



Climate Change, Anthropogenic Stressors, and Livelihood Sustainability in the Sundarbans, Bangladesh: A Field-Based Analysis

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Abstract: The Sundarbans Forest is a vital mangrove ecosystem where environmental processes and human livelihoods are closely intertwined. In Bangladesh, the forests and adjacent bodies of water provide protection against coastal hazards, support a variety of flora and fauna, capture carbon and sustain communities that rely on natural resources. However, the region is also becoming increasingly vulnerable to hydro-climatic risks and stresses related to human activities. This research employs a convergent mixed-methods approach based on primary fieldwork conducted in the Bangladeshi part of the Sundarbans. It incorporated a household survey of 400 participants, 150 semi-structured interviews, six focus group discussions (FGDs) and 20 key informant interviews (KIIs). Field observations, GPS tracking and photographs were used to record local environmental and livelihood conditions. The analysis distinguishes the evidence obtained from this fieldwork from the results documented in the wider literature on the Sundarbans and coastal Bangladesh. Of the 400 households surveyed, 267 (66.8%; 95% CI: 62.1–71.4%) reported direct exposure to sudden-onset disasters, and 324 (81.0%; 95% CI: 77.2–84.8%) reported experiencing significant economic hardship due to disaster events. Additionally, 358 households (89.5%, 95% CI: 86.5–92.5%) reported having health problems related to water. These observations are cross-sectional and self-reported, so cannot establish causal relationships between climate attribution and clinically diagnosed illness. Qualitative evidence shows that environmental hazards, in addition to human-made and institutional stressors, like salinity, brackish reared aquaculture, livelihood disruption, informal high-interest loans (*Dadan*) and restriction in forest access are factors that affect household vulnerability and coping mechanisms. The study argues that a holistic approach of drinking water security, livelihood diversification, disaster preparedness, ecosystem-based adaptation and provision of institutional support are important to achieve sustainable livelihoods in the Bangladesh Sundarbans.

Keywords: Sundarbans; Climate Change; Anthropogenic Stressors; Livelihood Vulnerability; Water Security; Ecosystem-Based Adaptation; Coastal Governance.

INTRODUCTION

The Sundarbans is the world's largest continuous mangrove forest and is a transboundary tidal wetland that

stretches across Bangladesh and India (Shamsuzzoha & Biswas, 2010). The ecosystem is influenced by semidiurnal tides and sediment transport, freshwater–saltwater interactions, and estuarine processes, and it supports globally

significant biodiversity, such as the Bengal tiger (*Panthera tigris*) and the Irrawaddy dolphin (*Orcaella brevirostris*). The Sundarbans Reserve Forest (SRF), Bangladesh, is the primary element of the Bangladeshi ecosystem. The legally protected forest and the broader ecological landscape, as well as the broader coastal zone where people live and their livelihoods depend, are not geographically congruent, so evidence on people and livelihoods should be understood in relation to the geographic unit from which it was collected.

The Bangladesh Sundarbans is also a coupled social–ecological system. Forest-dependent livelihoods are fishing, crab collection, honey collection and beeswax collection, and collection of non-timber forest products like Golpata (*Nypa fruticans*). Forest resource access is managed through permits and seasonal access, creating a linkage between household livelihoods and forest ecology and regulation. But vulnerability is not just a result of environmental exposures, it also depends on access to resources, assets, markets, infrastructure, credit, and governance.

Interplaying climatic and human-induced pressures

The southwest coastal area is exposed to fast onset and environmental changes. Immediate losses of assets and income are possible in the event of significant cyclones, storm surge, saline flooding, waterlogging and embankment failure, while salinity, freshwater resource fluctuations, and hydrology changes can affect agricultural production, freshwater resource access, fisheries and mangrove diversity over longer time scales. Previous research has reported uneven salinity threats and different ecosystem responses of species in coastal Bangladesh and the Sundarbans (Dasgupta et al., 2015; Dasgupta et al., 2017a, 2017b).

Simultaneously, human activities can alter both exposure and the ability to adapt. Regional findings have linked the growth of brackish aquaculture to the reduction of agricultural land, increased salinity, and waterlogging (Ahmed & Ambinakudige, 2023; Shamsuzzoha et al., 2026). Ethnographic studies have demonstrated that daily experiences of salinity are influenced by infrastructure, aquaculture, embankments, and developmental activities (Sen, 2023). These interrelated processes justify the need to explore environmental stress, livelihood results, and institutional factors collectively instead of viewing climate risks as separated drivers (Dasgupta et al., 2016; Sajal et al., 2026).

Study objectives and research questions

The research seeks to explore how environmental hazards, human-induced pressures, and institutional factors interact with livelihood stress faced by individuals directly involved with the Bangladesh Sundarbans. It aims to: (i) record documented experiences of disasters and water-related issues; (ii) analyze livelihood disruptions and the coping and adaptation methods of households; (iii) pinpoint environmental and institutional pathways mentioned by field participants; and (iv) create a framework that can facilitate the future of socioeconomic insights with ecosystem accounting.

- How are climatic hazards and anthropogenic environmental pressures associated with livelihood stress among the field-surveyed population within the Bangladesh Sundarbans?
- How do households perceive environmental change, experience livelihood losses, and respond through coping or adaptation strategies?
- Which institutional and governance conditions constrain or facilitate livelihood adaptation and resource access?
- How can field-based environmental and socioeconomic evidence contribute to a policy-relevant framework for ecosystem resilience and livelihood security?

CONCEPTUAL AND EMPIRICAL BACKGROUND

Climate, hydrology, and salinity

Salinity is a major environmental factor in the southwest coastal region that affects both freshwater availability and the quality of the soil, water and aquatic ecosystems, farming and plant life. Using data from 41 monitoring stations and environmental factors, Dasgupta et al. (2015) simulated the future salinity of soils in coastal Bangladesh, which also had considerable spatial variation. Dasgupta et al. (2017a) examined how aquatic salinization and fish habitat would change under different climate scenarios and identified some of the potential impacts on poor populations that depend on fish for their livelihood. Dasgupta et al. (2017b) pointed out species-specific responses to salinity, including reduced abundance of *Heritiera fomes* at higher salinities for mangrove vegetation. These research results call for considering salinity as a multi-faceted exposure, where the impacts on livelihoods are different by location, ecological characteristics, infrastructure and the dependence of the household on natural resources (Figure 1).

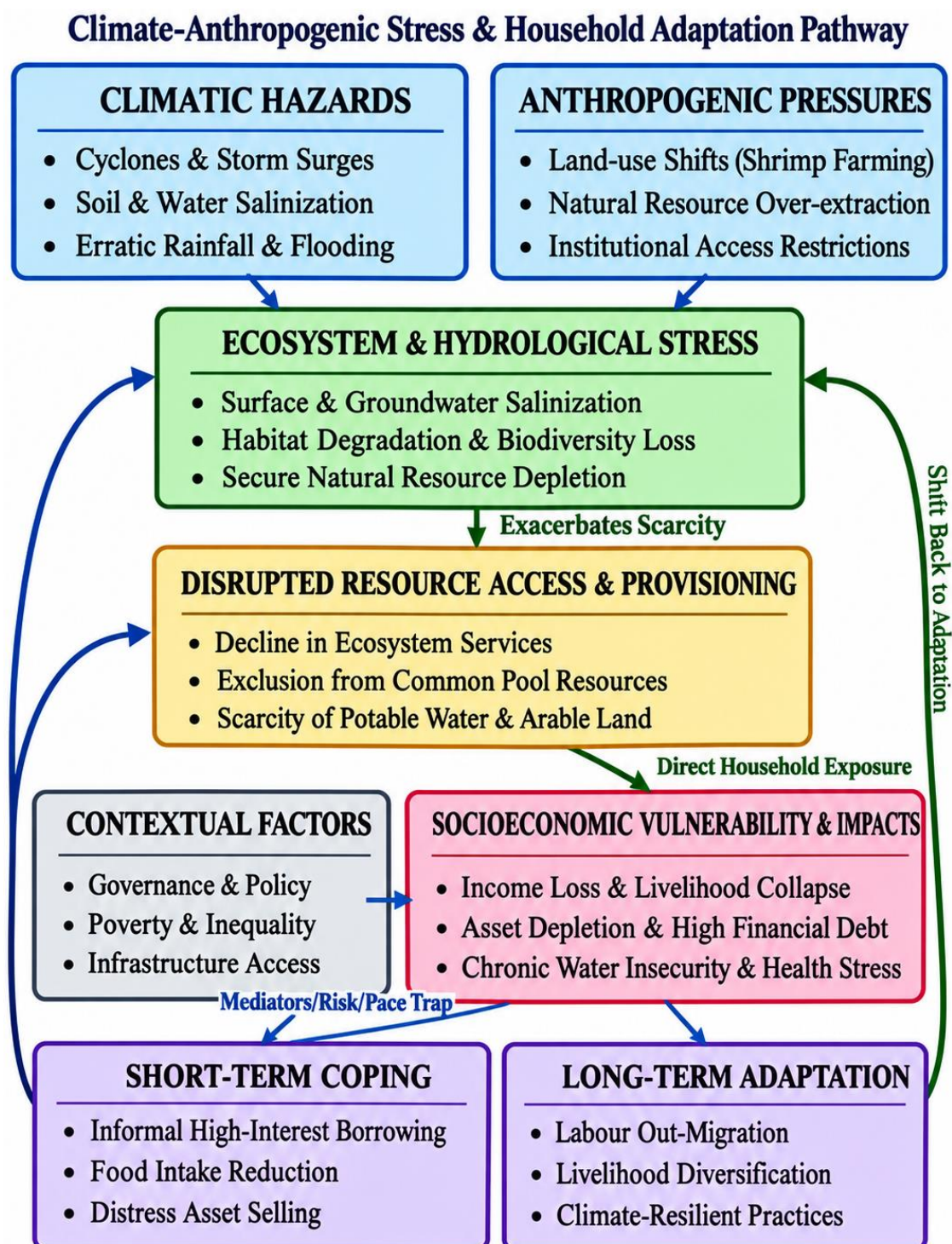


Figure 1: Conceptual framework of socio-ecological setting of the Sundarbans ecosystem

Land use, aquaculture, and anthropogenic stress

Human-related pressures work in conjunction with climate change. Ahmed and Ambinakudige (2023), using the data from three coastal upazilas in the southwest Bangladesh highlighted reductions in agricultural land alongside the expansion of shrimp farms, waterlogging, and rising salinity. Because the study did not directly sample the Bangladesh

Sundarbans Reserve Forest, its findings are used here solely as regional contextual evidence. Similarly, Hossain et al. (2024) documented long-term modifications in land cover across the larger Sundarbans using remote sensing. These results provide a broader environmental context but are not regarded as primary evidence from the current field sample.

The difference between firsthand evidence and contextual literature is quite large. This research is not designed to have conducted household surveys in areas outside of the designated study areas, nor is it intended to replace the use of regional literature for primary observations. Rather, existing data is used to explain mechanisms outlined by the participants and to bring the field findings into the frame of existing research.

Livelihoods, adaptation, and governance

Household responses to environmental stress on livelihoods are related to household assets, land and credit availability, social networks, gender responsibilities, market conditions, infrastructure, and institutional structure. For families living on natural resources, there may be several challenges in the Sundarbans: ecological disruptions can affect productive assets; seasonal access limitations can reduce income opportunities at times when families have the least options available. Unregulated loans can be a quick fix for cash but may lead to extended loan repayment challenges. Adaptation, therefore, needs to be understood as happening inside the household and as an institutional and political-economic process (Dasgupta et al. 2020; Sen 2023).

3STUDY AREA AND FIELD SETTING

For this study, primary empirical fieldwork was carried out in the accessible areas of the Bangladesh Sundarbans in 2022. The study is based on observations and experiences gathered from the persons met in the forest, and related field sites, then yielding a separate household survey of the adjacent peripheral communities. The Bangladesh Sundarbans Reserve Forest is spread across an area of about 6,017 km² and managed by Bangladesh Forest Department (Figure 2). The field setting includes mangrove forest, tidal creeks and rivers, estuarine environments, and resource use sites used for fishing and other forest-based activities.

Handheld GPS tracking was maintained during field operations to document field movements and coverage. Field photography was used as observational documentation of activities and environmental conditions, including fishing equipment, boats, water collection, and other visible features. Because the present manuscript is based on field evidence rather than a completed remote-sensing analysis, no unverified 2011–2022 land-cover, vegetation-index, shoreline, or salinity-change statistics are reported.

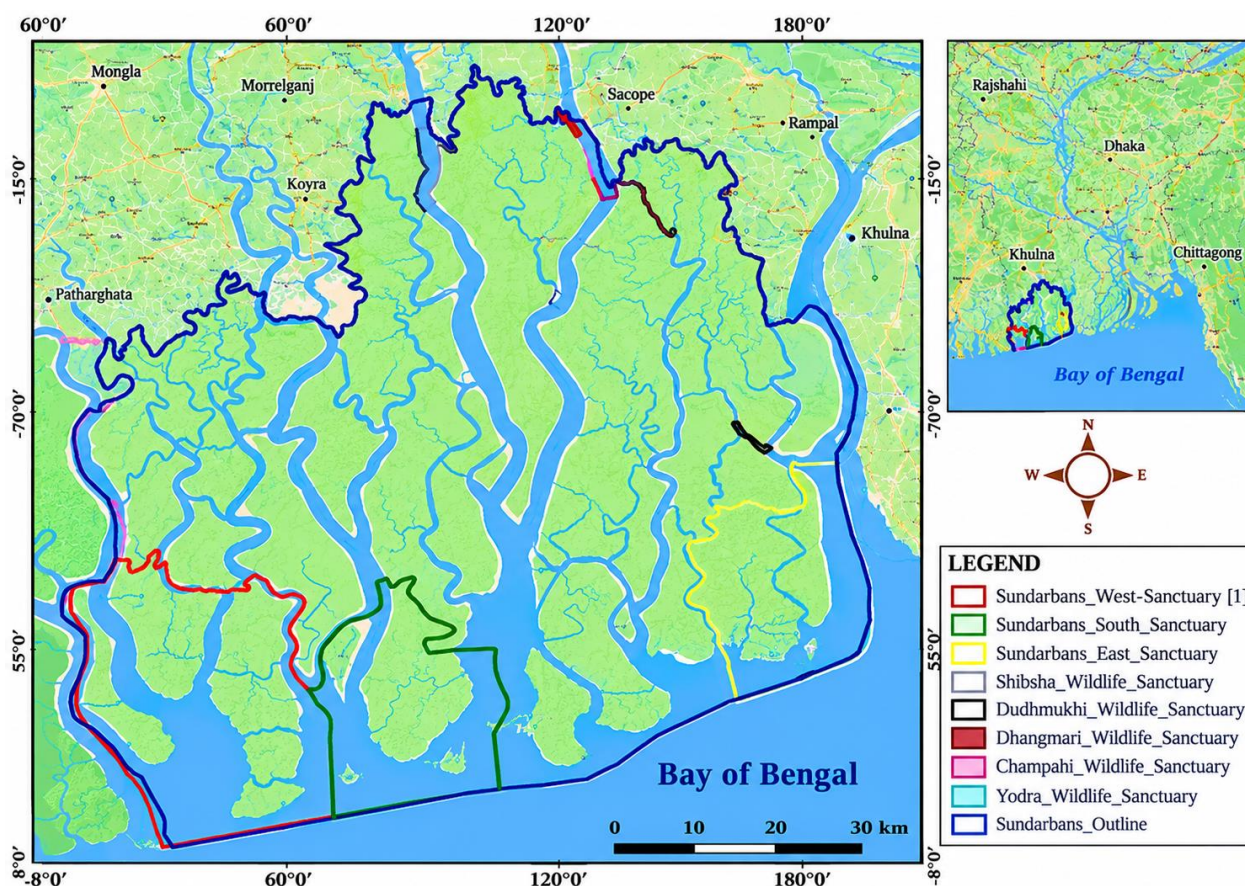


Figure 2: Map of the Sundarbans mangrove forest showing different zones of ecological conservation

MATERIALS AND METHODS

Research design

A convergent mixed-methods design was used, with quantitative and qualitative evidence analysed separately and then interpreted together around common constructs: environmental exposure, livelihood stress, water insecurity, health-related concerns, coping and adaptation, resource dependence, and institutional constraints. Mixed-methods integration is appropriate where quantitative evidence can

describe the distribution of reported outcomes while qualitative evidence provides contextual explanations of experiences and mechanisms (Creswell & Plano Clark, 2018).

The primary quantitative component comprised a structured household survey of 400 respondents conducted in 2024. The qualitative component comprised 150 semi-structured interviews, six FGDs, and 20 KIIs. GPS field tracks and photographs provided supplementary spatial and observational documentation.

4.2 Primary data streams

Data stream	Sample/scope	Analytical role	Provenance
Household survey	n = 400	Quantitative description of reported disaster exposure, economic hardship, and water-related health problems	Primary field data
Semi-structured interviews	n = 150	In-depth accounts of livelihood stress, coping, adaptation, and environmental experiences	Primary field data
Focus-group discussions	6 FGDs	Collective perspectives on shared risks, livelihood conditions, and institutional interactions	Primary field data
Key-informant interviews	20 KIIs	Governance, resource-access, and administrative perspectives	Primary field data
GPS field tracking	Field tracks	Documentation of field movements and fieldwork coverage	Primary field data
Field photography	Visual records	Observational documentation on livelihood activities and environmental conditions	Primary field data
Peer-reviewed literature	Published studies	Contextualisation and interpretation; not substituted for primary observations	Secondary evidence

Quantitative analysis

The current verified quantitative analysis is descriptive. Three primary indicators are reported: direct exposure to a sudden-onset disaster, severe economic hardship associated with disaster events, and self-reported water-related health problems. Percentages are calculated as the number of households reporting the outcome divided by the 400 households surveyed. Approximate 95% confidence intervals are reported using the simple-random-sampling normal approximation, with $Z = 1.96$. These intervals are descriptive and should not be interpreted as design-based population estimates unless the sampling design supports such inference.

Because the survey is cross-sectional and the current manuscript does not report a fully specified multivariable model, associations are not interpreted as causal effects. Reported disaster exposure is not treated as proof of climate-change attribution, and self-reported water-related health problems are not treated as clinically confirmed disease.

Qualitative analysis

Interview, FGD, and KII material was organized through thematic content analysis around six core analytical categories: (i) hydro-climatic hazard experiences; (ii) economic and asset losses; (iii) drinking-water and health vulnerabilities; (iv) resource dependence and extraction practices; (v) short-term coping versus longer-term adaptation; and (vi) institutional constraints and governance perceptions. The qualitative evidence is used to identify recurring mechanisms and experiences rather than to estimate population prevalence.

Evidence integration and SEEA EA linkage

The study uses the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) as a prospective framework for organizing evidence rather than claiming that a complete ecosystem account has already been produced. SEEA EA distinguishes ecosystem extent, ecosystem condition, ecosystem-service flows, and ecosystem-related monetary accounts (United Nations et al., 2021). The socioeconomic and service-use components of such an accounting structure can be provided by the present field evidence and should be based on currently available validated sets of data; spatial ecological and monetary components will need other validated sets of data with explicit methodological assumptions.

RESULTS

Household exposure and livelihood stress

The survey findings suggest that most of the 400 respondents experienced environmental stress (Figure 3). 267 respondents (66.8%, 95% CI: 62.1%-71.4%) directly experienced a disaster event and 324 respondents (81.0%, 95% CI: 77.2%-84.8%) had experienced significant economic hardship in relation to a disaster. Water-related health problems were reported by 358 respondents (89.5%; 95% CI: 86.5–92.5%). These results indicate that not only do environmental shocks occur as physical shocks, but they also have additional impacts on household livelihoods and access to key resources.

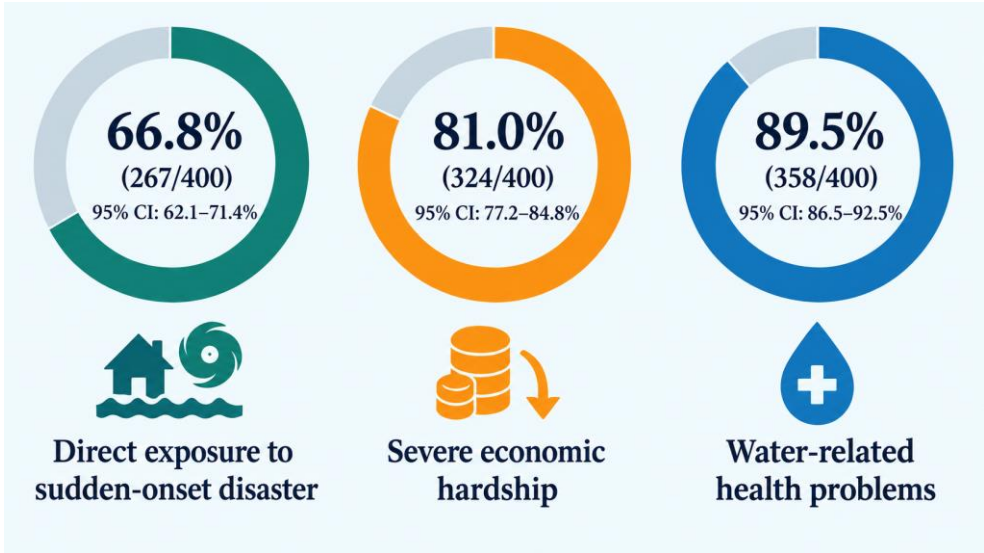


Figure 3: Reported environmental and livelihood stress indicators among surveyed respondents (n=400)

But the three indicators should not be looked at as a direct causal chain. The qualitative descriptions provide some insight into the pressures that may be reinforcing in practice. For instance, loss of productive assets or income due to cyclone impact or saline flooding, and reduced access to freshwater imposes extra domestic and health burdens. In situations where other income-generating activities and/or formal assistance are scarce, households may turn to borrowing or other coping mechanisms.

The value of mixed-methods design is that the survey provides an overview of the extent of reported stress within the study sample, while the qualitative evidence offers insight into how these challenges are experienced and managed in everyday livelihood settings. These results

describe reported experiences in the study sample. They do not establish trends in disaster frequency, quantify the causal contribution of climate change, or establish clinical disease prevalence. The water-related indicator should therefore be interpreted as self-reported health problems potentially related to water conditions.

5.2 Qualitative livelihood-impact pathways

The interview and FGD findings show that livelihood disruption was rarely the result of a single pressure. Instead, respondents described multiple, overlapping stressors that affected different parts of their livelihood system. Figure 4 presents the key pathways identified from the qualitative data.

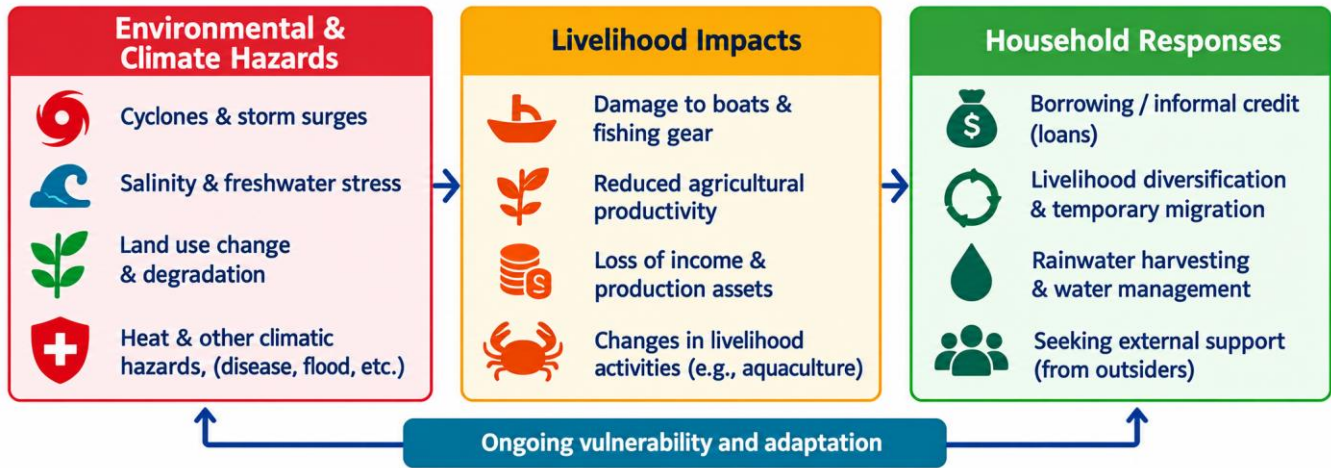


Figure 4: Interconnected pathways of livelihood stress (as reported in qualitative interviews and FGDs)

Cyclones and storm surges primarily resulted in acute losses due to damage to vessels, fishing equipment, and harvested resources. Salinity-related stress exerted a more protracted effect, diminishing agricultural productivity and increasing the time and effort required to collect freshwater. Institutional restrictions, such as seasonal closures and forest

access regulations, further curtailed livelihood opportunities, particularly during periods when households were already grappling with environmental or seasonal constraints. The qualitative accounts illustrate that environmental and institutional stressors do not affect household well-being uniformly; rather, their impacts are domain-specific (Figure

5). Cyclones and storm surges significantly affect income, assets, and forest mobility by directly destroying fishing boats, equipment, and coastal infrastructure, while also exerting moderate pressure on food security and health. Conversely, salinity and freshwater scarcity create significant barriers to accessing drinking water, along with

moderate limitations on income and food availability. The growth of aquaculture and temporary institutional prohibitions engender low-to-moderate widespread stresses on assets, water, and mobility, whereas informal high-interest loans (*Dadan*) primarily increase food security and health challenges during recovery phases (Figures 5, 6).

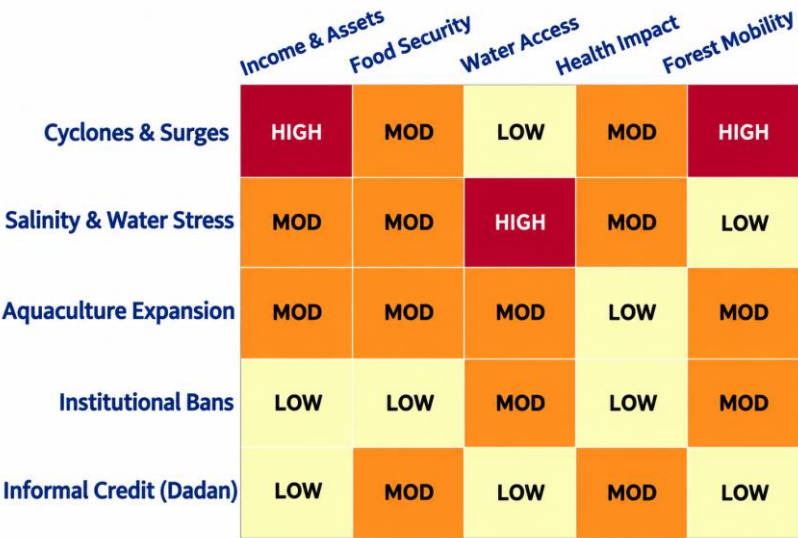


Figure 5: Stressor severity matrix across livelihood dimensions

Brackish aquaculture emerged as a mixed response. For some households it provided an income source under saline

conditions, while for others it reduced access to previous livelihood activities and altered land and water use.

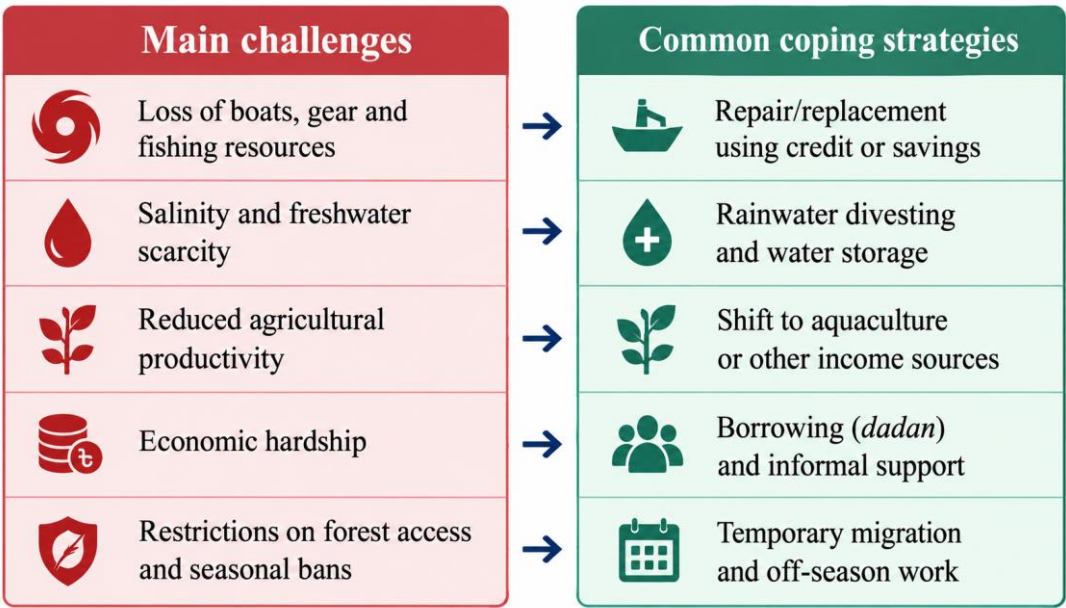


Figure 6: Common challenges and coping strategies

Household coping and adaptation

In this study, participants discussed both immediate responses and enduring adjustments. Reactive strategies included dependence on informal credit, decreased food intake during critical recovery phases, and short-term labour

migration when local resource-based employment was interrupted. Prolonged strategies involved diversifying livelihoods, collecting rainwater at home, and moving towards brackish aquaculture in areas where agricultural productivity was believed to have decreased. To gain a

clearer insight into household reactions, the research delineates a structural difference between immediate coping strategies and enduring adaptation routes (Figure 7). Reactive coping strategies – such as dependence on high-interest informal loans (*Dadan*), cutting back on food, selling off assets, and distress-driven migration – meet urgent survival demands but frequently exacerbate long-term debt

cycles and socioeconomic instability. Conversely, proactive adaptation strategies – such as capturing rainwater at home, transitioning to saline-resistant crops, diversifying into crab or honey production, and engaging in Ecosystem-based Adaptation (EbA) – enhance structural resilience to ongoing environmental pressures (Figure 7).

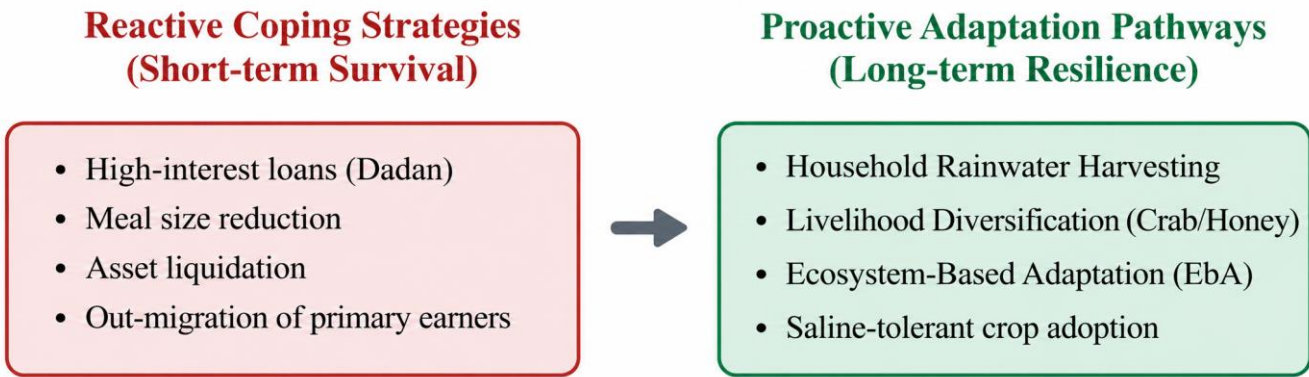


Figure 7: Coping strategies and adaptation pathways

- Informal credit (*Dadan*): temporary loans from moneylenders or fish traders to cover food, repair, or living expenses after shocks; participants noted the risk of repayment pressures and cycles of debt.
- Dietary cutback: decreasing portion size or protein intake when experiencing acute financial strain.
- Temporary labor migration refers to the movement of working-age household members to urban regional centers for wage work when local income-generating activities are interrupted.
- Livelihood diversification: seasonal movement among fishing, crab-related activities, agricultural day labour, and non-timber forest-product collection.
- Rainwater harvesting: household storage of rainwater to supplement drinking-water supplies during periods of dry-season scarcity.
- Shift toward brackish aquaculture: conversion of saline-affected agricultural plots to shrimp or mud-crab production in households with the necessary land and resources.

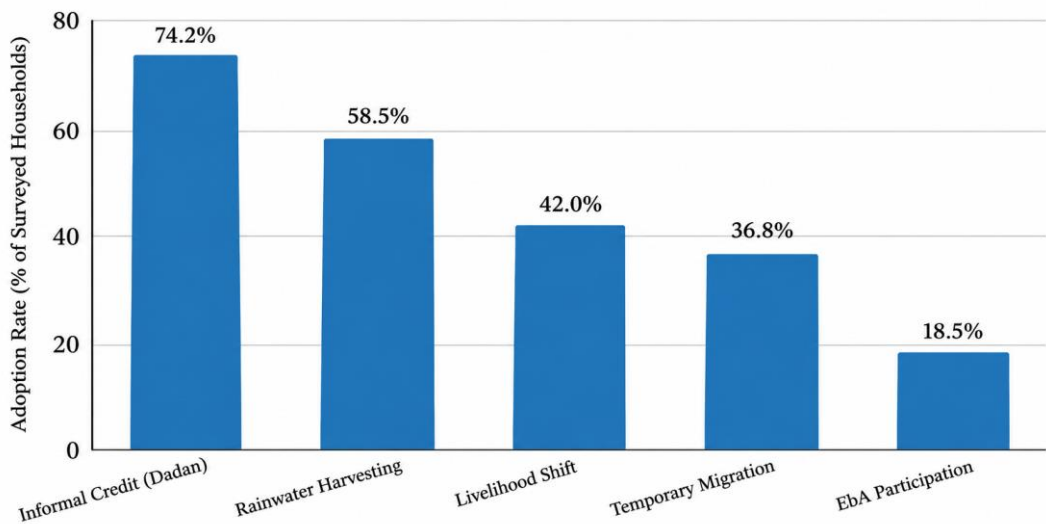


Figure 8: Distribution of adopted household coping and adaptation strategies

The empirical data from the survey emphasizes a strong dependence on short-term financial coping compared to organized long-term adaptation (Figure 8). It is a matter of concern that a significant proportion of the population, 74.2% in fact, have no recourse to formal financial institutions but are forced to rely on high-interest informal loans to tide over the immediate consequences of disasters

(*Dadan*). This is indicative of a critical liquidity shortage. To ensure water security, 58.5% of participants have implemented household rainwater harvesting as a prompt reaction to the salinization of drinking water. Sustainable adaptive changes, such as livelihood diversification (42.0%) and seasonal labour migration (36.8%), indicate structural modifications in response to ongoing ecological strain.

However, involvement in institutional Ecosystem-based Adaptation (EbA) is still limited at 18.5%, highlighting significant deficiencies in outreach and formal support programs at the community level.

DISCUSSION

Coupled social–ecological vulnerability

A survey was conducted on a sample of 400 individuals, of whom 267 had first-hand experience of a natural disaster. It was found that 324 of the respondents subsequently encountered financial difficulties, while 358 reported issues related to water safety. These statistics suggest a possible link between environmental hazards and health concerns within residential homes. However, it should be noted that these findings offer only a general overview of the situation faced by families in the Sundarbans.

In-depth interviews were also conducted with several individuals. It is an established fact that a single storm or flood has the potential to destroy a wide range of assets. These include boats, fishing equipment, homes and stored food. The loss of these items can make it challenging for individuals to obtain financial resources. This can result in families having to seek loans or reduce expenditure on essential items. Furthermore, access to clean water is also severely limited. When financial resources are depleted, women and family members often dedicate a significant amount of time to acquiring water that is suitable for consumption.

These pressures never impact two families in the same way. Households reliant on more than one source of income had, unsurprisingly, more leeway when fishing was restricted. Those with relatives or local loans, and the few who could draw on social safety nets, had some cushions; those reliant solely on fishing or forestry were left nearly bereft. In addition, local people were regulated on when they could even try to get work by strict seasonal bans and forest access permits, while unstable market prices and a lack of local jobs increased the divide between those who coped and those that fell into poverty further.

It is evident that being a survivor of a natural disaster is merely one aspect of the narrative. The survival of a family following a storm is contingent on tangible safety nets, including access to clean water, cash flow, credit or family ties, and natural assets. Regulatory rules and formal institutions further delineate the conditions for resource-dependent communities.

Such dynamics are in accordance with the findings of other previous studies across the Sundarbans and adjacent coastal zones (Dasgupta et al. 2016, 2020; Mallick et al. 2021). We combine those more general findings with our field data in real time local situations. In interviews, residents did not compartmentalise their problems in terms of such terms as "disaster" and "water," or "income." They termed them a continuous, rolling wave of intersecting issues, which is exactly why resilience differs so wildly between doorsteps.

Salinity, water security, and livelihood sustainability

Water has become a pivotal issue in the field evidence. A survey of households revealed that almost 90% of respondents reported health concerns related to water. This finding does not provide definitive evidence that salinity is the causative agent for these health issues, nor does it offer a comprehensive clinical evaluation of water-related diseases. However, the prevalence of water-related issues in both survey and interview data suggests that access to safe freshwater is a critical component of livelihood security within the research context.

The significance of salinity extends beyond drinking water. In coastal Bangladesh, changes in salinity can affect agricultural production, freshwater availability, aquatic habitats and vegetation. Dasgupta et al. (2015) demonstrated substantial spatial variation in soil salinity across coastal Bangladesh, while subsequent studies linked aquatic salinization with changes in fish habitats and potential livelihood consequences for poorer populations (Dasgupta et al., 2017a). Salinity can therefore influence several components of a household's livelihood at the same time. For families dependent on fishing, agriculture, forest resources or other natural-resource activities, changes in water conditions may have consequences that extend beyond the immediate problem of obtaining drinking water.

The field observations also suggest that households do not respond to water insecurity in a uniform way. Rainwater collection, freshwater storage and other household-level practices were reported as important responses, while some families adjusted their livelihood activities when environmental conditions became less favourable for agriculture or other occupations. Such responses can reduce immediate pressure, but they also depend on household resources and the reliability of local water infrastructure.

The implication is that water-security interventions should be considered together with livelihood conditions. Expanding freshwater storage or rainwater harvesting, for example, may reduce household water stress, but its usefulness will depend on storage capacity, maintenance, rainfall patterns and household access. Similarly, water-treatment technologies may have limited value if households cannot maintain or replace them. Local conditions therefore need to guide the selection and management of water-security measures rather than relying on a single intervention across all locations.

For future research, the present survey evidence would benefit from being combined with direct measurements of surface-water and groundwater salinity, microbial and chemical water quality, sanitation conditions and, where ethically appropriate, validated health information. Such data would make it possible to examine more clearly whether the water-related problems reported by households correspond to measurable environmental conditions.

Aquaculture and institutional conditions

The relationship between aquaculture and livelihood sustainability is more complicated than a simple distinction between positive and negative effects. The interviews indicate that brackish aquaculture can provide an income

opportunity in areas where conventional agricultural production has become difficult. At the same time, changes in land and water use associated with aquaculture may reduce access to previous livelihood activities for other households. The consequences therefore depend partly on who controls land and water resources and who benefits from the activity.

This observation is broadly consistent with evidence from southwestern coastal Bangladesh. Ahmed and Ambinakudige (2023) reported declining agricultural land together with increases in shrimp farming, waterlogging and salinity in the coastal areas they examined. Their study was not conducted as a household survey within the Bangladesh Sundarbans itself, so the findings are best used as regional context rather than as direct evidence of conditions among the respondents in the present study. The qualitative accounts collected here nevertheless point toward similar concerns about changing land and water use.

The distribution of costs and benefits is of particular importance. A household that has access to land, financial resources, and markets could gain advantages from aquaculture. Conversely, a landless labourer or small-scale farmer might face limited opportunities if agricultural land is converted or water conditions shift. Sen (2023) also demonstrates how salinity, infrastructure, and aquaculture become integrated into daily livelihood choices in the Sundarbans area. The pertinent inquiry, then, is not merely whether aquaculture is ecologically detrimental or financially advantageous. It pertains to the way its advantages and expenses are shared among various groups and how local entities affect that sharing.

Ecosystem accounting and future analytical development

The System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) provides a suitable framework for organizing these different types of information (United Nations et al., 2021). In a future application to the Sundarbans, field information on

household resource use and livelihood dependence could be combined with spatial data on mangrove extent and condition, hydrological characteristics and other ecological indicators. These datasets could then be used to examine physical ecosystem-service flows, identify beneficiary groups and, where appropriate, undertake monetary valuation.

The present study should therefore be regarded as one component of a larger accounting framework rather than as an ecosystem account. The household survey and qualitative interviews provide information about how ecosystem-related changes are experienced at the local level. Spatial and ecological datasets would provide the corresponding information about the extent and condition of ecosystems. Economic valuation could then be introduced only where the underlying ecological and socioeconomic evidence is sufficiently robust.

An important consideration in such future work will be avoiding the double counting of ecosystem services. For example, the protective function of mangroves and the economic benefits associated with avoided disaster losses may describe related components of the same ecological process. Similarly, income from fisheries should not automatically be added to the full value of the ecosystem service without accounting for production costs and other intermediate inputs. A credible ecosystem-accounting exercise therefore requires clearly defined ecosystem units, consistent service-flow measures, identification of beneficiaries and transparent valuation assumptions.

The field evidence collected in this study can contribute to that process by documenting resource dependence, livelihood effects and household responses. However, moving from these observations to a formal SEEA EA account will require additional spatial, ecological and economic datasets. The value of the present study is consequently less in providing a completed valuation than in establishing an empirical link between household-level experiences and the broader ecological functions on which those livelihoods depend (Figure 9).

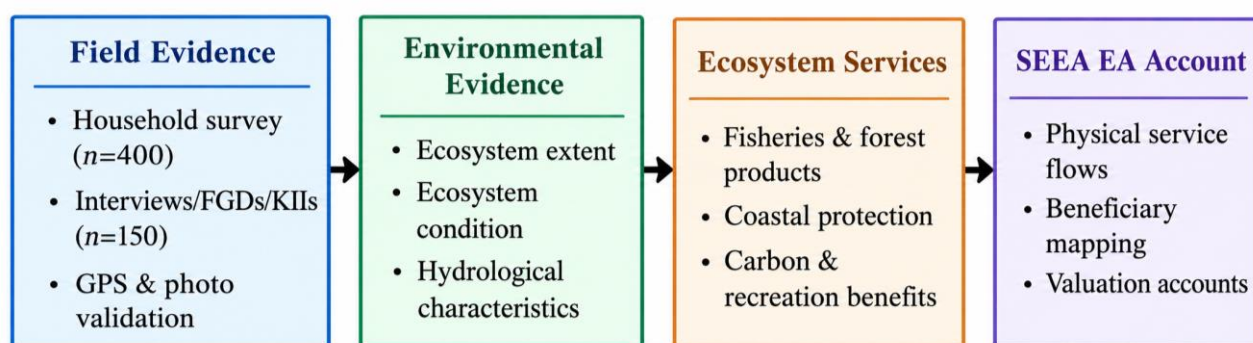


Figure 9. Prospective linkage between field evidence and the SEEA EA framework.

Limitations

- The household survey is cross-sectional; therefore, the reported associations cannot establish temporal precedence or causal effects.
- The current quantitative results are limited to the three verified primary survey indicators reported in this manuscript.
- Health issues related to water are based on self-reports and must not be regarded as clinically verified

waterborne illnesses without diagnostic proof or reliable tools.

- The research does not provide finalized remote-sensing results for 2011–2024. Consequently, no numerical results related to land cover, vegetation index, shoreline change, or salinity trends are asserted.
- Literature from wider research in coastal Bangladesh, India, or the trans-boundary Sundarbans is employed and not presented as primary proof solely pertaining to Bangladesh.

CONCLUSION

The Bangladesh Sundarbans is a coupled social–ecological system in which environmental hazards, salinity, hydrological conditions, livelihood dependence, aquaculture, and institutional rules interact to shape household vulnerability. The 2024 field survey documents high reported levels of disaster exposure, disaster-associated economic hardship, and water-related health problems among the 400 surveyed respondents. Qualitative evidence further shows that environmental shocks are experienced through livelihood and institutional pathways, including asset loss, water insecurity, informal credit dependence, restricted resource access, and livelihood diversification.

The central contribution of the present study is the integration of quantitative household evidence with qualitative accounts of environmental and institutional stress. The findings support a policy and research agenda centred on water security, livelihood diversification, inclusive disaster preparedness, context-sensitive ecosystem-based adaptation, and better coordination among environmental and social institutions. They also provide a foundation for future integration with SEEA EA, provided that validated spatial, ecological, service-flow, and valuation datasets are developed. Further analysis should strengthen the empirical basis through detailed sampling documentation, systematic qualitative coding, direct environmental measurements, and appropriately specified statistical models.

Policy and Management Implications

- a) Strengthen cross-sectoral coastal governance by coordinating forestry, fisheries, agriculture, water management, health, disaster risk reduction, local government, and social protection.
- b) Expand resilient drinking-water infrastructure, including appropriately designed pond-sand filters, rainwater harvesting, and other locally suitable freshwater storage and treatment options.
- c) Manage brackish aquaculture through context-specific spatial and hydrological safeguards while evaluating both livelihood benefits and distributional environmental costs.
- d) Establish ecosystem accounts following SEEA EA guidelines when adequate spatial, ecological, socioeconomic, and valuation data are available; including precise uncertainty metrics and safeguards against double counting.

Author Contributions

Md. Touhiduzzaman: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Conceptualization. **Mt. Farzana Yasmin:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Md. Shahin Siraj:** Writing – review & editing, Resources. **Md. Fuad Hasan:** Writing – original draft, Writing – review & editing, Software, Resources, Formal analysis, Visualization, Validation. **Md. Shamsuzzoha:** Writing – review & editing, Validation, Supervision, Resources, Methodology. **Sadnan Fahim:** Writing – review & editing, Validation, Resources, Methodology. **Rajib Shaw:** Writing – review & editing. All authors have read and approved the final version of the manuscript.

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Institutional Review Board Statement

The present study was not subject to the ethical review and approval process, as the research was classified as empirical social science research that did not harm any humans or animals.

Informed Consent Statement

Informed consent was obtained verbally from all the subjects involved in the research.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no competing interests.

Use of AI and AI-Assisted Technologies

The authors used DeepL to correct sentences and remove grammatical mistakes. All content was reviewed and approved by the corresponding author using a licensed Microsoft 365 subscription product.

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