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Research article

Evaluating the Relationship between Adaptation and Loss and Damage: A Case Study of Southern Coastal Bangladesh

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A B S T R A C T

Southern coastal Bangladesh faces escalating climate-induced disasters, placing immense stress on vulnerable communities and exceeding their adaptive capacities. Although loss and damage (L&D) is now recognized globally, the quantitative relationship between household adaptation strategies and L&D outcomes remains underexplored. This study aims to quantitatively assess how various household adaptation strategies influence the extent of L&D. It seeks to establish an empirical relationship between adaptation efforts and climate-induced L&Ds to guide effective resilience-building interventions. A total of 200 households from Munshiganj and Buri Goalini unions of Satkhira were surveyed using random sampling. Principal Component Analysis (PCA) used to construct indices for adaptation and L&D. Six adaptation components and six L&D dimensions were extracted. Multiple linear regression was then applied to evaluate how adaptation factors predict L&D outcomes. Results indicate that while community engagement and agricultural innovation significantly reduce L&D, overall adaptation measures explain only 23.6% of the variance in L&D. Many households fall into a 'Medium adaptation-medium L&D' profile, others remaining highly vulnerable due to insufficient adaptation or external compounding risks. Migration and housing adaptation showed moderate effectiveness, whereas cropping, environmental conservation, and educational efforts had limited standalone impact. The findings reveal that while adaptation is essential, it is not sufficient alone to fully mitigate L&D. Integrated resilience strategies are necessary, addressing both social vulnerabilities and environmental shocks. This evidence can inform targeted interventions by policymakers, NGOs, and local authorities to enhance adaptation planning and reduce the risk of irreversible L&D in climate prone regions.

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Introduction

Natural disaster and climate change both are considering as global crisis nowadays, create a huge impact and make people vulnerable, leading to significant loss and damage that often surpasses their capacity to adapt. The concept Loss and Damage has gained formal recognition and ranked by United Nations Framework Convention on Climate Change (UNFCCC) not too long ago but over the past few decades it has got attention for international policy and framework. A suggestion on insurance and funding for damages associated with sea level rise was made by the Alliance of Small Island States (AOSIS) during the UNFCCC's founding in the early 1990s (INC 1991; Mechler et al., 2020). At COP16 in Cancun, the parties agreed to establish a work program on loss and damage under the Cancun Adaptation Framework (CAF) which was the first formal acknowledgment of loss and damage within the UNFCCC process ("COP 16 Cancun," 2010) and at last A major turning point was reached at COP27 in Sharm El-Sheikh, Egypt, when it was decided to create a specific Loss and Damage Fund (COP27; UNFCCC). A crucial chance to talk about four key themes is presented by COP 29 in Baku: 'A synergistic financing framework, Transformative adaptation, Tech ecosystems to avert disasters and Resilient infrastructure and infrastructure for resilience' (COP 29 Baku, 2024). So, it is cleared that over three decade Loss and Damage has got huge attention to the international climate policy makers because the issue of Loss and Damage has emerged as a critical challenge, particularly for vulnerable countries and communities like Bangladesh. Southern Bangladesh is one of the disaster prone areas in the world. Due to disaster and

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climate change, certain losses and damages are unavoidable but can be reduced by taking adaptation strategies. People are more likely to migrate or relocate in order to improve their circumstances and maintain and protect their livelihoods as a result of the impacts of climate change and trying to reduce their Loss and Damage, which are already being felt by communities all over the world. These changes are having an impact on the habitability of places and the ability to sustain livelihoods (McNamara et al., 2018).

According to the UNFCCC, loss and damage encompass both slow-onset processes like sea level rise and harms brought on by sudden-onset occurrences, such cyclones and other climate disasters (McNamara et al., 2018; Murthy et al., 2023; Naz et al., 2024). In the context of loss and damage, two particular features are frequently discussed. The tools and methods used to address, assess, monitor, and control the loss and damage are included in the technical dimension. Conversely, the political aspect centers on the boundaries of equitable compensation, adaptation to climate change, and fairness (Naz et al., 2024). According to Warner & Geest (2013) loss and damage is considered to be the unfavorable consequences of climate change and unpredictability that humans have not been able to adapt to or cope with. Loss and damage has an unbreakable connection to adaptation and mitigation activities, as stronger mitigation efforts will result in lessening the effects of climate change and a reduction in the need for adaptation. Although these are acknowledged definitions of loss and damage, but in the context of disaster and climate change, loss and damage can be defined as the consequences of the unfavorable effects of the change of climate due to disaster that cannot be prevented through adaptation or mitigation measures.

There are different theories which are linked with loss and damage in the lens of adaptation, such as, Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA), migration including migration as adaptation and climate-induced migration, vulnerability, resilience etc. DRR is the theory and practice of lowering the losses and damages of disasters by methodically analyzing and managing the elements that lead to them like decreased exposure to hazards, decreased vulnerability of people and property (Begum et al., 2014). CAA is the method by which individuals minimize the negative consequences of climate change on their health and well-being (Burton, 1997). The theory of migration as adaptation can be understood in a way that migration can be a strategic response by individuals or communities to adapt to climate change and post disaster situation, by seeking better opportunities or safer living conditions elsewhere (Vinke et al., 2020). Climate-induced migration is the movement of people who are forced to leave their homes due to the impacts of climate change or disaster for making their current living conditions untenable (Lyster & Burkett, 2018). As higher vulnerability typically leads to greater loss and damage as vulnerability is related to post disaster effects, but through increasing resilience adaptive capacities can be enhanced (Nyamwanza, 2012; Paton et al., 2000). This research examines vulnerability and resilience through an adaptation lens, showing how resilience mitigates the high loss and damage caused by vulnerability.

Warner and van der Geest (2013) examine that community-based case studies in nine at-risk countries focus on how climate change impacts local people. They gather data on losses, social effects, and how people are dealing with the stress caused by climate change. While these studies give useful perspectives into local effects, they are not easy to apply to other regions or scale up. They also explain that using different methods like focus groups, expert interviews, household surveys, and local weather data helps to understand the losses and damages from climate change in detail. However, this mixed-methods approach requires a lot of resources and makes it hard to apply the findings more broadly. Moreover, they found that a mixed-methods approach, which uses both numbers and personal experiences, is the best way to study how families adapt to climate change. This method is also flexible for understanding loss and damage (Warner & Geest, 2013). McNamara et al. (2018) explained that even though semi-structured interviews and document analysis in places like Kiribati and Alaska take a lot of time and are specific to those locations, they provide deep insights into social and political issues related to migration caused by climate change. Naz et al. (2024) explained that using case studies and interviews help to understand loss and damage in depth with a viewpoint of migration as adaptation perspective in coastal Bangladesh, but this approach can take a lot of time, may be biased, and is hard to apply to larger trends. Bose & Mishra, (2021) agreed that while using a capital-based approach is complex and might oversimplify how different assets are linked, it does cover a wide range of effects from floods, including losses that aren't just about money.

From the study of ‘Household Climate Change Adaptation (CCA) and the loss and damages’ several research gaps is identified from existing literature. Firstly, there is a huge epistemological and ontological gap. Secondly, most of the literature we reviewed used qualitative method, no quantitative literature on Loss & Damage is found. Lastly, a little research has been found out to show or draw any specific conclusions about the relationship between household adaptation and loss and damages. Therefore, the main purpose of our study to establish a relationship between adaptation and loss & damage that might enhance the knowledge in the field of disaster and climate studies.

This paper emphasizes to develop indexing of household level both for adaptation strategy extents and loss and damage extents at the beginning, then make a relationship between these two distinctions. The findings will be helpful for us to measure the adaptation level and loss and damages and it will also comprehend about what kind of initiative can be taken to increase the adaptation capacity and deteriorate the amount of damages. Also, this finding will beneficial for planners, local authorities, administrators, non-governmental organization (NGO) to take action on expanding adaptation strategies.

Research Methodology

Study Area Selection

Munshiganj and Buri Goalini union of Shyamnagar Upazila are selected as the study area for this study. These areas are close to the coastal area and people of this area frequently face different kinds of natural disaster such as flooding, cyclone and river bank erosion. People here try to adapt by changing their livelihoods like switching to salt-resistant crops, crab and shrimp farming. But as these climate threats keep growing, these adaptation efforts are becoming less effective. These areas are highly dynamic and exposed to climate risks, which means people are constantly adapting to changing conditions, which is consistent with this research. The study area map is shown in the following figure.

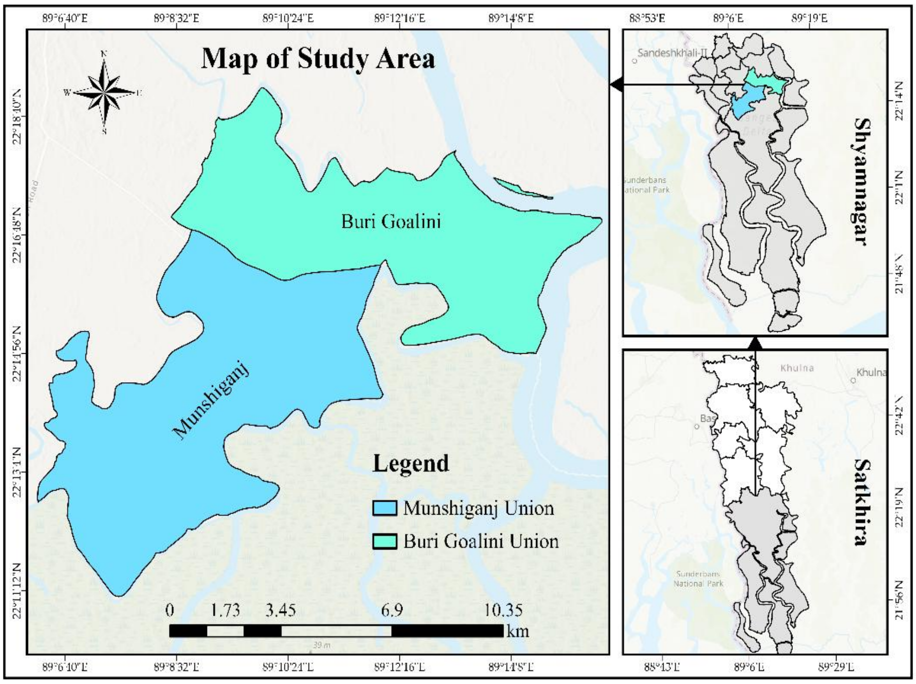

Figure 1: Study Area Map

Sample Size
Sample size is selected by following Yamane sampling formula, which is shown at equation *i* and modified at equation *ii*.

$$n = \frac{N}{1+Ne^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(i)$$

Here, $n = \frac{(N_1+N_2)}{1+(N_1+N_2)e^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$

Where, n is the sample size, N_1 Munshiganj which is 31832 and and N_2 is total population of Buri Goalini union is 24913, and e is the standard error or confidence level which is considered 7% in this study as less than 10% is standard. It is taken 7% to reduce sample size as the authors did not take any funding for the study.

So, total sample size, $n = \frac{(31832+24913)}{1+(31832+24913)*0.07^2} = 203.35$ ≈ 200

This research is mainly focused on the household questionnaire survey. This sample size is chosen to ensure a comprehensive understanding of how local communities are affected by climate hazards and to investigate how they cope with or adapt to unavoidable losses. By collecting feedback from a variety of individuals within these unions, we obtained a comprehensive understanding of local experiences and strategies. This sample size is sufficient for reliable findings and accurately represent the challenges facing the community which is shown in Table 1 and Table 5.

Sampling Technique
Firstly, multi-cluster sampling method was used to select the clusters from the study area which shown in the following Figure 2. Then random sampling technique was used to select 200 participants from the chosen clusters. Random sampling means that each person in the study area has an equal chance of being chosen, helping to ensure that the sample represents the larger population. By randomly selecting participants, we reduced biasness and gather data that more accurately reflects the views and experiences of the community. This approach strengthens the validity of our findings on adaptation and loss and damage by capturing a diverse set of perspectives within the study area.

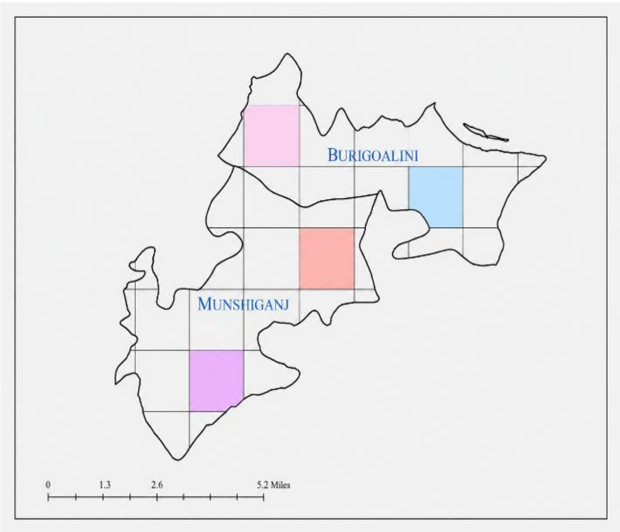

Figure 2: Sampling Technique

Factor Selection

The factors of adaptation taken in different dimensions like physical infrastructure development and repair, migration and occupation shift, cropping system, cyclone shelters and volunteer programs, educational shift, non-agricultural income, community awarenesss and training etc. and the factors are showed in Table 1.

Table 1: Factors for Adaptation Strategies

Factor(s)	Author(s)
Embankment Construction and Repair, Occupation Shift, Mixed Cropping System, Changing Cropping Patterns, Household Structural Improvements, Cyclone Shelters and Volunteer Programs, Infrastructure Development, Shift to Technical Education	(Ahmmed et al., 2020)
Migration, Buffalo and Poultry Farming, Tree Planting	(Ahmmed et al., 2020) (Alam et al., 2017)
Cultivation of direct seeded rice, Cultivation short duration rice, Changing planting and harvesting date, Conversion of agricultural land into mango orchard, Practice of agroforestry, Use of different crop varieties	(Abdur Rashid Sarker et al., 2013)
More Aman rice with supplementary irrigation, Cultivation of jute, wheat, and plum, Cultivation of different type of pulses	(Abdur Rashid Sarker et al., 2013), (Alam et al., 2017)
Change planting time, Cultivating vegetable, Petty business, Off-farm work (van, rickshaw, tampo driving), Non-agricultural, Duck rearing, Livestock rearing, Cultivating HYV rice varieties (e.g., BRRI-28), Cultivating spices and oil seed	(Alam et al., 2017)
Switching to Saline-Tolerant Rice Varieties, Pond Sand Filters (PSF) and Rainwater Harvesting, Excavation and Raising of Ponds, Switching to Non-Farm Livelihoods, Temporary and Permanent Migration, Loans and Financial Adjustments, Collecting Water from Distant Sources, Using Freshwater to 'Wash' Fields, Raising Seed Beds with Fresh Soil, Community Awareness and Training Programs, Cyclone Shelters and Community Safety Programs, Water Source Rehabilitation, Repairing Irrigation Channels	(Rabbani et al., 2013)

Table 2 outlines the comprehensive set of factors used to measure the multidimensional nature of loss and damage, categorized into health, structural, agricultural, and socio-economic domains. These metrics assess both tangible impacts, such as infrastructure destruction and income loss, and intangible effects, including social displacement and psychological stress.

Table 2: Factors for Loss and Damage

Factor(s)	Author(s)
Increased Medical Expenses, Increased number of water-borne disease	(Owiyo, 2013) (Lilibeth A. Acosta, 2016)
Increased number of chronic cardiac issues, Increased number of skin diseases	(Bimal Kanti Paul, 2011) (Rube ´n J. Lara, 2009)
Increased Pregnancy incautions among women	(Schindler, 2016)
Increased mental illness	(N. Hilker, 913–925) (Lucinda Coates, 2014)
Inundation of toilet	(Owiyo, 2013) (rutten, 2014)
Inundation of house structure, Damage of toilet, Increased no of death, Damage to road culvert	(Bodo Damm, 2015)
Inundation of road culvert	(C.A. Velásqueza, 2014)
Inundation of tube-well	(Lilibeth A. Acosta, 2016) (Geest, 2018)
Food Insecurity	(Lilibeth A. Acosta, 2016) (Qiwei Yu, 2018) (Seydou Traore, 2013)
Loss of agricultural production	(A. Bhattachana, 2018)
Loss shrimp production, Increased Unemployment, Increase in saline concentration bin surface water source	(Owiyo, 2013)
Loss fish production, Loss of crab production	(Qiwei Yu, 2018)
Loss of agricultural land	(Heidi Kreibich, 2015)
Migration	(Wei Houa, 2018)

Increased domestic violence against women, Increased number of conflicts of resource collection, Increased number of conflicts on relief collection	(Lilibeth A. Acosta, 2016)
Hampered education of children	(C.A. Velásqueza, 2014) (Aline Costa Minervino, 2015)
Enforcement of children into work	(Aline Costa Minervino, 2015)
Increased number of early marriage cases	(Lilibeth A. Acosta, 2016)
Increased Livelihood of expenses , Loss of income	(Geest, 2018)
Reduced savings	(Lilibeth A. Acosta, 2016) (Schindler, 2016)
Indebtedness	(Golam Rabbani, 2013)
Shortage of rainwater	(Schindler, 2016)
Increased in poll surface water source, Depletion of groundwater table	(Lilibeth A. Acosta, 2016)

Data Analysis Procedure

To meet the objectives of this research, Principal Component Analysis (PCA) based indexing was followed, and then multiple linear regression was used to predict the relationship between adaptation and loss and damage.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a technique used to reduce the dimensionality of a dataset by creating principal components. PCA is used in for data reduction, uncovering latent structures, and simplifying multivariate data while minimizing information loss. It does this by transforming the data into a new set of uncorrelated variables called principal components, which capture the most variance in the dataset. Through PCA, we will get some factors for both adaptation and loss & damage.

Generating Index

Firstly, indicators are normalized by using HDI method. The equation is given below,

$$Index\ X_s = \frac{X_S - X_{min}}{X_{max} - X_{min}} \quad \text{(iii)}$$

Where, index X_s is normalized index value, X_s is original indicator value, X_{min} and X_{max} are the minimum and maximum value of indicator.

After normalizing the indicators, and completing PCA, the factors scorers are added together for indexing and the equation is given below,

$$Adaptation\ index = \frac{(Factor1 + Factor2 + Factor3 + \cdots)}{Total\ number\ of\ factor} \quad \text{(iv)}$$

$$L\&D\ index = \frac{(Factor1 + Factor2 + Factor3 + \cdots)}{Total\ number\ of\ factor} \quad \text{(v)}$$

Linear Regression

Linear Regression is a used to examine the relationship between dependent and independent variables. Through the regression we can assess the relationship between adaptation and loss and damage. The dependent variable is Loss and damage Indexing result and the independent variable is different factors of adaptation extracted from PCA. The equation of linear regression is given below,

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+......+\epsilon \quad \text{(vi)}$$

Where, Y is the dependent variable, X_1, X_2, X_3 are independent variables and β_1, β_2, β_3 are coefficients.

Results and Discussion

Adaptation Index

To assess whether the adaptation indicators were suitable for dimensionality reduction, Principal Component Analysis (PCA) was applied and sampling adequacy as well as sphericity were evaluated. The overall KMO value was 0.687, indicating moderate adequacy, while Bartlett's Test of Sphericity was significant ($\chi^2 = 1215.860$, df = 406, $p < 0.001$), confirming that the correlation matrix was appropriate for PCA (Table 2).

In addition to the overall KMO, the KMO Measure of Sampling Adequacy (MSA) for each variable, obtained from the anti-image matrix and the extraction communalities were examined to justify indicator retention. All retained indicators met the commonly accepted criteria of MSA ≥ 0.50 and communality ≥ 0.40 (or 0.50). Indicators failing to satisfy these thresholds were removed or transformed prior to the final factor extraction (Table 3).

Table 3: KMO and Bartlett's Test for Adaptation

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.687
Bartlett's Test of Sphericity	Approx. Chi-Square	1215.860
	df	406
	Sig.	.000

These results confirm that the dataset is adequate for factor analysis. The moderate KMO value (0.687) suggests that the sample is reasonably representative, while the significant Bartlett's Test ensures that the variables are meaningfully correlated. This allows for the exploration of latent dimensions or patterns in household adaptation strategies in the context of loss and damage, helping to identify the key drivers and impacts within the dataset.

Table 4: Rotated Component Matrix for Adaptation

Variables Name	Components					
	1	**2**	**3**	**4**	**5**	**6**
Participated in community volunteer program	0.550					
Switched to cultivating direct seeded or short duration rice varieties	0.629					
Crop area is now devoted to short duration rice or other innovative crop varieties	0.555					
Attended community awareness or training programs on climate adaptation	0.676					
Initiatives to repair local irrigation channels	0.720					
Engage in livestock, buffalo, or poultry farming		0.562				
Benefited from local infrastructure development		0.640				
Taken any loans to support adaptation measures		0.500				
Access to improved irrigation systems		0.404				
Contributed to embankment construction or repairs		0.419				
Percentage of household income derived from non-agricultural work		0.356				
Migrated temporarily or permanently			0.702			
Estimated cost of improvements of house			0.610			
Structural improvements			0.546			
Adopted mixed cropping systems or changed cropping pattern			0.373			
How far you travel to collect fresh water			0.366			
Percentage of your total crop area is devoted to mixed cropping				0.602		
Percentage of household income generated from livestock and poultry farm				0.573		
Percentage of crop area now devoted to short duration rice or other innovative varieties				0.505		
Effectiveness of embankment construction and repairs				0.396		
Engaged in tree planting activities					0.645	
Tree planted in last year					0.475	
Pond sand filters or rain water harvesting					0.530	
Make use of cyclone shelters during emergency					0.421	
Shifted to technical or vocational education						0.456
Type of technical education pursued						0.575
Usefulness of community programs						0.642

Table 4 presents the full rotated component matrix with complete indicator names, rotated factor loadings across all six components, and corresponding communalities (h^2). Principal Component Analysis was conducted using Varimax rotation with Kaiser normalization, and factor loadings with absolute values below 0.40 were suppressed for presentation clarity. Cross-loadings were evaluated and flagged where an indicator exhibited loadings greater than 0.30 on more than one component or where the difference between the two highest loadings was less than 0.20, ensuring transparency in component interpretation. Component labels were assigned based on the indicators exhibiting the highest factor loadings within each component. To ensure conceptual clarity, the revised factor-naming table explicitly lists the indicators and their dominant loadings that justify each component label, thereby strengthening the empirical basis for factor interpretation (Table 5).

Table 5: Naming the Factors Resulted from PCA for Adaptation

Components	Name of PC
PC 1	Community Engagement and Agricultural Innovation
PC 2	Livelihood Support and Economic Measures
PC 3	Migration and Housing Adaptation
PC 4	Cropping and Resource Management
PC 5	Environmental and Water Conservation
PC 6	Education and Community Programs

The scree plot reveals that the first six components (Community Engagement and Agricultural Innovation, Livelihood Support and Economic Measures, Migration and Housing Adaptation, Cropping and Resource Management, Environmental and Water Conservation, Education and Community Programs) have eigenvalues greater than 1, signifying that each of them explains more variance than an individual variable. According to the Kaiser criterion, these components are considered significant and should be retained for analysis. These components are critical for capturing the underlying structure of the data and represent key adaptation factors.

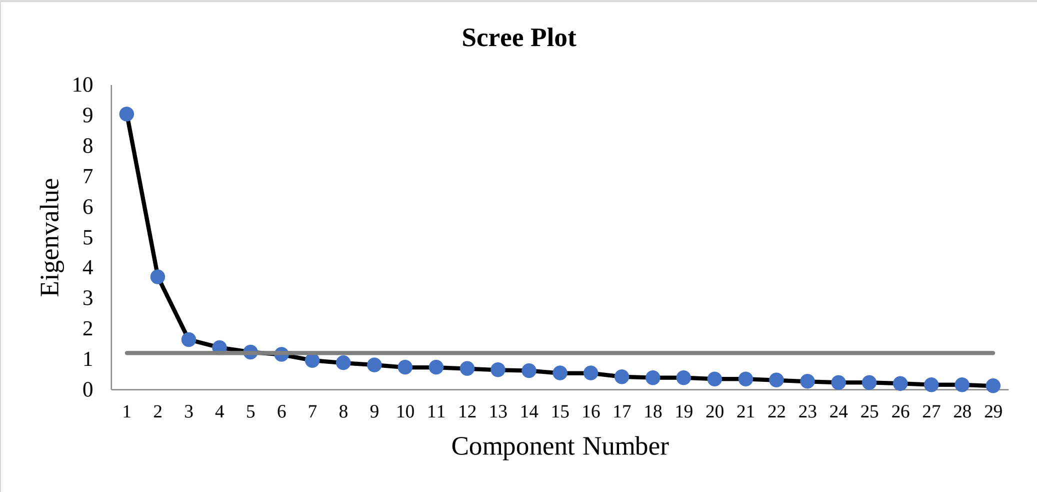

Figure 3: Scree Plot for Adaptation

On the other hand, the remaining components, with eigenvalues below 1, contribute only marginally to the explained variance. Including them would add little value to the analysis and could introduce unnecessary complexity, so they can be disregarded. This approach ensures a balance between dimensionality reduction and retaining meaningful information.

Table 6: Frequency of Adaptation Indexing Result for Adaptation

Adaptation Index	Frequency	Percentage
High	23	11.5
Low	51	25.5
Medium	126	63.0
Total	200	100.0

The household-level Adaptation Index was used to classify respondents into High, Medium and Low adaptation categories using an explicitly defined cut point rule based on percentiles. The exact threshold values applied for classification are reported. Medium Adaptation (63%). The majority of households (126 out of 200) fall under the "Medium" category, indicating a moderate level of adaptation efforts or success in mitigating climate-related risks. A significant proportion (51 households) are in the " Low Adaptation (25.5%)" category, reflecting limited adaptation measures, potentially due to resource constraints, lack of awareness, or other barriers. And only 23 households have achieved "High (11.5%)" adaptation levels, showcasing robust and effective strategies. This group represents a smaller, better-prepared segment of the population. The distribution suggests that while most households are making moderate efforts to adapt, a notable portion remains vulnerable due to low adaptation, emphasizing the need for targeted support to bridge this gap. Additionally, increasing the number of households in the "High" category would enhance overall resilience.

Loss and Damage Indexing

For loss and damage, the table presents the results of the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity, both used to assess the suitability of the dataset for factor analysis. The overall Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy for the Loss and Damage (L&D) indicators was 0.646, indicating a moderate level of adequacy and approaching the lower acceptable bound for Principal Component Analysis. Bartlett's Test of Sphericity was statistically significant ($p < 0.001$), confirming that the correlation matrix was appropriate for factor extraction. In addition to the overall KMO value, variable-level measures of sampling adequacy (MSA) obtained from the anti-image correlation matrix and extraction communalities (h^2) were examined.

Indicators exhibiting low MSA values or weak communalities were evaluated critically and were excluded or transformed prior to the final PCA to ensure the robustness of the L&D component structure (Table 7).

Table 7: KMO and Bartlett's Test for Adaptation

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.646
Bartlett's Test of Sphericity	Approx. Chi-Square	1562.225
	df	561
	Sig.	.000

These results confirm that the dataset is adequate for factor analysis. The moderate KMO value (0.646) suggests that the sample is reasonably representative, while the significant Bartlett's Test ensures that the variables are meaningfully correlated.

Table 8 presents the full rotated component matrix for the Loss and Damage Index, including complete indicator names, rotated factor loadings across all six components and corresponding communalities (h^2). Principal Component Analysis was conducted using Varimax rotation with Kaiser normalization and factor loadings with absolute values below 0.40 were suppressed for clarity of presentation. Cross-loadings were examined and flagged where indicators exhibited loadings greater than 0.30 on more than one component or where the difference between the two highest loadings was less than 0.20, thereby ensuring transparency in the interpretation of component membership.

Table 8: Rotated Component Matrix for Loss and Damage

Variables Name	Components					
	1	2	3	4	5	6
Agricultural land been lost due to environmental issues	0.512					
Increase in domestic violence or conflicts	0.564					
Disruption of education of child	0.634					
Child labor	0.733					
Early marriage	0.708					
Condition of girl due to early marriage	0.441					
An increase in pollution of local surface water sources		0.367				
An increase in conflicts over resource or relief collection in community		0.423				
Increased mental health issues (stress, anxiety, depression)		0.473				
An increase in water-borne disease cases		0.392				
Damage of toilet or sanitation system		0.719				
Damage to nearby roads or culverts affecting access to essential services		0.645				
Structure has been inundated or sustained any structural damage		0.701				
Shortage of rainwater for drinking or irrigation			0.714			
Increase in the saline concentration in surface water sources			0.778			
Increase in pollution of local surface water sources			0.560			
Temporarily or permanently migration				0.412		
Difficulty in securing enough food				0.404		
Losses of agricultural production				0.452		
Estimated condition of loss				0.600		
Reduction in shrimp, fish, or crab production				0.384		
Condition of production lost				0.421		
Condition of the total land has been lost				0.632		
Increase in pregnancy-related health issues					0.531	
Experienced skin-related diseases					0.359	
Condition of skin related diseases					0.427	
Developed or experienced an increase in chronic cardiac issues					0.423	
Death attributed to recent environmental or health issues					0.588	
Members have migrated					0.501	
Able to save money in the past year					0.336	
Average monthly expense on medical needs						0.447
Medical needs expense amount increased						0.489
Experienced water-borne diseases						0.306
Had to take on debt to cope with recent challenges						0.599
Amount of debt						0.402

The six extracted components represent distinct dimensions of loss and damage and were interpreted based on the indicators exhibiting the strongest factor loadings within each component. To ensure conceptual clarity, the revised factor interpretation table explicitly lists the indicators and their dominant loadings supporting each component label (PC1-PC6), thereby strengthening the empirical justification for component naming (Table 9).

Table 9: Naming the factors resulted from PC for Loss and Damage

Components	Name of PC
PC 1	Environmental Degradation and Land Loss
PC 2	Health and Social Well-being
PC 3	Infrastructure Damage and Resource Scarcity
PC 4	Economic Challenges and Food Security
PC 5	Migration and Loss of Livelihood
PC 6	Resilience and Coping Mechanisms

The scree plot reveals that the first six components have eigenvalues greater than 1, signifying that each of them explains more variance than an individual variable. According to the Kaiser criterion, these components are considered significant and should be retained for analysis. These components are critical for capturing the key aspects of loss and damage. On the other hand, the remaining components, with eigenvalues below 1, contribute only marginally to the explained variance. Including them would add little value to the analysis and could introduce unnecessary complexity, so they can be disregarded. This approach ensures a balance between dimensionality reduction and retaining meaningful information.

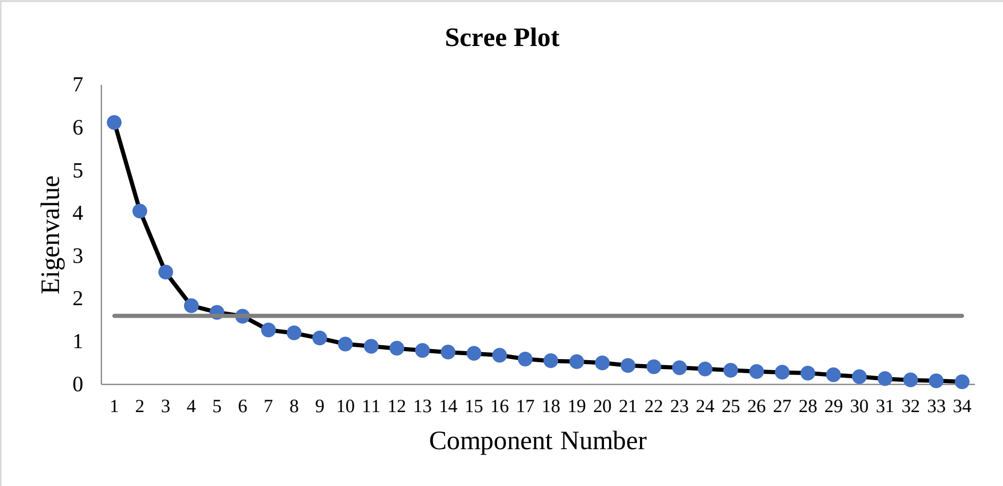

Figure 4: Scree Plot for Loss and Damage

Table 10: Frequency of Loss and Damage indexing result for Loss and Damage

Loss and Damange Index	Frequency	Percentage
High	43	21.5
Low	25	12.5
Medium	132	66.0
Total	200	100.0

The household-level Loss and Damage Index was used to classify respondents into High, Medium and Low loss and damage categories using an explicitly defined cut point rule based on percentiles. The exact threshold values applied for classification are reported. The validity of the index is further assessed by examining its association with relevant external or objective indicators, such as reported infrastructure damage and income loss (Table 10). Medium level of loss and damage (66%). The majority of households (132 out of 200) fall under the "Medium" category, indicating that most households experience a moderate level of loss and damage which suggests a significant portion of the population is somewhat impacted but not severely. A notable proportion (43 households) are in the "High (21.5%)" category, reflecting they experience substantial loss and damages. These households are highly vulnerable and may require more targeted support and resources to mitigate the impacts. And 25 households fall into low category, indicating minimal loss and damages. These households are less vulnerable compared to others and this can be because of their better adaptation strategies or lower exposure to disaster risk.

Co-existence between Adaptation and Loss & Damage

The scatter plot provides a visual representation of the relationship between the Adaptation Index (x-axis) and the Loss & Damage (L&D) Index (y-axis). Low Adaptation Index, High L&D Index Top-Left quadrant households are highly vulnerable due to low levels of adaptation efforts and measures. They suffer significant loss and damage as they lack sufficient protective or mitigating strategies. So we have named this category as “High Vulnerability Zone”. High Adaptation Index, High L&D Index Top-Right Quadrant indicate households with high levels of adaptation efforts but still experiencing high levels of loss and damage, indicating external or compounding challenges. So, we have named this category as “Resilient but Struggling Zone”. Low Adaptation Index, Low L&D Index Bottom-Left Quadrant reflect households with low levels of adaptation efforts and low levels of loss and damage, likely due to reduced risk exposure or the presence of other unmeasured protective factors. This category is identified as “Passive Zone”. High Adaptation Index, Low L&D Index Bottom-Right Quadrant represent households with high levels of adaptation efforts and low levels of loss and damage. These households are effectively managing disaster risks through robust adaptation strategies, resulting in minimal loss and damage, and this category is named as "Optimal Adaptation zone.

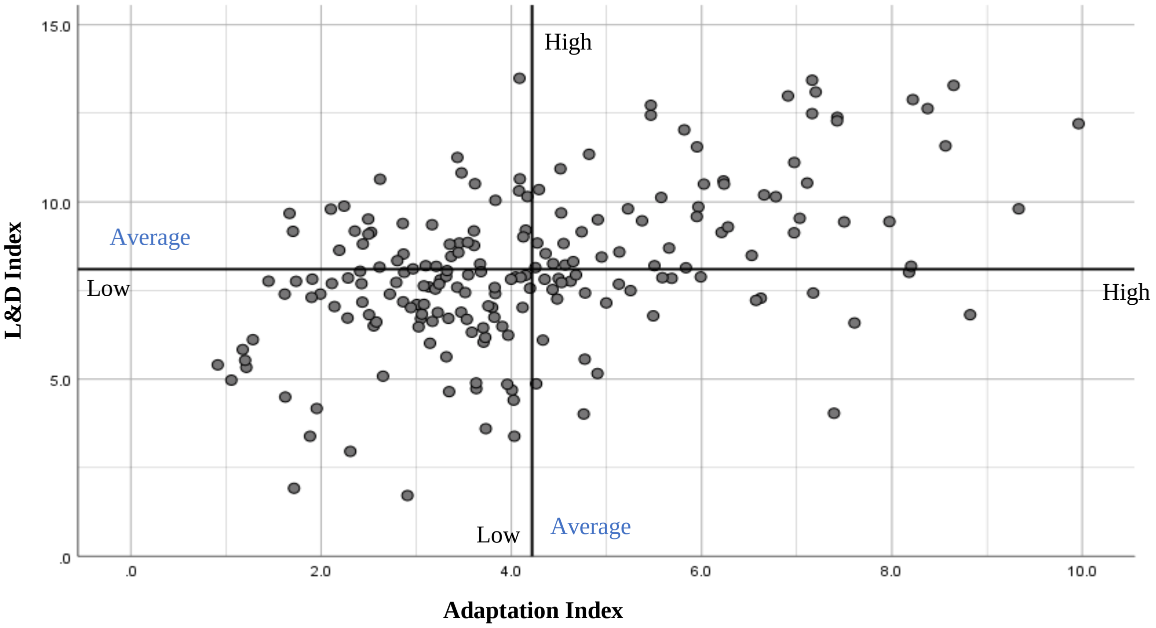

Figure 5: Adaptation and Loss & Damage Indices

The scatter plot (Figure 6) is highlighting the correlation between adaptation measures and the extent of loss and damage experienced by households. Top-Left Quadrant: "High Vulnerability Zone "(cyan circle), households in this quadrant have low adaptation measures and suffer high levels of loss and damage, these household are in worst situation. Top-Right Quadrant: "Resilient but Struggling Zone" (yellow circle), households in this quadrant face higher level of loss and damage but have higher adaptive measure and they can overcome this situation over time by high networking, get relief from local government and NGO. Bottom-Left Quadrant: "Passive Zone" (purple circle), households here exhibit low adaptation measures but also low levels of loss and damage. This could be due to a lower exposure to disaster risks or inherent protective factors that are not measured. These households are less vulnerable compared to others. Bottom-Right Quadrant: "Optimal Adaptation Zone" (blue circle), households in this quadrant have high adaptation measures and experience low levels of loss and damage. They are in the best situation compared to others. But in our study area these number of households are minimal as we can see from the scatter plot.

Relationship between Adaptation and Loss & Damage

The multiple regression analysis indicates that the six adaptation dimensions collectively have a statistically significant association with the Loss and Damage Index. The model produces an R value of 0.485 and an R^2 of 0.236, indicating that the predictors collectively explain **23.6% of the variance in the Loss and Damage Index**. The adjusted R^2 is 0.212, suggesting that approximately **21.2% of the variance** remains explained after adjustment for the number of predictors and sample size. The overall model is statistically significant (Sig. F Change < 0.001).

Table 12: Model Summary of Regression Model for All parameters of Adaptation

Model Summary[b]						
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Change Statistics**	
					R Square Change	**Sig. F Change**
1	.485[a]	.236	.212	1.953	.236	.000

a. Predictors: (Constant), Community Engagement and Agricultural Innovation, Livelihood Support and Economic Measures, Migration and Housing Adaptation, Cropping and Resource Management, Environmental and Water Conservation, Education and Community Programs

b. Dependent Variable: Loss and Damage Index

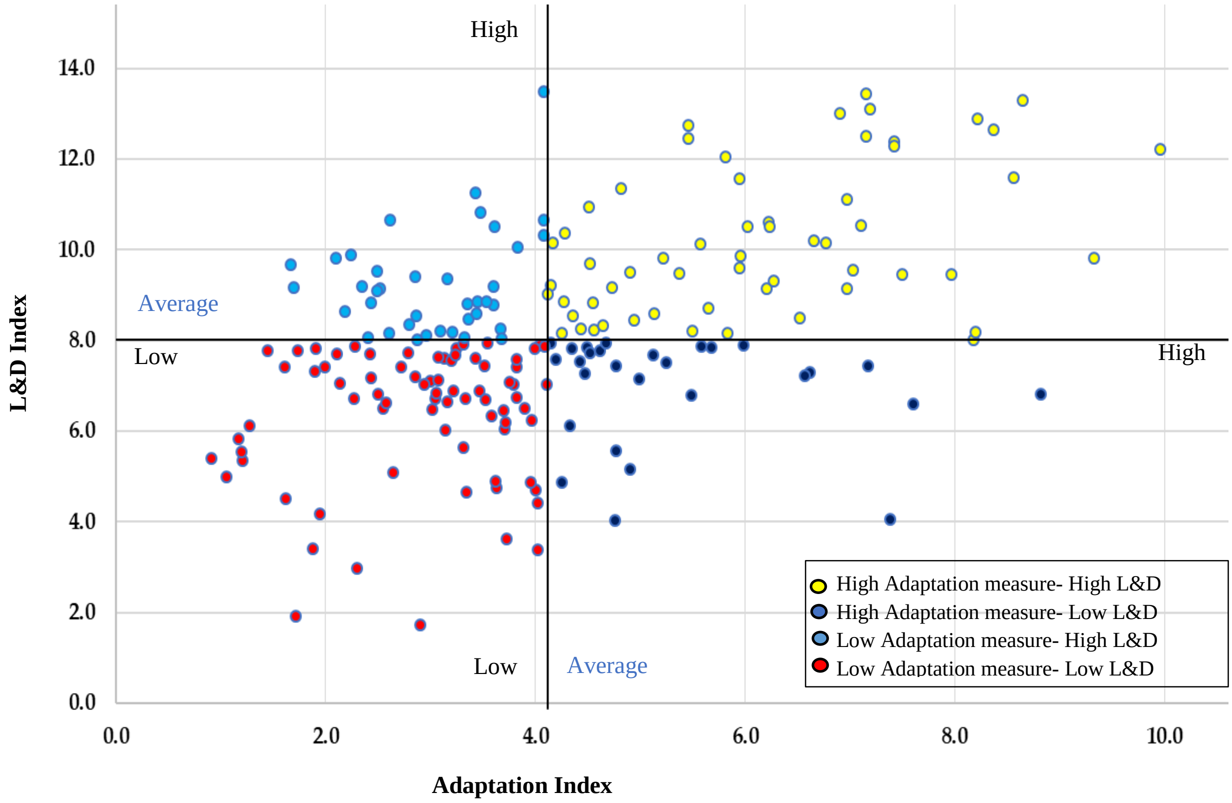

Figure 6: Nature of co-existence

The coefficient table reflects that 'Community Engagement and Agricultural Innovation' is the strongest predictor in the model. A one unit increase in this factor reduces the L&D Index by 0.863 units. 'Livelihood Support and Economic Measures' predictor is statistically significant but less impactful which reflects moderate effectiveness in reducing L&D. 'Migration and Housing Adaptation' predictor is statistically significant and moderately impactful, indicating that migration and housing adaptations help reduce L&D. Other three predictors are not statistically significant and reflect that these have minimal effect in reducing L&D.

Table 12: Coefficients of Regression Model for All parameters of Adaptation

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	8.104	.138		58.656	.000
	Community Engagement and Agricultural Innovation	.863	.139	.392	6.231	.000
	Livelihood Support and Economic Measures	.362	.139	.165	2.614	.010
	Migration and Housing Adaptation	.444	.139	.202	3.208	.002
	Cropping and Resource Management	.162	.139	.074	1.173	.242
	Environmental and Water Conservation	.169	.139	.077	1.221	.223
	Education and Community Programs	.112	.139	.051	.807	.421

Coefficients[a]

a. Dependent Variable: Loss and Damage Index

Discussion

Household adaptation plays a critical role in reducing Loss and Damage (L&D), particularly through community engagement programs and agricultural innovations. These measures were found to be the most effective, with each unit increase in adaptation efforts leading to a reduction of 0.863 units in the L&D index. Migration and housing adaptations also contributed to lowering L&D; however, their overall explanatory power was limited, accounting for only 4.1% of the variance. In contrast, changes in cropping patterns, environmental conservation initiatives and education programs showed limited individual statistical significance in reducing L&D, suggesting that their impacts may be more indirect or context-dependent.

Despite the presence of adaptation strategies, L&D remains widespread among households. Approximately 66% of households experience moderate levels of L&D, primarily driven by reduced agricultural yields, losses in fisheries and climate-related health impacts such as water-borne diseases and the incidence of early marriages. Moreover, 21.5% of households face high levels of L&D, which are closely associated with inadequate adaptation measures and greater exposure to disasters.

The findings further highlight the complex co-existence of adaptation and L&D. Adaptation efforts alone do not ensure complete mitigation of L&D, as external factors such as the intensity of disasters, systemic inequities and limited access to resources continue to influence household vulnerability. Notably, some households with relatively high levels of adaptation still experience substantial L&D, underscoring the need for integrated and multi-dimensional resilience-building approaches.

Overall, households that adopted robust adaptation strategies, particularly those emphasizing strong community engagement and innovative practices are tended to experience lower levels of L&D. However, adaptation measures collectively explained only 23.6% of the variance in L&D, indicating that a significant proportion of loss and damage is shaped by broader structural vulnerabilities and external shocks beyond household-level adaptation efforts.

Conclusions

This study demonstrates a clear association between household adaptation strategies and levels of loss and damage (L&D) in Southern Coastal Bangladesh. Community engagement and agricultural innovations are more strongly associated with lower L&D, while other measures such as cropping changes, environmental conservation and education programs show limited individual associations. However, adaptation alone does not prevent L&D, as households with higher adaptation levels may still experience significant losses due to factors such as disaster intensity, structural inequalities, and resource constraints. The findings indicate that adaptation measures explain only part of the variation in L&D, highlighting the importance of broader systemic and external influences. These results suggest the need for integrated resilience-building approaches that combine household adaptation with institutional and structural support. The study has limitations, including its cross-sectional design, small localized sample, reliance on self-reported data and potential overlap between adaptation and L&D indicators, which restrict causal interpretation. Despite these constraints, the findings offer useful insights for policymakers and development practitioners in designing more targeted and context-sensitive climate resilience interventions.

Conflict of Interest

The authors declares no conflict of interest.

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