

Article

Differential Livelihood Impacts of Cyclones Bulbul, Amphan and Yaas: The Role of Landholding in Shaping Vulnerability and Recovery in Kultali CD Block, Indian Sundarban

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Abstract: Cyclone-induced vulnerability is a major threat to livelihood security and socio-economic stability in coastal areas. The Indian Sundarban is especially vulnerable to cyclone-related impacts and has high exposure due to its population pressure, diminishing natural resources, and climate-sensitive livelihood choices. Cyclones have created massive destruction in the physical and socio-economic spheres. This study evaluates the differential impacts of cyclones Bulbul, Amphan, and Yaas, with particular focus on the relationship between livelihood structure and landholding in the Kultali CD block. A mixed-method approach is applied; a total of 550 household surveys and 54 Key informant interviews were conducted across the study area. The cyclone impact categorization-high impact, moderate impact, and low impact- was developed based on socio-economic losses. The descriptive statistics, crosstabulation and Kruskal–Wallis test were conducted to assess the relationship between cyclone-induced livelihood impact and landholding categories. The Kruskal–Wallis test results stated that livelihood vulnerability is different among the occupational groups for these three successive cyclones: Bulbul ($H = 43.936, p < 0.001, \epsilon^2 = 0.072$), Amphan ($H = 34.626, p < 0.001, \epsilon^2 = 0.054$), and Yass ($H = 60.918, p < 0.001, \epsilon^2 = 0.103$). The statistical results showed that cultivator households were found to be most vulnerable to the Bulbul cyclone, and fishing households faced the highest level of livelihood disruption to the Amphan and Yaas cyclones. Interviewed respondents are landless (60.7%), marginal farmers (36.4%) and small farmers (2.9%). Landless households are mostly from wage labour and fishing occupations and have less resilience to livelihood diversification and asset ownership. The statistical figures indicated that livelihood vulnerability is not only defined by cyclone intensity but also by unequal access to asset ownership. The findings suggested that there is a need to integrate a disaster reduction framework that gives special emphasis separately on direct asset exposure and broader socio-economic vulnerability. The disaster reduction policy should incorporate livelihood-specific interventions that provide a resilience pathway in the cyclone-prone coastal regions.

Keywords: cyclone impacts; livelihood vulnerability; landholding; Kultali community development (CD) block; Indian Sundarban



1. Introduction

The coastal and deltaic regions across the world have faced climate change and extreme weather consequences, which hinder sustainable development [1–3]. Among these climatic events, tropical cyclones have become acknowledged as the most damaging environmental phenomena because of their combined impact on the ecosystem, the livelihood system, human settlement, and infrastructure [4–6]. The Bay of Bengal is gaining the most attention for the genesis of cyclonic disturbances, which have severely disrupted the socio-economic condition of the vulnerable coastal communities [7–9]. The low-lying deltaic regions are more susceptible to climatic shocks due to a fragile ecological base, high population density, and high dependence on climate-sensitive livelihoods and limited adaptation capacity [10]. The repetitive cyclone exposure not only damages the physical assets but also weakens long-term resilience and adaptive capacity, and pushes them backwards, slowing down development [11].

The Sundarban is famous for its rich biodiversity [12] and is also known for its hazard-prone, distressed nature [13]. The Sundarban is located in the lower Gangetic delta, characterised by a complex river system [14], mudflats, mangroves, estuaries and a low-lying island system [15–17]. This region was previously marked as extremely susceptible to cyclone impacts due to its geographical location, inadequate embankment and infrastructure, and a complex ecosystem (Table 1). The Indian Sundarban faces severe cyclones, such as Aila (2009), Bulbul (2019), Amphan (2020), and Yaas (2021), which cause extensive socio-environmental impacts throughout the Sundarban [18–20]. The livelihood structure and landholding are critical determinants to assess the vulnerability in the cyclone-prone region. The livelihood structure is determined by the degree of exposure to and sensitivity to particular climatic shocks, where landholding refers to productive assets and recovery capability [21,22]. People who depend on livelihoods like fishing have higher exposure to environmental disasters because they are directly dependent on river or coastal ecosystems [23–25]. Wage laborers are also the most vulnerable group, as they have a limited asset base and irregular work, which makes it difficult for them to adapt in the post-disaster phase. A landowner can also experience severe economic loss if any climatic disaster takes place during the cropping season, saline water intrusion in the crop land, making the land infertile for the next two to three years [20]. Therefore, vulnerability cannot be judged based on assets or poverty, but rather it is interconnected with livelihood dependence, disaster exposure, and asset ownership.

Table 1. Summary of recent literature on cyclones' impact and research gap.

Author (s)	Hazard (s) Studied	Main Focus	Limitation/Gap
Roy et al. [26]	Multiple cyclones, including Amphan	Cyclone preparedness plan, early warning, cyclone shelter, vulnerability assessment	Does not discuss household-level livelihood impact and landholding as an asset in post-disaster recovery
Kar et al. [19]	Climate-induced hazards include cyclones, floods, and storm surges	Socio-economic vulnerability of the Sundarban Biosphere Reserve, using vulnerability index-based exposure, hazard and adaptive capacity.	Does not compare the successive cyclone impacts, and the importance of landholding is not included
Paul & Paul [27]	Climatic variability and sea level rise, cyclone	Adaptation strategies of coastal communities in response to climatic variabilities and livelihood stress	Primarily focuses on long-term adaptation to climate variability rather than comparing the individual livelihood impact of Cyclone Bulbul, Amphan and Yaas and landholding importance
Mandal et al. [28]	Aila and Bulbul	Cyclonic consequences, Impact on agriculture, soil salinity, crop production	Focusing on environmental changes and agricultural impacts rather than individual livelihood impacts, and does not include land assets as an important parameter for disaster recovery
Mandal et al. [29]	Aila, Amphan and Yaas	Climate-induced vulnerability and human migration in the Patharpratima CD Block	Did not evaluate Bulbul; focused on migration risk and composite coastal vulnerability
Mandal et al. [30]	Climatic vulnerability, cyclones (Aila, Amphan and Yaas), sea-level rise and related coastal hazards	Climatic consequences in the Indian Sundarban focus on environmental changes, socio-economic vulnerability and climate-induced human migration	Primarily, a conceptual overview of climatic variability, individual cyclone consequences and landholding does not consider
Edmonds et al. [31]	Tropical cyclone and sea level rise	Climate resilience and mortality risk in the Indian Sundarban	Does not focus on the livelihood impact; individual cyclone impacts, Bulbul, Amphan and Yaas are not investigated, and the importance of landholding is not considered

Table 1. Cont.

Author (s)	Hazard (s) Studied	Main Focus	Limitation/Gap
Tenhunen et al. [32]	Aila	Politics of climate change, governance, and adaptation policies following the Aila cyclone	Qualitative socio-political analysis; successive cyclone impacts, Bulbul, Amphan and Yaas are not investigated, and the importance of landholding is not considered.
Paul and Chatterjee [33]	Aila	Climate change-induced hazard, relief, and rehabilitation measures in the Indian and Bangladesh Sundarban	Focus on relief, rehabilitation and environmental hazards rather than household-level impacts of the successive cyclones and landholding.
Roy, S. [34]	Aila	Highlights gender vulnerability and adaptation among Muslim women in Bangladesh, Sundarban	Focus on gender, mobility, and social vulnerability in Bangladesh. The household-level impact analysis and importance of landholding are excluded.
Pal and Ghosh [35]	Aila	Analysis of post-disaster risk management, response, resilience and recovery measures of cyclone Aila in the Indian Sundarban	Focus on governance and recovery rather than the household level. Does not compare successive cyclone impacts Bulbul, Amphan and Yaas and the importance of landholding is not considered.
Prakash et al. [36]	Amphan	Analysis of ecological disturbance caused by cyclone Amphan using Remote sensing in the Indian Sundarban	Focuses on ecological and environmental impact rather than household-level empirical analysis.
Majumder, M. [37]	Amphan	Assessed the Amphan cyclone impact on biodiversity and the mangrove ecosystem in Sundarban	Not focused on socio-economic impact; mainly focused on ecological impact, like biodiversity loss and ecosystem rehabilitation.
Chowdhury et al. [38]	Amphan	Analysis of ecosystem-based disaster-risk reduction and mangrove restoration in the Indian Sundarban	Focuses on environmental resilience rather than the impact of household livelihood cyclones and the importance of land assets.
Mishra et al. [39]	Amphan	Assess the ecological disturbances and vegetation damage using remote sensing and geospatial techniques in the Indian Sundarban	Focus only on ecological and environmental assessment.
Basu, S. [40]	Bulbul and Amphan	Analysis of the economic consequences of Cyclone Bulbul and Amphan on the fishing community in Bangladesh	Focuses on income loss, production decreases, and recovery challenges of fishing households in Bangladesh and two cyclones are analysed.
Nath et al. [41]	Bulbul and Sitrang	Assess the effectiveness of a natural mangrove buffer in reducing cyclone damage and intensity	Focus on ecosystem services, the natural buffering process, and the importance of mangroves rather than the household-level impact of cyclones. importance of landholding in vulnerability management is not considered.
Present study	Bulbul, Amphan and Yaas	Comparative livelihood impacts across landholding categories	Examines how landholding plays an important role in shaping livelihood vulnerability and recovery using household survey data (550 households), 54 KIIs and statistical testing.

Source: Compiled by the authors based on the reviewed literature.

The study focused on two objectives: to evaluate the differential livelihood impacts of multiple cyclones (Bulbul, Amphan, and Yaas) in the Kultali CD Block and to analyze the role of landholding in shaping vulnerability and recovery. This study uses household-level survey data to examine the relationship between livelihood structure, landholding and cyclone impacts at the micro-level. The descriptive statistics, crosstabulation and Kruskal–Wallis test are used to analyze the data.

This study will contribute to existing literature in many ways. First, the multiple cyclones and their cumulative impact assessment in the same socio-ecological settings; second, the statistics demonstrate how the livelihood pattern was influenced differently by the successive cyclones, and third, this study provides a complex view that landholding is considered a socio-economic asset and experiences major economic loss during a disaster. This study gives more emphasis on multidimensional and context-specific climatic vulnerability in the Indian Sundarban. The study findings help formulate a ground-level disaster risk reduction plan and develop appropriate strategies for resilience-building policy, which can be applied to the fragile, deltaic region in the border context.

2. Conceptual Framework

Livelihood vulnerability to recurrent cyclones Bulbul, Amphan and Yaas are integrated to understand the socio-economic character and livelihood losses of the household. The cyclones have impacted the coastal region, but at the household level, the experiences are different. The differences in livelihood dependence, assets, and recovery capacity define the degree of vulnerability and resilience. This study adopted a conceptual framework in combination with the Pressure and Release (PAR) Model and the Sustainable Livelihoods Framework (SLF) to understand how landholding influences livelihood vulnerability and post-disaster recovery following cyclones Bulbul, Amphan, and Yaas in the Kultali CD block, Indian Sundarban.

The Pressure and Release Model is mainly conceptualised as disaster outcomes being the interaction between natural hazards and socially built vulnerabilities [42,43]. The Sustainable Livelihood Framework depicts how access to the various types of capital affects households' ability to cope with adverse situations and recover from external shocks [44,45]. These two frameworks help to understand how the cyclone hazard interacts with livelihood characteristics and asset ownership to produce differential outcomes. Landholding plays an important role in shaping livelihood vulnerability and adaptive capacity during the recovery process. People may face the same level of hazard exposure, but differences in livelihood assets and socio-economic conditions create unequal levels of vulnerability.

The Pressure and Release (PAR) Model, conceptualised by Wisner et al., states that disasters occur not simply due to a hazardous event but due to a natural hazard interacting with socially constructed vulnerabilities [42]. Vulnerability develops through root causes, like heavy reliance on natural resources, marginalisation, and small land tenure, creating dynamic pressure on environmental degradation, weak infrastructure, population pressure, limited livelihood opportunities, slow disaster response, and limited credit access, creating unsafe conditions like frequent embankment breaching, fragile housing and assets, leading to high susceptibility to hazard impacts. In the Indian Sundarban, recurrent cyclones like Bulbul, Amphan and Yaas interact with the pre-existing fragile socio-economic status, increasing household susceptibility to cyclone-induced livelihood loss. This theoretical framework helps to explain the differential livelihood impacts among households with varying landholding sizes.

The Sustainable Livelihood Framework (SLF) was introduced by the Natarajan, et al. [44]. This framework comprehends how households sustain their livelihood under environmental and socio-economic change [44,45]. This framework also shows that a household's ability to recover from external shocks not only depends on a long-term resource base but also on skills, ability and activities to secure means of living. This framework acknowledges that disasters as natural events and livelihood outcomes are shaped by differential access to assets, livelihood strategies, and institutional support. The Framework states five livelihood assets; in the case of the Kultali CD block, the natural capital is landholding, mangrove, forest, water resources, biodiversity and other ecological services. Physical capital comprises housing, infrastructure (embankments, roads, bridges), irrigation facilities, agricultural tools, energy, and communication. Human capital is education, livelihood skills, health and labour availability. Financial capital is income sources, savings, credit, access to formal finance and remittances, and social capital comprises community networks, NGOs, local institutions, trust, and collective action for disaster recovery. The livelihood asset, landholding, is one of the important forms of natural capital for households and its help with agricultural production, income generation, livelihood diversification and many more. Conversely, landless or small marginal landholders depend on climate-sensitive activities like fishing and casual labour, which makes them vulnerable to any climatic shocks. In the case of the Sundarban region, natural capital is fragile, physical capital is inadequate, and financial capital is scarce; households mostly rely on social and human capital for their survival and recovery. In the context of the present study, this SLF provides a theoretical foundation to understand how differences in livelihood assets contribute to unequal vulnerability among households affected by cyclones Bulbul, Amphan, and Yaas.

These two frameworks, the Pressure and Release (PAR) Model and the Sustainable Livelihood Framework (SLF), capture both vulnerability and resilience dynamics for the Study area. The Pressure and Release (PAR) Model shows structural and dynamic vulnerability phases, and the Sustainable Livelihood Framework (SLF) shows how communities mobilise livelihood assets to adapt, recover and build a resilient society.

3. Methodology

3.1. Study Area

The Kultali CD block is one of the administrative units under the Baruipur Subdivision of South 24 Pargana, West Bengal. This Community Development (CD) block is an administrative unit of a district in rural India comprising a group of Gram Panchayats and villages, responsible for implementing development programmes. This administrative block extends from 21°49'37.09" N to 22°13'1.79" N and 88°29'33.08" E to 88°38'22.53" E [46]. This

CD block is surrounded by the Canning-I and Jaynagar-I CD blocks in the North, the Basanti CD block to the east, the Sundarban reserve forest to the southeast, the Patharpratima CD block to the southwest, the Mathurapur-II CD block to the west, and the Jaynagar-II CD block to the northwest [46].

The CD block is bounded by two major rivers on the west side, the Thakuran River, and to the east, the Matla River, margin in the south. As per the *Statistical Handbook, in South Twenty-four Parganas*, the total area of the CD block is 306.18 km² (30,618.2 hectares). The total population, according to the last census (2011), is 8,161,961. The total embankment length of the Kultali CD block is 123.80 km approximately. The CD block has 1 Panchayat Samiti and 9 Gram Panchayats, 46 mouzas where 43 are inhabited and 3 are uninhabited (Lot-118, Lot-120, and Lot-121). The CD block is rural, with no statutory or census town, and the headquarters is in Jamtala. There are two police stations: the Kultali police Station and the newly added Maipith coastal police station. The block has 43 inhabited villages and 3 uninhabited villages under nine Gram Panchayats (GP): Meraganj I, Meraganj II, Jalaberia I, Jalaberia II (BDO Office- Jamtala), Kundakhali Godabar, Gopalganj, Deulbari Debipur, Gurguria Bhubaneswari (Lot-120 and 121, two uninhabited villages), and Maipith Baikunthapur (Lot-118, an uninhabited mouza). This CD block's climatic character is a tropical monsoon type, with average maximum and minimum temperatures of 25–35 °C (April–May), 12–24 °C (December–February), and 75% annual rainfall occurs in the monsoon season, 1700–2000 mm (June–September). This area is characterised by high humidity and frequent tropical cyclones and tidal surges. This CD block is considered one of the vulnerable CD blocks due to various climatic consequences [19,47–50]. A location map (Figure 1) of the study area was made with ArcGIS software version 10.8 to represent the locational presence and importance of that area.

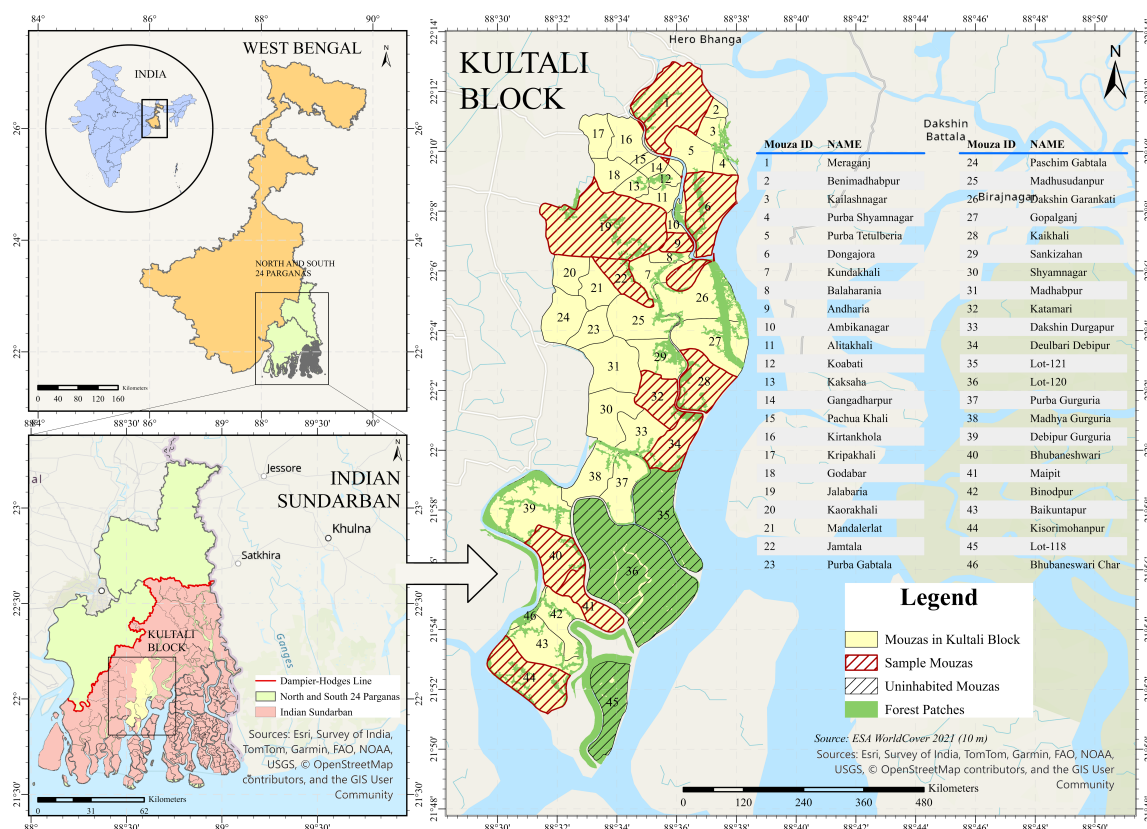


Figure 1. Location map of the study area.

3.2. Sampling Technique and Selection of Villages

The study uses a two-stage sampling technique to examine the differential livelihood impacts. This approach is considered useful to analyse the repetitive cyclone (Bulbul, Amphan and Yaas) impact and the role of landholding in shaping the vulnerability of the Study area. The Kultali CD block is selected as one of the cyclone-prone administrative blocks and has experienced repetitive impacts from cyclones Bulbul (2019), Amphan (2020) and Yaas (2021). In the first stage, villages are selected purposively from each of the nine Gram Panchayats to represent spatial representation across the study area; this technique is helpful to represent the inclusion of diverse spatial characteristics (geographical exposure and importance, such as proximity to the river, tidal creek, forest frontier environment and block headquarters) and study objectives. Village-level census data from 2011 were used

to rank the socio-economic vulnerability of that area based on total population, SC and ST population, literacy rate, sex ratio, and occupational structure (main and marginal workers). In the second stage, 50 households are selected from each village through random sampling to represent the exposure of the community within the Kultali CD block rather than of the entire region. The households are identified with local panchayat representativeness and community information based on predefined criteria.

The selected villages are Meraganj (Meraganj- I GP), Dongajora (Meraganj- II GP), Andharia (Kundakhali Godabar GP), Jalabaria (Jalabaria-I GP), Jamtala (Jalabaria- II GP), Kaikhali (Gopalganj GP), Katamari and Deulbari Debipur (Deulbari Debipur GP), Bhubaneshwari (Gurguria Bhubaneshwari GP), Maipit and Kisorimohanpur (Maipith Baikunthapur GP) to represent diverse Socio-ecological settings, including river, inland, fishing-dominant, agriculture-dependent and forest fringe areas. In this study area, at least one village is selected from each Gram Panchayat (GP), and two Gram Panchayats have been selected to capture environmental extremeness, demographic characteristics, and livelihood variation.

3.3. Sampling Design and Sample Size

A random sampling technique has been used to collect primary data to examine the impact of cyclones (Bulbul, Amphan and Yaas) on livelihood and landholding groups across the study area. A total of 550 sample household surveys were conducted across the eleven villages (Meraganj, Dongajora, Andharia, Jalabaria, Jamtala, Kaikhali, Katamari, Deulbari Debipur, Bhubaneshwari, Maipit and Kisorimohanpur). The sample sizes of the villages are set to 50. An equal sample size is selected to ensure balanced comparison among the villages and to minimize the influences of unequal village sampling across the study area. The Survey was conducted from the fourth week of April 2025 to the end of the first week of August 2025. During the interview, the household head or the principal income-earning member was interviewed. Respondents had clear knowledge about economic loss, landholding, and cyclone damage, ensuring the accuracy and reliability of data. For statistical analysis, the household was considered the primary unit for this study.

3.4. Data Collection

This study used both primary and secondary data. A comprehensive, structured questionnaire-based household survey was conducted in the eleven villages of the nine Gram Panchayats, Kultali CD block. This Household survey aimed to analyze the impact of repetitive cyclones and the importance of landholding based on vulnerability. This questionnaire survey covers demographic parameters, livelihood activities, income sources, landholding status (agricultural land plot), cyclone-induced damages, agricultural losses, fishery-related disruptions, housing damages, and other socio-economic impacts to ensure the adequacy of the study. The survey data were further categorized into different livelihood groups such as cultivators, fishing households, wage laborers, business households, salaried job holders, and self-employed. The landholding record is further classified into three categories according to the Ministry of Agriculture and Farmer Welfare, Government of India. A press brief noted that a less than 1-hectare land plot is a marginal farmer and a 1–2-hectare landholding is a small farmer (1 hectare $\approx$ 150 Katha) [51]. The household survey was conducted in the Bengali language and across genders and ages, for their unique living experiences. The key Informant interviews were conducted with the disaster management officer, agricultural development officer, agriculture extension officers, forest beat officers, local knowledgeable persons like priests, schoolteachers, migrant workers, community leaders and local administrative officers. Multiple times, field walks have taken place to understand the physical and socio-economic Setting. The total number of Key informant interviews is 54. This approach improved contextual knowledge and facilitated the ground truth of the surveyed data.

Secondary data collected from the Census of India (2011 and 2001), the District Statistical Handbook (2014), IPCC reports, WWF, and UNESCO, official records from the Block Development Office and Agriculture Development Office, Jamtala, were used. Multiple literary works, such as newspapers, journals, research papers, books, dissertations, and theses, were accessed for analysis.

3.5. Cyclone Impact Assessment and Score Classification

The effect of the cyclones has been evaluated by examining household-level responses to various types of impact experienced during Cyclone Bulbul (2019), Amphan (2020), and Yaas (2021). Evolution considers impacts related to crop loss, livestock loss, fishing equipment damage, fish mortality, loss of daily wage opportunities, business disruption, house damage, destruction of stored food materials, tree uprooting, and other cyclone-induced livelihood disruptions. Household-level responses are coded and aggregated to generate a total household-level impact score or degree of impact for each of the cyclone events (Table 2).

Table 2. Cyclone impact indicators and coding.

Impact Indicator	Coding	Score
Crop loss	Yes = 1, No = 0	1
Livestock loss	Yes = 1, No = 0	1
Fishing equipment damage	Yes = 1, No = 0	1
Loss of wage opportunities	Yes = 1, No = 0	1
Business interruption	Yes = 1, No = 0	1
Fish mortality in ponds	Yes = 1, No = 0	1
Tree uprooting	Yes = 1, No = 0	1
House damage	Yes = 1, No = 0	1
Storage crops and food materials damage	Yes = 1, No = 0	1
Other livelihood damage	Yes = 1, No = 0	1

The total impact score of each household's impact score is calculated by summing up the reported Impact indicators. Since the indicator is coded as binary, the impact score is calculated using a simple formula:

$$\text{Cyclone Impact Score (CIS)} = \sum_{i=1}^n D_i$$

where $D_i = 1$, if the household experienced any particular impact, $D_i = 0$, the household experienced no impact.

The CIS is defined as equal weightage because the goal of the score is to capture direct cyclone-induced livelihood impact rather than to estimate the monetary or financial severity of individual losses. All the indicators are dichotomous (Presence = 1, Absence = 0), and no empirical or expert-based evidence was available to justify the weightage of the damage indicators. This process leads to an unweighted additive technique, which has been widely utilised for cyclone vulnerability assessment. A higher CIS score means the household experiences a higher level of livelihood-related direct impact following the cyclones.

The recorded damages vary with cyclone intensity, timing, and spatial impact. To maintain compatibility, a cyclone-specific proportional categorisation of impact scores has been employed [52,53]. For cyclones Bulbul and Yaas, the total impact score ranges from 0 to 4. The impacts are categorised as follows: 0 indicates 'No Impact', 1 signifies 'Low Impact', 2 represents 'Moderate Impact', and 3–4 denote 'High Impact'. In the case of the Amphan cyclone, the impact score ranges from 1 to 6. The method of proportional categorisation has been used to reduce scale distortion caused by varying maximum impact ranges among cyclones to facilitate meaningful comparison. The inferential statistics were conducted using an ordinal scale impact while ensuring the data remained statistically appropriate for comparative analysis.

3.6. Data Analysis Techniques

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$$\text{Effect sizes } (\varepsilon^2) = H - k + 1/n - k$$

where, H- Kruskal-Wallis H-test statistic, K is the number of groups, and n-number of observations [54].

The effect size (ε^2) interpretation is evaluated using Peres (2026) classification criteria as Small: $\varepsilon^2 \geq 0.01$, Medium: $\varepsilon^2 \geq 0.06$ and Large: $\varepsilon^2 \geq 0.14$ [55].

The statistical test results were found to be significant at the 5% significance level ($p < 0.05$). The descriptive statistics, cross-tabulation, and Kruskal–Wallis test help to identify the pattern of cyclone impacts on livelihood vulnerability and landholding-related disparities across the study area.

The Kruskal–Wallis test is based on rank ordering. So, this is an appropriate method for the ordinal impact score rather than using a standardised score. The standardised Z-score is not applied here, as this technique will obscure the actual difference in cyclone severity.

4. Results

A household survey was conducted across 11 villages in the Kultali CD block, which is completely rural in character and livelihood dependent on natural resources. Wage labor, fishing, and agriculture are the primary livelihoods. Most households are economically vulnerable, ranging from landless to small landholders. The socioeconomic background provides important context for understanding differences in cyclone vulnerability across livelihood categories.

4.1. Livelihood Structure

The distribution of primary livelihoods across the study area heavily relies on informal and climate-sensitive occupations. The 550-household survey shows that more than 50% of households rely on wage labour as their dominant livelihood due to limited agricultural opportunities, seasonal unemployment, a larger proportion of household landlessness, and greater dependency on the informal labour market. The wage labour livelihood is mainly an adaptive choice to constrain livelihood opportunities. Fishing (21.5%) and cultivation (7.3%) rank as the second and third most dominant livelihoods, respectively. Non-farm, comparatively stable livelihood categories, such as self-employed (7.6%), salaried jobs (6.9%), and business (6.2%), collectively account for a small share of households (Figure 2). This livelihood is mostly linked to income diversification and enhanced livelihood stability, which may contribute to improving adaptive capacity during environmental disasters [56–58]. Households that depend on a single livelihood or only one income source have direct exposure to any climatic shocks. The Sustainable Livelihood Framework also gives importance to livelihood diversification to strengthen adaptive capacity and reduce vulnerability.

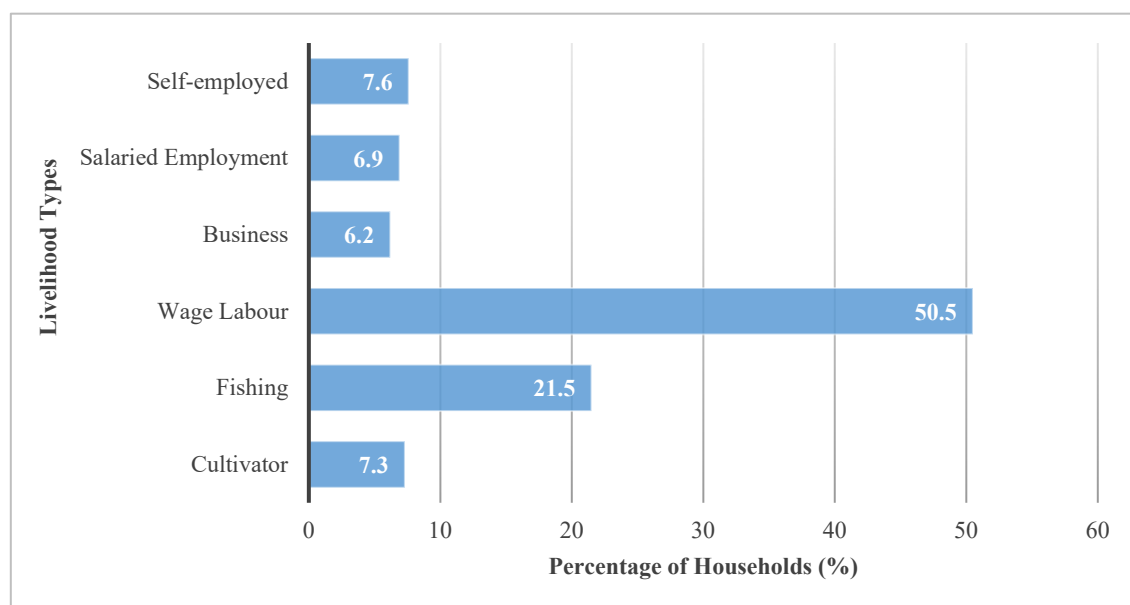


Figure 2. Distribution of primary livelihoods in the study area.

There is a noticeable spatial distribution of livelihoods across the villages in this administrative block. Fishing-based livelihood concentration is observed in Deulbari Debipur (60%), Maipit (50%), and Kaikhali (36%), which shows a greater reliance on aquatic and estuarine resources. In contrast, wage labor is predominant in Jalaberia (76%), Bhubaneswari (68%), Andharia (66%), and Meraganj (58%), which is indicative of an unstable daily payment basis of livelihood. A diversified livelihood structure is found for Jamtala Village, also the block headquarters, where a high proportion of self-employed (40%) is present. The Meraganj village has been profoundly marked by different business activities.

The predominance of wage labor and fishing activity is indicative of economic insecurity, environmental sensitivity, and a high level of exposure within the socio-economic structure. Cyclones, saline water inundation, and environmental instability directly influence income generation and resource availability in this deltaic and

coastal realm. Therefore, the livelihood profile of the study area provides an important contextual basis for understanding differential vulnerability across successive cyclone events.

4.2. Nature of Cyclone Impacts

The categorisation of cyclone impacts was revealed through cross-tabulation techniques. The intensity and extent of impact varied significantly across Cyclones Bulbul, Amphan, and Yaas throughout the study area. The analysis indicates that the impact is not a single factor but rather influences several aspects, such as rural livelihoods, including agriculture, fishing, wage labour, and resource-based activities. The reported impacts came from field investigations, primarily crop loss, fishing equipment damage, fish dying in the pond or canal, loss of daily wage opportunities, business shutdown, tree uprooting, house damage, destruction of stored crops and food materials, and land infertility due to saline water inundation. These impacts replicate the multidimensional nature of cyclone-induced livelihood vulnerability across the study area [47].

Cyclone Amphan was the most devastating of the three cyclones. Based on the degree of impact caused by Cyclone Amphan, 72% of households fall into the moderate effect category, meaning that these households experience three to four types of impact. In comparison, 16% of households are classified in the high category, meaning that these households face an extreme level of vulnerability, such as five to six types of impact. Widespread severity recorded mainly includes house damage (due to the cyclone and sometimes due to the falling of uprooted trees on houses), storage crops and food materials damage, death of fish, livestock loss, crop loss like Moong, vegetables, Betel vine, sesame, and others, and fishing equipment. Some coastal areas face severe vulnerability due to saline water intrusion, inland flooding and embankment breaching in low-lying villages of Kultali. Wind speed and wind direction, along with tide times, control vulnerability, such as inland flooding and waterlogging, as reported in many villages. Almost all homes were impacted by Amphan to varying degrees, as indicated by the low percentage of households in the low-impact group (12%) (Table 3).

Table 3. Distribution of cyclone impact score (%).

Cyclone	No Impact	Low Impact	Moderate Impact	High Impact
Bulbul	13	35	43	9
Amphan	0	12	72	16
Yaas	39	35	23	3

Source: Household Survey, 2025; Author's Calculation using SPSS (version 27).

Cyclone Bulbul shows a moderate level of impact, where 43% household found in this category, 35% in the low-impact category and 13% of households reported no impact from the cyclone (Table 3). The high-impact group are mainly found at about 9%. According to the crop calendar, paddy harvesting starts from the second week of November, and Cyclone Bulbul took place on 10 November 2019, thus resulting in havoc in the agricultural sector. Apart from crop loss, trees were uprooted in a very extensive way, and house damage was also noticeable due to this cyclone. Although the intensity of damage was less than that of the Amphan cyclone, temporary livelihood disruption and damage to fishing equipment were also found at this time.

In contrast to the two cyclones above, Yaas had a lower overall impact on the study area. 39% of households fell under the no-impact category, 35% under the low-impact category, 23% under the moderate-impact category, and 3% under the high-impact category (Table 3). These statistics indicate lower exposure, local preparedness, and measures to eliminate disaster risk. The impact was observed in partial house damage, livestock loss, tree uprooting, storage crop and food damage, and the death of fish due to saline water intrusion in some places.

A comparative analysis of cyclone impacts highlighted an extremely uneven and event-specific distribution. Amphan caused widespread and severe impacts on livelihoods, Bulbul caused moderate impacts, and Yaas caused the least impact. The findings indicate that cyclone disturbance created spatial livelihood insecurity for cultivators, fishers, and wage labourers.

4.3. Impact of Cyclones on Livelihood Groups

4.3.1. Impact of Cyclone Bulbul across Livelihood Groups

A Kruskal–Wallis test was conducted using the original impact score of Cyclone Bulbul to analyse differential impacts across the various livelihoods in this study area. Livelihood dependency on cyclone exposure, risk and adaptive capacity indicates uneven distribution across livelihoods. The cultivators' group recorded the highest mean rank (346.20) (Table 4). The highest mean rank indicates that cultivators are the most vulnerable group among the six livelihood groups, as the cyclone landfall occurred before the crop harvesting period and cultivators face huge

losses due to crop inundation. The fishing household experiences the second-highest impact score (336.64). In contrast, the self-employed household was found to have the lowest mean rank (Table 4), meaning they experienced the lowest impact rate from the Bulbul cyclone. The Bulbul mean rank score clearly indicates that people who are not directly dependent on the environment are less affected by this cyclone.

The result (Table 5) indicates a significant difference among the six livelihood categories ($H = 43.936$, $df = 5$, $p < 0.001$, $\epsilon^2 = 0.072$). The effect size ($\epsilon^2 = 0.072$) (Table 5) of the test is medium, which indicates that socio-economic and environmental factors also play an important role in shaping livelihood vulnerability during the Bulbul cyclone at the household level.

Table 4. Mean rank comparisons of cyclone Bulbul, Amphan and Yaas across the different livelihood categories.

Livelihood Group	N	Bulbul Mean Rank	Amphan Mean Rank	Yaas Mean Rank
Cultivator	40	346.20	291.94	309.75
Fishing	118	336.64	342.37	361.85
Wage Labour	278	253.83	253.20	243.68
Business	34	246.18	290.35	294.75
Salaried Job	38	265.00	247.21	229.55
Self-employed	42	213.10	233.14	236.87

Source: Household Survey, 2025; Author's Calculation using SPSS (version 27).

Table 5. Kruskal–Wallis test results of cyclone Bulbul, Amphan and Yaas (livelihood-wise impact).

Cyclone	H	df	p	ϵ^2
Bulbul	43.936	5	<0.001	0.072
Amphan	34.626	5	<0.001	0.054
Yaas	60.918	5	<0.001	0.103

Source: Household Survey, 2025; Author's Calculation using SPSS (Version 27).

4.3.2. Impact of Cyclone Amphan across Livelihood Groups

The Kruskal–Wallis test was conducted using the actual livelihood impact score at the household level. The test output indicated a significant result that Cyclone Amphan had a widespread impact across the livelihood categories ($H = 34.626$, $df = 5$, $p < 0.001$, $\epsilon^2 = 0.054$) (Table 5). The most affected group constitute mainly of households involved in fishing activity, as Amphan's mean rank score is 342.37. The second-highest mean rank score is the cultivators' group (291.94), followed by business households (290.35). The fishing-based livelihood experienced significant adverse effects due to its direct reliance on the coastal or aquatic ecosystem. This impact was exacerbated by the occurrence of the cyclone (20 May 2020) [59] during the fishing-prohibited period (April–June), resulting in damage to fishing equipment, such as boats and nets, as well as saltwater intrusion, embankment breaching or overtopping, which were among the most prevalent issues. The Lowest mean rank (233.14) was found for the self-employed group.

The effect sizes were found to be small (0.054) from the Kruskal–Wallis test result. The findings indicate a very small magnitude difference. This means livelihood type significantly influences the severity of Cyclone Amphan; the proportion is modest.

4.3.3. Impact of Cyclone Yaas across Livelihood Groups

A Kruskal–Wallis test was conducted to find out Yaas's cyclone impact across the six livelihood groups. The analysis stated statistically significant results ($H = 60.918$, $df = 5$, $p < 0.001$, $\epsilon^2 = 0.103$) (Table 5), which indicates a different type of livelihood impact with variation of cyclone. The fishing-dependent households recorded the highest mean score, 361.85, which means they experienced the severe impact during the Yaas cyclone. The cultivator households (309.75) and business households (294.75) show higher mean rank scores. The dominance of fishing livelihood in the high-impact category reveals that the highest vulnerability is even to comparatively low-intensity cyclone events.

The effect size ($\epsilon^2 = 0.103$) of the Kruskal–Wallis test falls within the medium class. The statistic indicated that cyclone Yaas' impact across the livelihood group is significant. In cases of household vulnerability, other factors play an important role; the livelihood category plays a moderate role in shaping the severity of cyclone-induced impacts.

Cyclone Yaas took place on 23 May 2021, which is also a prohibited fishing period, indicating that they depended directly on this activity, and the pre-existing fishing ban period cut off their income sources, further

damaging fishing equipment, houses, and increasing debt. Furthermore, saline water intrusion, embankment breaching and overtopping increase the potential of vulnerability.

4.4. Landholding Structure of the Study Area

The landholding structure of the study area indicated pre-existing economic vulnerability. Here, landholding data mainly consider only agricultural land plots; data are collected in Katha units (1 Bigha = 20 Katha, whereas Katha corresponds to 720 sq. ft of land area). The Ministry of Agriculture and Farmer Welfare, Government of India, press brief noted that acquiring a less than 1-hectare land plot is a marginal farmer and a 1–2-hectare landholding is a small farmer (1 hectare $\approx$ 150 Katha).

The household survey record stated in the pie graph (Figure 3) that 60.7% of households are landless, followed by 36.4% marginal farmers, and only 3% are small farmers. The distribution pattern highlighted the predominance of landless households, and land ownership is very limited in the Kultali CD block. This uneven distribution significantly influences the socio-economic conditions of the people, such as livelihood dependency, economic instability and less adaptive capacity to any sudden shocks. These statistics also indicate that landless and marginal farmer households share a large portion of the rural population that depends on insecure wage-based occupations. In the case of the Sundarban region, recurrent cyclone impacts like storm surge, inland flooding, and embankment breaching are most common, and as a result, the decline in agricultural productivity declines, which further decreases land-based subsistence. As a result, climate-sensitive farming activities force people to shift their occupations to non-farm-based activities. The landless households are the most vulnerable group in this category, with a limited asset base and livelihood insecurity found in this study area.

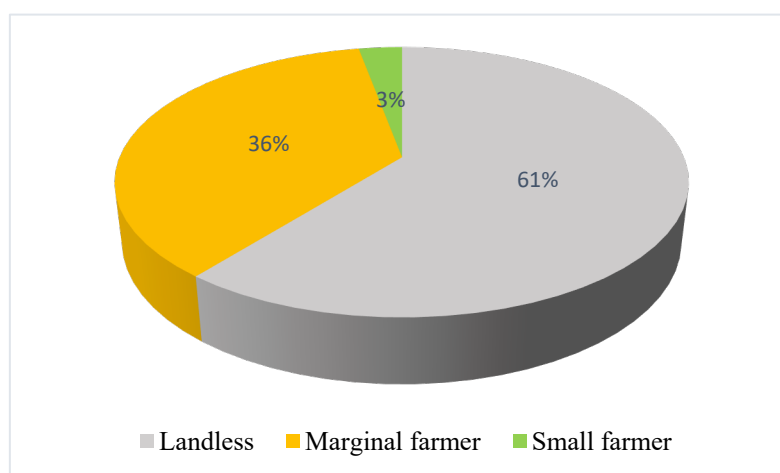


Figure 3. Landholding distribution across the study area.

4.4.1. Impact of Cyclone Bulbul across Landholding Categories

The Kruskal–Wallis test shows a significant result of the Bulbul cyclone across landholdings within the study area. It is clearly stated that small landholders experienced the highest cyclone impact mean score (328.25), followed by marginal farmers' households (324.51). The landless household mean score is the lowest (243.63) (Table 6). This statistic indicates that farming households faced greater vulnerability to cyclones compared to landless households. The agricultural practice is more susceptible in climate-sensitive regions like Sundarban, as this activity is linked to crop loss, saline water intrusion or harm to agricultural resources. The landless people also face a direct impact due to the absence of other productive asset bases.

The effect size of the Kruskal–Wallis test is medium ($H = 39.198$, $df = 2$, $p < 0.001$, $\epsilon^2 = 0.068$) (Table 7). The statistical test clearly stated that agricultural households faced greater direct loss as the Bulbul cyclone coincided with the maturity of the crop and the harvesting period.

Table 6. Mean rank comparisons of cyclone Bulbul, Amphan and Yaas: landholding-wise.

Landholding	N	Bulbul Mean Rank	Amphan Mean Rank	Yaas Mean Rank
Landless	334	243.63	269.48	259.66
Marginal	200	324.51	278.16	301.27
Small	16	328.25	368.00	283.88

Source: Household Survey, 2025; Author's Calculation using SPSS (version 27).

Table 7. Kruskal–Wallis test results of cyclone Bulbul, Amphan and Yaas (landholding-wise impact).

Cyclone	H	df	p	ϵ^2
Bulbul	39.198	2	<0.001	0.068
Amphan	6.593	2	0.037	0.008
Yaas	9.727	2	0.008	0.014

Source: Household Survey, 2025; Author's Calculation using SPSS (Version 27).

4.4.2. Impact of Cyclone Amphan across Landholding Categories

The Kruskal–Wallis test finds a significant impact difference among the landholding categories ($H = 6.593$, $df = 2$, $p = 0.037$, $\epsilon^2 = 0.008$) (Table 7). The smallholders are found to have the highest mean rank (368.00), a highly impacted group by the Amphan cyclone. The marginal landholders rank 2nd in mean rank (278.16) and are followed by the landless householder (269.48) (Table 6). Agricultural practices like Moong, vegetables, Beetle vine, and Sesame were cultivated sparsely during this season.

The effect size (ϵ^2) of the Amphan cyclone score is quite negligible (0.008), which means the landholding explains a very small portion of the variation in cyclone impact score. The Amphan cyclone caused widespread destruction across all the livelihood groups irrespective of landownership status. Although there is a statistical difference observed, the magnitude is limited. The effect size indicates that landholding is not a major determinant of cyclone-induced impact in this context.

4.4.3. Impact of Cyclone Yaas across Landholding Categories

The Kruskal–Wallis test revealed a significant difference in Yaas cyclone score among the landholding categories ($H = 9.727$, $df = 2$, $p = 0.008$, $\epsilon^2 = 0.014$) (Table 7). The marginal farmers recorded the highest rank (301.27), followed by small farmers (283.88). The landless households secured the lowest mean rank (259.66) (Table 6).

The effect sizes (ϵ^2) of the Kruskal–Wallis test for the Yaas cyclone is small (0.014). Although there is a statistical difference present among the landholding groups, the influence is quite modest based on the observation of cyclone impact.

The result indicates that households primarily relay of cultivation remain relatively more exposed to cyclone-related losses, such as crop loss, salinisation of land due to storm surge or embankment breaching, inland flooding due to excessive rainfall, and infertile land as a result of prolong salt water inundation are mainly found in this study area.

5. Discussion

The present study shows that the impact of cyclones Bulbul, Amphan, and Yaas were not uniform across the livelihood and landholding groups in the Kultali CD block, Indian Sundarban. The study analyses the original impact score using the Kruskal–Wallis test. These tests provide a crystal-clear picture based on the actual cyclone impact score rather than categorisation based on the impact class of the cyclones. The statistically significant result confirms that livelihood choice and land assets substantially influence the nature and magnitude of cyclones. The cyclone impact score captures the immediate impact of the cyclones, which are directly related to livelihood and assets, and does not cover the long-term socio-economic stresses or impacts on the people. Therefore, the cyclone impact score can be interpreted primarily as a direct indicator rather than an overall socio-economic indicator of vulnerability of the Kultali CD Block.

5.1. Differential Livelihood Impacts across Successive Cyclones

The present study demonstrated that the Cultivators' households faced a greater impact during Cyclone Bulbul. The Bulbul cyclone landfall time (10 November 2019) [60] coincided with crop harvesting time; as a result, mature crops were smashed and waterlogged due to high wind speed, inland flooding due to excessive rainfall, and saline water intrusion due to high storm surge and embankment breaching [28,60–62]. Damages to crops, reduced income, and increased food insecurity among the cultivators' households. The seasonal sensitivity of farming-based livelihoods created uncertainty among the cultivators.

The fishing households exhibited the greatest vulnerability during cyclones Amphan and Yaas. The people involved in fishing and aquaculture frequently face different types of coastal hazards. The Amphan (20 May 2020) [63] and Yaas (23 May 2021) [64] cyclones made landfall in May, in the fishing-prohibited time zone from April to June (fish breeding period), cutting off their income sources. These cyclone landfalls cause further damage, such as

boat or trawler damage, fishing equipment damage, embankment breaches, and aquaculture water body damage, substantially reducing the recovery rate and reducing income opportunities [65–69]. The repetitive cyclones made the situation even worse, as the cumulative effect created an unstable situation for the families who rely only on fishing.

Wage labour is the dominant livelihood activity in the study area. They secure a lower direct impact score, which means they generally possess limited physical assets that can be directly affected by cyclones. They remain highly vulnerable as they are indirectly impacted through income loss, employment opportunities and declining local economic activity after the cyclone [70].

On the other hand, Self-employed, salaried jobs, and business activities are placed in a lower vulnerability scale because of less direct dependency on climate-sensitive resources and have diversified income sources and better adaptive capacity to fight against unusual circumstances.

5.2. Differential Cyclone Impacts across Landholding Groups

The findings reveal that the impacts of cyclones across the landholding groups are different across the study area. Households with agricultural land experience greater direct loss because their productive assets are directly exposed to cyclone hazard. The greater impact was observed for marginal and small landholders, as they experience a higher level of asset exposure rather than socio-economic vulnerability. The landless household has the lowest mean score for the three cyclones; this does not mean that they are less vulnerable to cyclone impact. Landless households generally have fewer assets, meaning they have less direct exposure to cyclone impact, as the cyclone impact score is based on direct cyclone impact. Landless households mainly depend on a daily income source, such as casual labour or informal activities, which are disrupted due to the cyclone's impact in the post-hazard period. Temporary unemployment and indebtedness, which cut off income sources, often hinder recovery.

These findings state that small and marginal farmer households face a greater direct loss, whereas landless households indirectly experience chronic socio-economic vulnerability due to a limited asset base and less adaptive capacity. This distinction can be explained through the Sustainable Livelihood Framework (SLF) [44,45], that vulnerability is not shaped by physical exposure but also by assets, financial support, and institutional support. The Pressure and Release (PAR) Model also states that disaster emergence intersects with natural hazards and pre-existing poor socio-economic conditions such as unemployment, no asset base and limited access to resources [42].

The overall finding indicated that there is a need for a disaster risk reduction policy which accounted direct asset vulnerability and indirect livelihood vulnerability separately in the Sundarban region. Agricultural and fishing households should take measures like climate-resilient agriculture and fisheries practices and crop insurance to reduce losses [71,72]. The landless and daily wage earner households need stronger social protection, livelihood diversification, employment security, and post-disaster assistance [73,74]. The disaster-based preparedness plan, such as strengthening and regular maintenance of the embankment and early warning, and institutional support, are needed to reduce exposure and develop a resilient society [75]. Recognising this distress, the vulnerability pathway should incorporate an equitable and context-specific solution for the hazard-prone coastal region.

6. Conclusions

The present study examined the differential impact of cyclones Bulbul, Amphan and Yaas on livelihood groups and landholding categories across the Kultali CD block, Indian Sundarban. The 550-household survey and 54 KIIs reveal that cyclone vulnerabilities are not evenly distributed across the population; they are strongly influenced by livelihood choices and dependencies, asset ownership, and exposure to successive cyclones.

Cyclone Bulbul had a direct impact on cultivators' households, occurring during the harvesting period of the Aman paddy season. The cyclones Amphan and Yaas affected the fishing households the most directly. These findings indicate that livelihood vulnerability varies according to the nature of the cyclone and household dependency on natural resources. The Study further revealed that landholding has a significant influence on direct cyclone impact. The marginal and small farmer households experience a greater loss due to asset exposure. In contrast, landless households experienced a lower damage rate due to a limited physical asset base. The landless households are highly vulnerable to indirect livelihood disruption, employment instability and reduced wages in the post-cyclone period and have less recovery capacity. The present study examines the importance of disaster impact assessment differently between direct asset exposure and indirect socio-economic vulnerability.

This study will contribute to the growing literature on livelihood vulnerability and the importance of landholding in the Indian Sundarban. This study not only compares the assessment of successive cyclone impact also provides rank-based statistical analyses with original cyclone impact scores, unfolding a robust picture of livelihood vulnerability. This will have significant implications for disaster risk reduction and climate adaptation. Disaster risk

reduction is not concentrated on relief operations, but rather includes livelihood-specific interventions, climate-resilient farming, crop insurance, livelihood diversification and targeted support for vulnerable groups. Additionally, there is a need to strengthen adaptive capacity by improving the early warning system, infrastructure, communication, and long-term life support mechanisms, especially in the post-disaster phase, to reduce cumulative vulnerabilities.

Future studies should incorporate longitudinal research for both direct and indirect micro-level livelihood loss and a multidimensional vulnerability assessment in the post-disaster period of successive cyclones. In-depth research will help to understand the actual resilience pathway and design evidence-based disaster risk management strategies in similar vulnerable coastal regions.

Author Contributions

P.M.: Conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing—original draft preparation; S.S.: Conceptualization, supervision, writing—review and editing; T.G.: conceptualization, supervision, writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable. Jadavpur University does not have an IRB system applicable to this study. This study is a community-based social science study involving household surveys and key informant interviews, and it did not involve any clinical intervention, medical procedure, or experimental treatment. Therefore, formal IRB approval was not obtained for this study. Nevertheless, informed consent was obtained from participants prior to data collection, and confidentiality and voluntary participation were maintained throughout the research process.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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