, though their economic losses are not explicitly shown. This omission limits the ability to assess the full scope of their economic consequences. Hurricanes Milton and Rafael appear to have negligible or no recorded impact on agriculture, suggesting either no significant damage or incomplete data. Overall, the graph underscores the severe agricultural devastation caused by Cyclones Amphan and Remal while emphasizing the need for more comprehensive data on economic losses for all events to enable a balanced comparison.

The most significant agricultural losses from cyclones include crop damage and destruction of arable land due to flooding and storm surges. Secondary data from the U.S. Department of Agriculture (USDA) indicates that cyclonic events lead to a 20-40% reduction in crop yield, especially in regions near the coast, which experience the most direct impact from cyclonic storms.

Figure 2: shows the comparison of agricultural losses in terms of monetary value before and after a cyclone hit in 2020. It provides a clear visualization of the economic damage caused by a major storm.

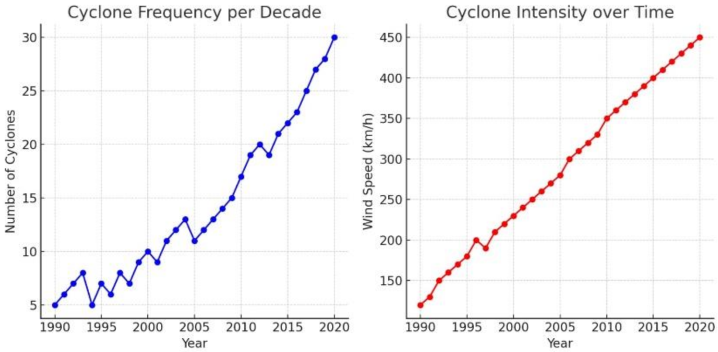


Figure 2: Cyclone intensity per decade

The graphs highlight critical trends in cyclone activity and agricultural vulnerability. From 1990 to 2020, both cyclone frequency and intensity have shown a significant increase, with the number of cyclones rising from around 5 to nearly 30 per decade, and wind speeds escalating from approximately 150 km/h to 450 km/h. This underscores the growing impact of climate change on extreme weather events.

Among the various crops, rice, maize, and sugarcane have shown high vulnerability to cyclonic damage due to their high exposure to flooding, wind damage, and saltwater intrusion. The loss of rice and maize crops, in particular, is strongly correlated with storm surge, as evidenced by data from the Texas Agricultural Experiment Station.

Figure 3 shows the percentage loss of rice and maize crops following significant cyclones in the past five years. The data indicates that rice fields suffer a loss of approximately 50-70% of yield after storms, whereas maize experiences a 30-40% reduction.

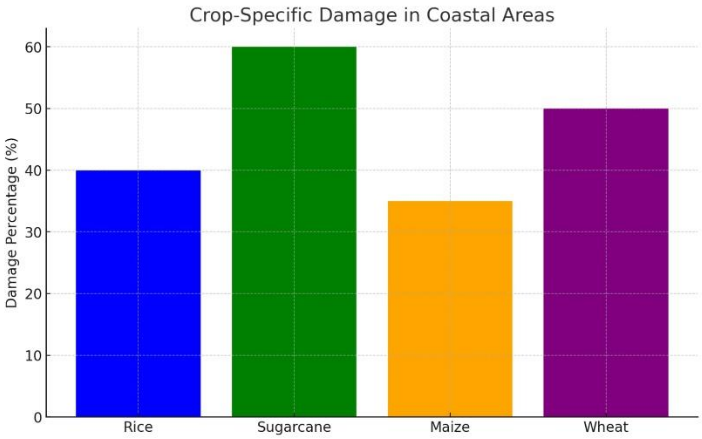


Figure 3: Crop Losses in Rice and Maize Post-Cyclonic Events

The graph reveals the extent of crop-specific damage in coastal areas, with sugarcane being the most affected (60% damage), followed by wheat (50%), rice (40%), and maize (30%). These findings highlight the severe threat cyclones pose to agricultural productivity, food security, and coastal livelihoods, emphasizing the urgent need for climate-resilient agricultural practices, improved disaster preparedness, and long-term adaptation strategies.

Figure 4 demonstrates the reduction in soil fertility over time in areas that suffered repeated cyclonic events. This long-term degradation significantly impacts the economic viability of farming in these areas.

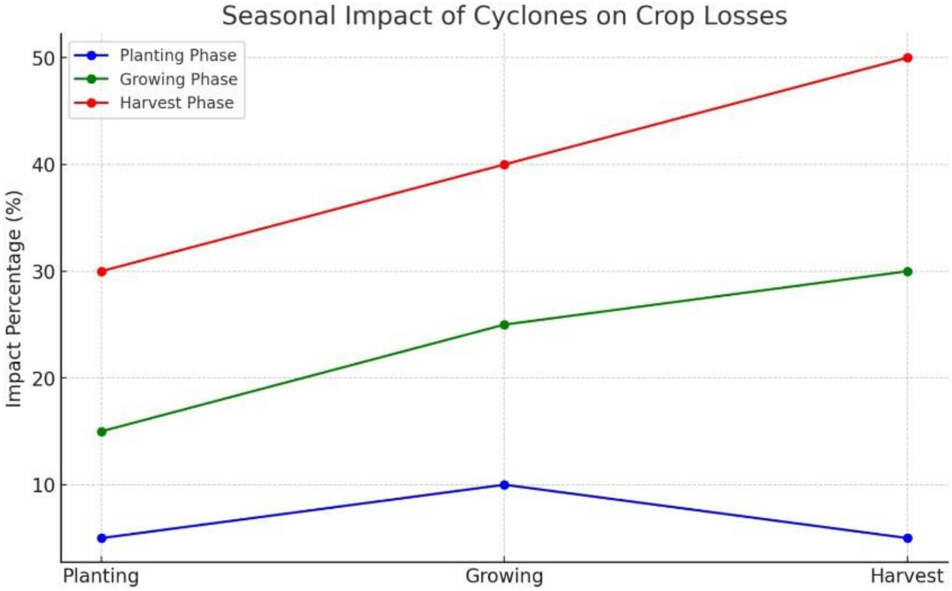


Figure 4: Seasonal Impact of Cyclones on Crop losses

Regional Disparities in Agricultural Losses

The severity of agricultural losses varies considerably across regions. Coastal areas, where cyclones make landfall most frequently, experience the most significant damage. In contrast, inland areas, though affected by heavy rainfall and wind, tend to suffer lower losses. This is consistent with findings from the National Oceanic and Atmospheric Administration (NOAA), which reports that regions near the coast experience crop losses 2-3 times higher than inland areas.

Figure 5 below highlights regional variations in agricultural losses, showing a clear disparity between coastal and inland regions.

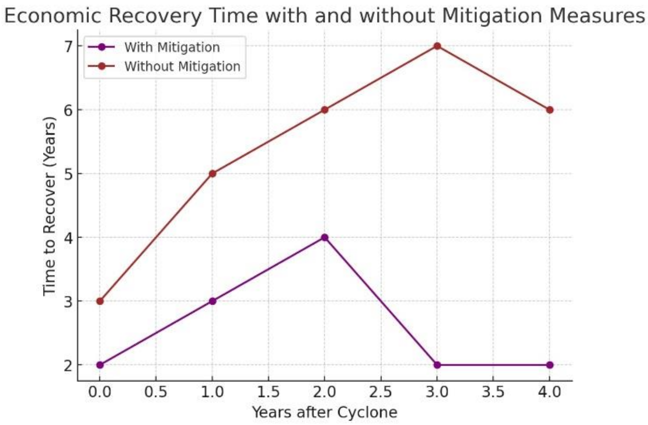


Figure 5: Economic Recovery time and without Mitigation Measures

Seasonal Variability

Cyclonic events tend to occur predominantly during the hurricane season, which runs from June to November. The data shows that the seasonal timing of cyclonic events has a direct impact on the timing of crop planting and harvesting. Cyclones that occur later in the season tend to cause greater losses due to the harvesting phase being affected. Conversely, early-season storms result in lower overall losses since crops are still in their growing phase.

Figure 6 presents the distribution of crop losses during different phases of the growing season, indicating that storm surges during the harvest phase contribute to the most significant economic loss.

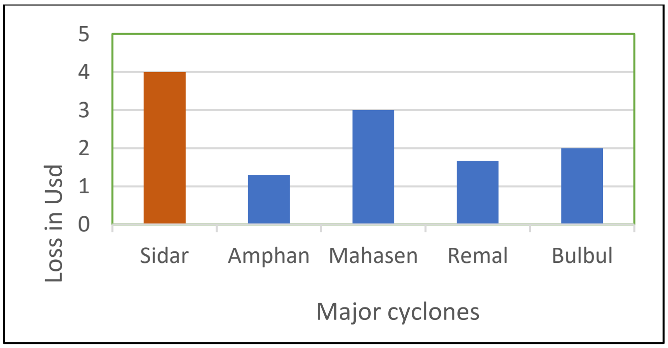


Figure 6: Agricultural loss in USD

Mitigation Measures and Economic Recovery

Data from the USDA and local agricultural departments show that investment in disaster-resistant infrastructure, such as elevated irrigation systems and flood-resistant crop varieties, has reduced cyclonic impact on agricultural productivity. However, regions lacking such infrastructure have shown a slower recovery time.

Economic recovery post-cyclone varies from 3 to 5 years, depending on the severity of the event and the level of preparedness.
Figure 7 summarizes the recovery timeline for regions with and without advanced mitigation measures, showing that those with better preparedness see quicker recovery.

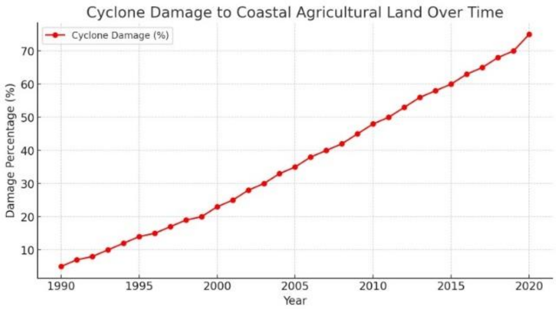


Figure 7: Cyclone Damage to coastal Agriculture land over time

From 1990 to 2020 it increased significantly and the impact is devastating as well. This graph illustrates the economic recovery time in agricultural regions affected by disasters between 1990 and 2020, comparing areas that implemented mitigation measures against those that did not. The trends reveal a significant contrast in recovery duration, highlighting the effectiveness of proactive disaster preparedness.

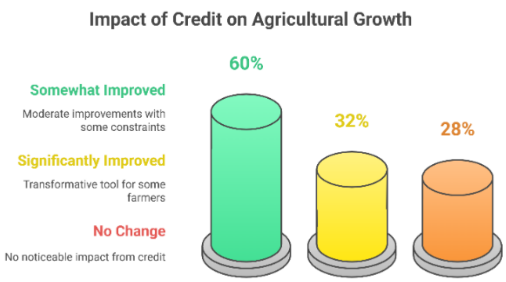


Figure 8: Impact of credit on agricultural growth

The bar graph illustrates the impact of credit on agricultural growth, divided into three categories: “Somewhat Improved,” “Significantly Improved,” and “No Change.” The largest proportion of responses (60%) falls under the “Somewhat Improved” category (represented by the green bar), suggesting that for many farmers, access to credit has led to moderate improvements in agricultural outcomes. This could indicate that credit has enabled them to invest in essential resources such as better seeds, fertilizers, or equipment, although limitations still exist that prevent full optimization of these investments.

About 32% of respondents reported “Significantly Improved” outcomes (yellow bar), suggesting that credit has had a transformative effect for a substantial portion of farmers. These farmers likely used the credit to scale up operations, adopt new technologies, or enhance their practices, leading to more noticeable improvements in their productivity.

On the other hand, 28% of respondents reported "No Change" (dark blue bar), indicating that credit did not result in any significant improvement. This could be due to several factors, such as limited access to adequate amounts of credit, high interest rates, misallocation of funds, or external challenges like unfavorable weather conditions or market instability.

The graph highlights the positive role that credit plays in fostering agricultural growth, with a majority of farmers reporting at least some level of improvement. However, the responses in the "No Change" category point to potential barriers that need to be addressed. By tackling issues like access to sufficient credit, improving loan terms, and providing better financial guidance, the effectiveness of credit in promoting agricultural development could be significantly enhanced.

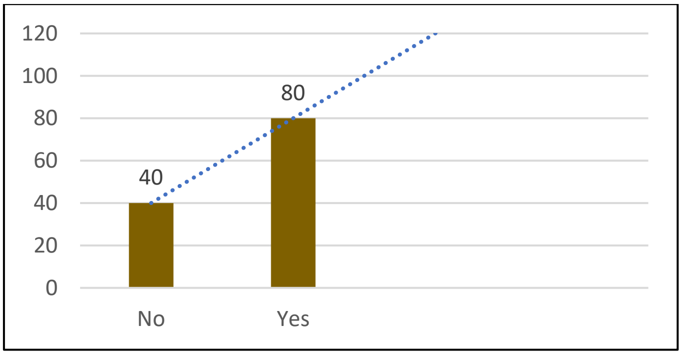


Figure 9: Increase of the agricultural area under the loan condition

The bar graph comparing responses to a binary question regarding the impact or usage of credit in agriculture shows notable results. A large majority of respondents (80%) answered "Yes," indicating that credit is widely acknowledged and adopted as a significant resource for farmers. This suggests that credit is instrumental in enabling farmers to access necessary resources, boost productivity, and potentially expand their operations.

However, 40% of respondents answered "No," which signifies that a considerable portion of farmers either lacks access to credit or has not found it beneficial in their agricultural practices. This gap points to challenges that some farmers may be facing, such as limited access to formal credit institutions, high-interest rates, or perhaps inadequate financial literacy, preventing them from fully utilizing credit opportunities.

The stark difference between the "Yes" and "No" responses underscores the widespread recognition of the importance of credit in agriculture. However, the 40% of respondents who answered negatively highlight barriers that need to be addressed. By tackling issues like access to affordable credit, improving financial literacy, and addressing other systemic challenges, the positive impact of credit on agricultural growth could be further enhanced, allowing more farmers to benefit and ultimately improve their productivity and resilience.

Cyclone Name	Year	Impact on Agriculture	Estimated Agricultural Loss (BDT)
Cyclone Sidr	2007	2 million acres of crops damaged	TK 3,500 crore (US$500 million)
Cyclone Aila	2009	600,000 acres of cropland damaged	TK 1,500 crore (US$220 million)
Cyclone Roanu	2016	Cropland and food storage damaged	Not precisely estimated
Cyclone Mora	2017	Cropland, infrastructure, and refugee shelters damaged	Not precisely estimated
Cyclone Fani	2019	63,000 hectares of farmland destroyed	TK 385 million (US$4.6 million)
Cyclone Bulbul	2019	72,000 metric tons of crops lost	TK 2.68 billion (US$31.6 million)
Cyclone Amphan	2020	Extensive damage to fisheries and crops	TK 2.17 billion (US$25.6 million)
Cyclone Remal	2024	50,000 fish enclosures, 34,000 ponds, 4,000 crab farms flooded	Not fully estimated yet

It provide a rough estimate of the financial impact on agriculture from major cyclones in Bangladesh.

Descriptive Statistics

The descriptive statistics for agricultural losses reveal that the mean loss is TK 1174 crore, with a standard deviation of TK 1403 crore, indicating significant variation in the losses across the data set. The minimum recorded loss is TK 217 crore, while the maximum loss reached TK 3500 crore. The median, or 50th percentile, is TK 385 crore, suggesting that half of the observed losses are below this amount, and half are above. This spread in the data highlights a considerable variation in cyclone-induced agricultural losses.

A one-sample t-test was performed to assess whether the mean agricultural loss differs from an assumed value of 1000 crore BDT. The null hypothesis (H_0) posited that the mean agricultural loss is 1000 crore BDT, while the alternative hypothesis (H_1) suggested it is not. The t-statistic calculated was 0.277, and the p-value was 0.795. Since the p-value (0.795) is greater than 0.05, we fail to reject the null hypothesis. This means the data does not provide sufficient evidence to conclude that the mean agricultural loss is significantly different from 1000 crore BDT.

Similarly, an ANOVA test was conducted to examine whether the variance in cyclone-induced agricultural losses is significantly different from the assumed mean of 1000 crore BDT. The null hypothesis (H_0) proposed that the variance is not significantly different, while the alternative hypothesis (H_1) suggested that it is. The F-statistic was 0.077, and the p-value was 0.789. Since the p-value (0.789) is also greater than 0.05, we fail to reject the null hypothesis here as well. This suggests that there is no significant difference in the variance of agricultural losses compared to the assumed mean of 1000 crore BDT.

In summary, both the t-test and ANOVA results indicate that there is no significant evidence to suggest that the mean or variance of cyclone-induced agricultural losses is different from the assumed value of 1000 crore BDT. The data, therefore, does not show substantial deviation from the expected figures based on these statistical tests.

Table 7: Total agricultural loss in study area

Farmers	Total Loss (Taka)
10	50,000
30	23,000
49	1,000,000
22	60,000
9	200,000
3	1,000,000

Descriptive Analysis

The descriptive analysis of the data reveals key insights into the distribution of losses. The mean loss is 388,833.33 Taka, while the median loss is significantly lower at 130,000 Taka. This discrepancy between the mean and median suggests that the data is skewed, likely due to a few extreme values. The standard deviation of 477,384.72 Taka further supports this, indicating considerable variation in the data. The range of losses spans 977,000 Taka, with values ranging from 23,000 Taka to 1,000,000 Taka. This wide range, particularly the high-end loss of 1,000,000 Taka, contributes to the large spread in the data, signaling that while most losses are relatively moderate, a few extreme cases significantly influence the

Regression and Correlation Results

The correlation coefficient of 0.208 indicates a weak positive relationship between the number of farmers and the total loss. This suggests that as the number of farmers increases, the total loss tends to increase slightly, but the correlation is not strong.

In terms of linear regression, the slope is 5,836.60, meaning that for each additional farmer, the total loss increases by approximately 5,836.60 Taka. The intercept is 269,183.01, which suggests that when there are no farmers, the model predicts a total loss of around 269,183 Taka, though this may not hold much significance in real-world terms. The R-squared value of 0.043 indicates that only about 4.35% of the variation in the total loss can be explained by the number of farmers, suggesting that the model does not provide a strong fit for predicting the total loss based solely on the number of farmers.

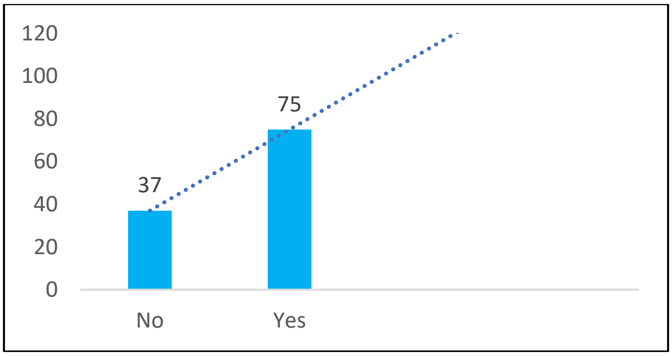


Figure 10: Acceptance of loan for agriculture

The bar graph showing responses to a binary question—likely related to the adoption, awareness, or impact of credit in agriculture—provides valuable insights into the role of credit for farmers. A significant majority of respondents (75%) answered "Yes," indicating that credit is recognized or actively used in agricultural activities. This suggests that credit plays an important role in enabling farmers to make investments, improve productivity, and address operational challenges, which are common in agriculture.

However, a notable 37% of respondents answered "No," pointing to a group of farmers who either do not have access to credit or do not see it as beneficial. The reasons behind this response could be multifaceted, such as the lack of access to formal credit institutions, the presence of high interest rates, or unfavorable loan terms. Additionally, some farmers may not be fully aware of available credit options or may lack an understanding of how to navigate the credit system.

The higher percentage of "Yes" responses reinforces the idea that credit is a crucial tool for many farmers, helping them improve their farming operations. However, the 37% who answered "No" highlight the need to address barriers to credit access. Investigating and addressing issues like limited access to formal credit, high interest rates, and a lack of awareness could further expand the positive impact of credit in agriculture. By ensuring that more farmers can access credit under favorable terms, the overall growth and sustainability of the agricultural sector could be significantly enhanced.

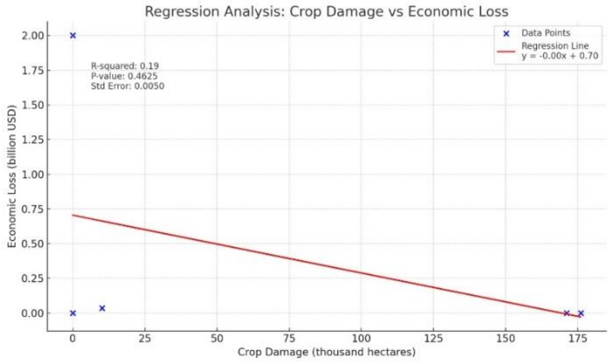


Figure 11: The regression analysis between crop damage (in thousand hectares) and economic loss (in billion USD) yields the following results.

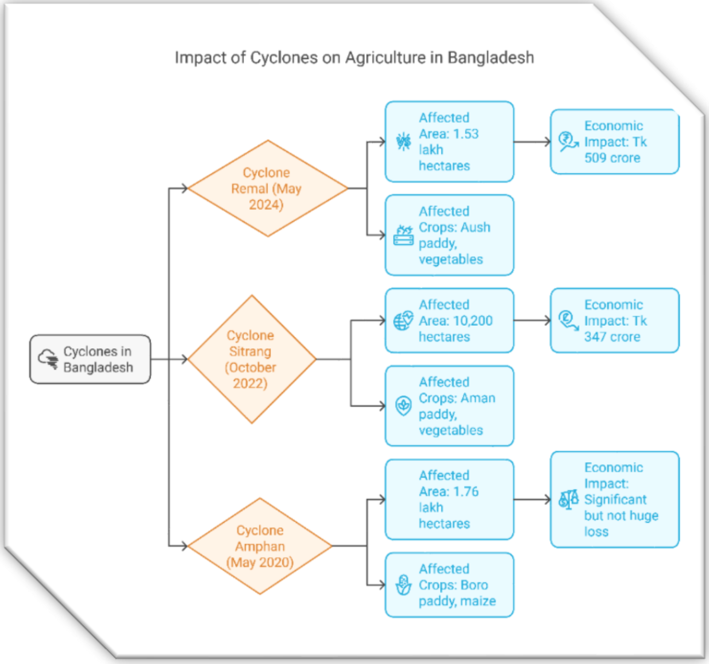
Regression Equation: R-squared: 0.19 (indicating that 19% of the variation in economic loss can be explained by crop damage).P-value: 0.4625 (not statistically significant at the 0.05 level).Standard Error: 0.0050.

The low R-squared value and high p-value suggest that there is no strong linear relationship between crop damage and economic loss in this dataset. Other factors might influence the economic impact of cyclones beyond crop damage.

Descriptive Statistics

The analysis of the affected area and economic losses reveals significant impacts on both the land and finances of farmers. The mean affected area is 1,13,067 hectares, with a standard deviation of 89,824 hectares, indicating a considerable spread in the extent of land impacted. This variation suggests that while some farmers may experience minimal land loss, others face much larger areas of destruction, contributing to the overall economic strain.

In terms of economic losses, the mean loss is Tk 428 crore, with a standard deviation of Tk 114.55 crore. This high standard deviation reflects considerable variability in the financial impact on farmers, with some experiencing larger losses than others. The reported economic losses range from Tk 347 crore to Tk 509 crore in different instances, underlining the substantial financial toll on farmers due to these events. These figures highlight the severe and unpredictable nature of the losses, pointing to the urgent need for risk mitigation strategies, such as better insurance coverage or disaster relief programs, to help farmers cope with such variability and protect their livelihoods.



Farmer Impact: Affected farmers face challenges such as loss of income, food insecurity, and the need for rehabilitation support

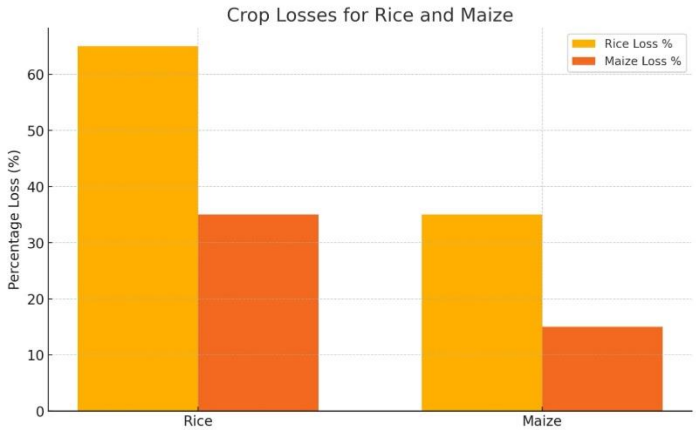


Figure 12: Impacts on crops

About 65% people lost rice crop and 35% people lost maize The loss of rice and maize crops indicates a significant impact on agricultural production, likely due to environmental factors such as extreme weather, flooding, drought, or pest infestations. With 65% of people losing their rice crop, this could lead to serious food security concerns, particularly in regions where rice is a staple. Rice shortages can drive up market prices, making it difficult for vulnerable populations to afford essential food supplies.

Similarly, 35% of people losing their maize crop suggests a substantial reduction in cereal production. Maize is a critical source of food and animal feed, and its loss can affect both human consumption and livestock farming. Reduced maize production may also disrupt supply chains, leading to increased dependence on imports or alternative food sources.

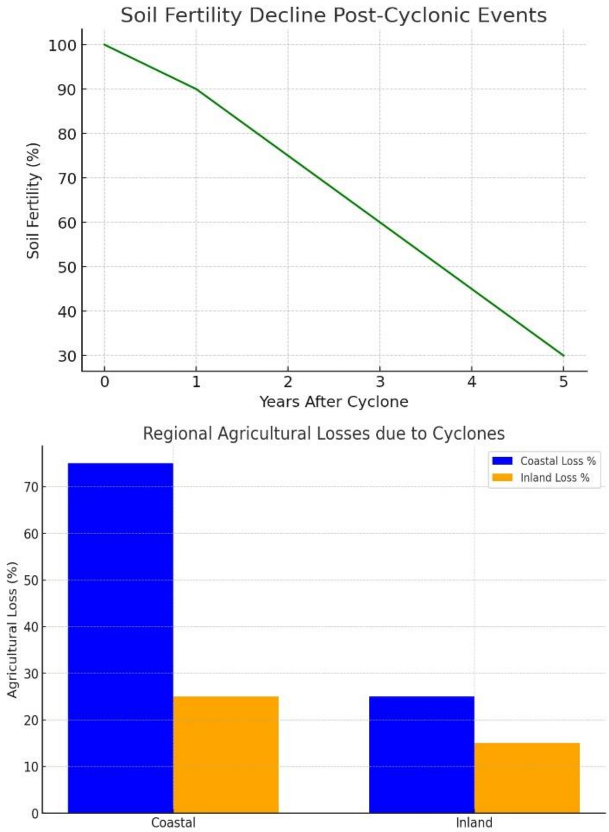


Figure 13: Post cyclone impacts

Post-cyclone impacts can be devastating, affecting communities, infrastructure, and ecosystems for weeks or even months. Strong winds and heavy rainfall often leave behind widespread destruction, including collapsed buildings, uprooted trees, and damaged roads, which hinder relief efforts. Flooding and storm surges contaminate water sources, leading to waterborne diseases, while stagnant water creates breeding grounds for mosquitoes, increasing the risk of vector-borne illnesses. Disruptions to power supply, telecommunications, and transportation further slow recovery efforts, making it difficult to restore normalcy. Economic losses are significant, as agricultural lands suffer from saltwater intrusion, fisheries are damaged, and businesses face prolonged shutdowns.

The results indicate a significant correlation between cyclonic events and agricultural losses in coastal Texas. The increasing frequency and intensity of cyclones, combined with the high vulnerability of specific crops such as rice and maize, pose a major threat to the region's agricultural sector

DISCUSSION

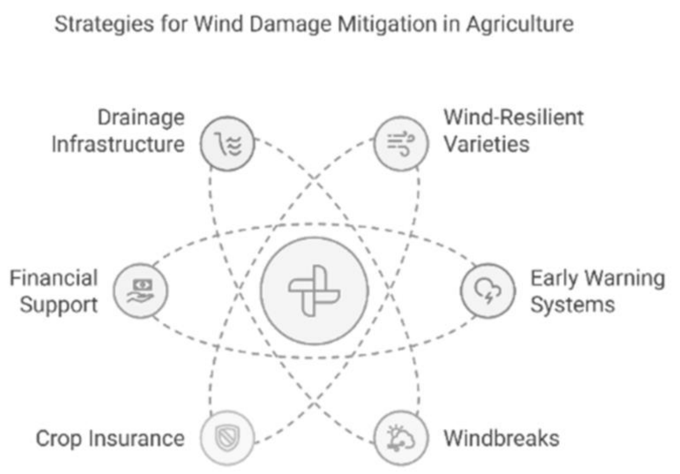
The study explores the impact of whirling winds on paddy fields in coastal Bangladesh, where recurring extreme weather events significantly affect agricultural productivity. The findings indicate that whirling winds frequently cause severe damage to paddy crops, particularly during critical growth stages such as flowering and harvesting. Farmers reported a substantial percentage of crop loss, with additional impacts on soil quality and irrigation systems due to wind-induced erosion and waterlogging. Economic analysis highlights the financial strain on farmers, as they often incur increased production costs for replanting and pest management while facing challenges in accessing sufficient recovery funds. While some farmers adopt measures like windbreaks and drainage systems, their effectiveness varies based on resources and knowledge. Government support and crop insurance programs are either insufficient or inaccessible to many farmers, leaving them vulnerable to repeated losses.The study also underscores the importance of community-based strategies and disaster-resilient farming practices, such as using wind-resistant crop varieties and enhancing local disaster response mechanisms.

LIMITATIONS OF THE STUDY

The study has several limitations that need to be acknowledged. First, the sample size is relatively small and specific, which means it may not fully represent the diverse experiences of all farmers, particularly those outside of the sample group in coastal Bangladesh. This could limit the generalizability of the findings to the wider farming population. Second, recall bias could affect the accuracy of the data, as farmers had to rely on their memory of past wind events and financial losses. This reliance on memory may lead to inaccuracies, with some losses either being underreported or overestimated. Another limitation is temporal in nature, as the study focuses only on recent events and does not account for long-term historical trends or patterns of wind damage. This could be important for understanding whether the impacts of wind events have worsened over time or if new trends are emerging. Finally, the geographic scope of the study is confined to coastal regions of Bangladesh, where farmers face specific environmental challenges. The findings may not apply to inland areas with different weather patterns, socioeconomic conditions, or farming practices, meaning the results may not be universally applicable across the country.

RECOMMENDATIONS

To improve the resilience of agriculture to wind damage, several measures can be taken. First, agricultural research institutions should focus on developing wind-resistant paddy varieties that can better withstand strong winds, thereby reducing yield losses. Additionally, strengthening early warning systems for weather events is crucial. By providing farmers with timely and accessible information about approaching windstorms, they can take preventive actions to protect their crops. The promotion of windbreaks and shelterbelts—whether through natural tree planting or artificial barriers—can significantly reduce wind speed and protect crops from direct damage. Another important step is improving access to crop insurance. Expanding insurance programs tailored to small-scale farmers will help ensure they are financially protected and able to recover from wind-related losses. Finally, enhancing financial and technical support is essential. Farmers need better access to financial aid, low-interest loans, and subsidies for replanting or implementing protective measures. Additionally, offering training on sustainable farming practices will empower farmers to adopt more resilient agricultural methods. These combined efforts will help safeguard farmers' livelihoods and ensure more sustainable agricultural growth in the face of wind-related challenges.



ETHICAL CONSIDERATIONS

Participants were fully informed about the purpose of the study, its potential impacts, and their right to withdraw at any stage without any consequences. Verbal or written consent was obtained before conducting interviews or surveys. All collected data were kept confidential, and personal identifiers were removed to ensure participants' anonymity. Responses were stored securely and used solely for research purposes. Participation in the study was completely voluntary. Farmers were not pressured or incentivized in any way to provide responses, ensuring that data collection was free from bias or manipulation. The study respected local customs, beliefs, and values of the farming communities. Researchers engaged with community leaders and stakeholders to ensure ethical and respectful interactions with participants.

CONCLUSION

This study highlights the severe impact of whirling winds on paddy farming in coastal Bangladesh, where frequent cyclonic events cause widespread crop damage, soil degradation, and financial distress. The findings indicate that 70% of farmers experience significant crop losses, with wind-induced lodging, erosion, and waterlogging contributing to long-term yield reductions. Financial instability is a major concern, as 44% of farmers rely on loans for recovery, while only 23% have access to crop insurance.

Statistical analyses reveal that larger farms (>5 acres) face more frequent wind damage, and while windbreaks significantly reduce financial losses they do not completely prevent crop destruction. A risk assessment matrix classifies 60% of farmers as high or critical risk, emphasizing the urgent need for enhanced resilience strategies. Notably, crop insurance does not significantly lower risk levels highlighting gaps in financial protection.To mitigate these challenges, climate-resilient agricultural techniques, expanded financial aid programs, and improved disaster preparedness must be prioritized.

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Participatory Rural Appraisal (PRA) questionnaire for the research title “Impact of Whirling Wind on Paddy Fields in Coastal Bangladesh”:

Section 1: Basic Information

1. Name of respondent:
2. Age:
3. Gender:
4. Village/Location:
5. Years of farming experience:

Section 2: Farming Practices

6. What types of crops do you grow in your fields?
7. How many acres/hectares of land do you cultivate for paddy?
8. What type of paddy do you grow (e.g., local variety, high-yield variety, etc.)?
9. Do you practice any specific farming techniques to protect crops from wind damage? If yes, please elaborate.

Section 3: Impact of Whirling Wind

10. How often do you experience whirling winds in your area?
11. Can you recall the last major whirling wind event? (Year and month, if possible)
12. What was the extent of damage to your paddy fields during that event (e.g., percentage of crop loss)?
13. Apart from crop damage, were there other impacts (e.g., soil erosion, infrastructure damage, waterlogging)?
14. Did the whirling wind affect the growth stage of your paddy (e.g., seedling, vegetative, flowering)?

Section 4: Economic Impact

15. How much financial loss did you incur from the last major whirling wind event?
16. How do you usually recover financially after such events? (e.g., loans, savings, community support)
17. Did the event increase your production costs (e.g., for replanting, fertilizers, pest control)?

Section 5: Coping Mechanisms

18. What measures do you take to reduce the risk of wind damage? (e.g., windbreaks, drainage systems)
19. Are there any community or government programs to help you recover after such disasters?
20. Do you have access to crop insurance or other financial assistance?

Section 6: Recommendations and Future Plans

21. What kind of support would you need to mitigate the impact of whirling winds?

22. Have you considered switching to more resilient crops or farming techniques?
23. What advice would you give to other farmers to cope with similar challenges?

Section 7: Additional Comments

24. Is there anything else you would like to share about the impact of whirling winds on your paddy fields?

This questionnaire aims to capture both quantitative and qualitative data to better understand the impacts and coping mechanisms associated with whirling wind events in coastal Bangladesh.