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# *"What is a 'very severe cyclone' please"?* Uncovering knowledge and communication gaps in climate resilience realities

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## 1. Introduction

Significant advancements in climate and meteorological sciences, communication technologies and geo-engineering in the past decade have had limited success in mitigating losses and damages from disasters originating in the environmental domain [1,2,4]. At an average of US$250 billion–US$300 billion a year, total losses and damages from disaster between 1998 and 2017 reached $2.9 trillion, 90% of which were climate-related disasters. This is a rise of 151% when compared with losses and damages of $1.3 trillion between 1978 and 1998 [147](UNDRR 2018). US recorded maximum losses followed by China, Japan and India. This, however, constitutes reported and documented losses only, no loss data was available for nearly 87% of disasters in low-income countries, even high-income countries reported losses from 53% of disasters (ibid). Also, the spatial distribution of losses was extremely uneven – an average of 130 people died per million living in disaster-affected areas in low- and middle-income nations compared to just 18 people in high-income countries since 2000, demonstrating that while absolute economic losses might be concentrated in high-income countries because of the high asset values, human costs of disasters are borne overwhelmingly by the low and lower-middle income countries. Also, relative losses are not reflected in this data (as percentage of household income, for example), which are often significantly higher in lower- and middle-income countries compared to high income ones despite the latter suffering greater financial losses because of high-value infrastructure.

One of the key reasons behind increasing losses and damages seems to be growing complexities in the interaction between rapidly changing climate and anthropogenic processes that not only turns risks into disasters but also determines the quantum of losses and damages. Climate change, local ecological governance, inequality and poverty, environmental changes produced by development activities (such as pollution, heat islands) interact to undermine resilience across scales [5–7]. Another emerging concern seems to be recurrent smaller disasters producing greater cumulative losses across a temporal scale, compared to extreme weather events. Frequent and more intense storm surges, Perigean Spring Tides, cyclones, hurricanes, flooding, draughts, landslides are jeopardising hu-

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man security of marginal communities worldwide [146](GNDR 2015, [8–11]. Such accrued losses are pushing development back by years and making it more expensive [12]. Disentangling this nexus in specific socioecological and developmental contexts becomes critical to understand specific patterns of vulnerabilities and enhance resilience to these resilience to these loss and damages. However, mainstream scientific inquiries on sustainability, climate change and disaster risk reduction continue to run parallel instead of socio-spatially and temporally integrating with each other [13].

Situated in the Indian Sundarbans, the cyclone capital of India,[1] this study attempts to uncover how and why advances in scientific knowledge and technological developments are failing to enhance resilience of the marginal and vulnerable populations. The investigation is carried out in three steps. Examining the pre-disaster phase about whether the scientific advancements are producing knowledge that are locally actionable and contextual for the end-users comprises the first part of the study. At the second level, it examines whether the knowledge is communicated as comprehensible information that would allow timely action for different stakeholders. Finally, it examines whether the available knowledge is informing resilience governance at a systemic, socioecological level while enhancing specific capabilities of various vulnerable groups. The analytical framework is inspired by multi-criteria mapping[145] that uniquely bridges qualitative and quantitative approaches, science and society[148], enabling participatory analysis. Future uncertainties and threats that climate change poses, necessitate the study to adopt a postnormal science approach[149] which emphasizes on co-producing context-specific knowledge and inclusive communication design.

## 2. The study site: indian sundarbans along the Bay of Bengal, south Asia

Indian Sundarbans, situated along the Bay of Bengal, is an archipelago shared by India and Bangladesh. It is a fragile and ecologically vulnerable ecosystem, a disaster-prone region and a climate change hotspot. The unique mangrove ecosystem spans 10,000 sq. km and is home to a wide range of endangered flora and fauna as well as 4.5 million human inhabitants. A UNESCO heritage biodiversity hotspot and a Ramsar wetland, the region is part of the world's largest delta created by three major Himalayan rivers – the Ganges, Brahmaputra and Meghna. About 2.5 million residents out of the total human population are critically vulnerable [10,14] living in the low-lying coastal areas, floodplains and flood prone riverbanks. Particularly vulnerable are those inhabiting 54 islands (among a total of 102).

Impacts of global warming in the Sundarbans are particularly intense, which include frequent and stronger cyclonic activities and storm surges [15–17,19,20]. Three super cyclones – *Aila* in 2009, *Amphan* in 2020 and *Yaash* in 2021 – have hit the region in addition to six severe cyclones in the past two decades (1997–2017). Smaller and localised but more frequent flooding incidents in particular critically threatens resilience-building and risk reduction efforts [10]: 87). Institutionally not defined as *'disasters'*, episodic inundations from storm surges, heavy rains, tidal bores, Perigean Spring tides – regular oceanic events – have severely escalated vulnerability of the region [10,14,21–23]. For households, every flood – irrespective of its geophysical magnitude – leaves medium to long-term impacts on their lives, assets and livelihoods. Cumulative, partial loss from such events – between 2010 and 2016 – is estimated to be well over €500 Million [10]: 87), highlighting the importance of approaching risk governance and resilience as a continuous process rather than one determinate goal comprising relief and rehabilitation in post-disaster scenarios.

## 3. Theoretical framework: from vulnerability to resilience

Actionability of the 'knowledge' on disasters can be traced to hazard studies – a conflict between the hazard paradigm [24,25] and vulnerability paradigm [26,28]— that has shaped contours of the debate. The former approach treats disasters from a 'predict-and-provide' perspective [29] that constitutes, firstly, forecasting a disaster based exclusively on physical parameters such as wind speed, tidal height, quantum of rainfall. This is followed by offering physical security through temporary relocation and finally with post-disaster relief. In the cycle of risk-disaster-recovery, however, production and continuation of risk remains largely unattended [150] (Ghosh and Boyd 2019). In Sundarbans for example, the flood defence constructed for over a century now appears to be the most critical driver of erosion, land loss and flooding in the region (ibid.) Disaster management systems also ignore socio-spatial impacts of the disaster in the protracted temporal scale, which heavily undermines resilience [151](Imeriale and Vanclay 2021). The vulnerability paradigm, while identifying structural drivers of risks, often fails to produce a clear understanding of temporally spaced actions and fails to provide actionable information needed by different stakeholders and communities [10,22,30]. In this context, bolstering social resilience and addressing real challenges faced by the community can ally better with development planning [31] to limit losses and damages from eco-climatic hazards induced by climate change. However, the definitive conditions and parameters under which this can be achieved needs to be better understood [152](Gawith et al., 2016). It is increasingly realised that a holistic and informed social resilience approach [163](Saja et al., 2019) has better potential than the temporally restrictive approach of disaster management which fails to rupture the risk-disaster-recovery cycle, leaving risks not only reproducing continually but even getting intensified under the influence of climate change and environmental shifts it induces.

Postcolonial geographies face a particularly acute challenge – in building resilience of vulnerable communities to the ever-intensifying impacts of the changing climate while developing sustainably. It is largely understudied how sustainable development must internalize risk reduction, enhance human security, mitigate losses and damages from disaster events [153,154] . [155]Le Blanc (2015) for example calls for resilience to be integrated with sustainable development goals (SDGs) and their corresponding targets. Globally, disaster management discursively (and rhetorically) shifted from "managing disasters" to "reducing disaster risks and building resilience" [156,157](IDNDR, 1994; UNISDR, 2005 [9], without any clear idea how to achieve this goal. Past development

[1] *Climate hazards and vulnerability atlas of India*; Indian Meteorological Department, Government of India, 2022.

processes have often created socioecological vulnerabilities and risks, producing much higher burden of negative impacts of disasters in certain areas [158,159](Barca 2009; Barca et al., 2014; [7]. Therefore, the nature of uneven spatial and temporal distribution of risks needs to be better deconstructed – particularly engaging with issues of access, entitlements and power struggles.

There is increasing demand from communities and governments for useable knowledge derived from experiences as much as from science, production of which demands greater engagement between scientists and different stakeholders foregrounding mutual trust in both [32,33]. Compartmentalising scientific knowledge and creating black-boxes separate society and nature [34]: [160] whereas networks of stakeholders can provide stronger basis for progressive action and change to build upon local and scientific knowledge [35]. This demand shifting the focus of the scientific discourse away from 'the environment' as the problem and towards an integrated understanding of change based on critical research on space, place, politics, power, culture, identities, emotions, connections [36,37]. Existing work already suggests that co-production of actionable knowledge could empower communities much more effectively [161]. Only when science and society inform each other, actionable knowledge that meets the needs of various end-users can be produced [38]; [149]. For instance, [180] argue that a better understanding of how inequality impacts climate change mitigation policies uncovers structural power dynamisms between individuals, social groups, households and communities. Similarly [7] underscore the importance of empowerment, capacity building, co-production of knowledge and equity in enhancing resilience. "How disaster risk is understood, and how risks are assessed and early warning systems are designed … what research and capacity gaps exist and how difficulties in creating and using science for effective DRR can be overcome" [162] remains a key weakness in DRR and resilience governance. Despite clearly emphasised in the Sendai Framework 2015–2030, societal and individual behaviours, norms, values and perceptions of risk remain conspicuously absent in the DRR approaches [40]. Limited relevance to local realities – fragility, insecurity, conflict, informality – continues the upward trend in disaster losses.

Access to contextual, actionable, comprehensible and timely information related to impacts of climate change in the context of short- and long-range development & adaptation responses can significantly reduce losses and damages from disasters along with informing resilience building [42–44]. Strong and clear communication between end-users and knowledge producers can yield much more effective and successful DRR [38]. Bangladesh has achieved significant success in mitigating and reducing disaster risks for its coastal population, largely because of forecasts targeted to specific communities like fishers and farmers, delivering messages through various media and most importantly for being comprehensible by the community for its alliance with the local culture and language [45]. This underpins the importance of downscaling global climate models to regional scales for resilience governance [38].

## 4. Methodology and methods

Fieldwork for this study was conducted between 2018 and 2021, with the aim of finding what kind of knowledge was required by different stakeholders and how the same could effectively inform resilience; what information was needed to make critical decisions at the household, community and systemic levels; what action different stakeholders needed to perform both in the pre and post disaster phases for stronger resilience building and what capacities were required. Co-production of knowledge, however, is not a neutral activity but contested outcomes of power struggles over meanings [46]. This necessitates questioning assumptions underlying contemporary science, policy, and practice [47] which can only be achieved by disentangling discursive contestations through on-site, ethnographic methods and empirical evidence how knowledge co-production can build resilience, which is currently unclear at best [33].

Generating knowledge claims on pragmatic grounds (e.g., consequence-oriented, problem-centered, and pluralistic) lie in a continuum – between post-positivist quantitative methods and post-constructivist qualitative methods [48]. By mixing methods, strategies of inquiry elicit data either simultaneously or sequentially to best understand research problems [49]. This is a practice where identifying variables with a clear research design can contribute to a broader and robust approach facilitating newer tools, measures and ways of reporting [50] – more so in environmental studies, where insights can be derived from a broad range of observations from diverse stakeholders which have to be pegged towards an effective and generalizable analysis. It appears best to combine "multiple views" and "multiple research methods" [51]: 117) to understand environmental and concomitant social changes, since it is a domain positioned across humanities, natural sciences and social sciences [52]: 104) [53]. used mixed methods to decode subjectivities in the interpretation of environmental hazards and risks at the local producers, resource managers and global agencies, aspirations, sustainability and adaptation, and how those differences influence household action and policy. We worked at the intersection of "geospatial technology, knowledge, and representations of landscapes" [55]: 12), using geospatial technologies to link the detailed local scale ethnographic research with the broader scale, though it often faces certain methodological and epistemological challenges (ibid).

The study was conducted in four sub-districts in the Indian Sundarbans – Sagar, Namkhana, Gosaba and Sandeshkhali – across 20 coastal villages. The selection of the sub-districts and villages allowed standardising and uniformalising parameters for quantitative as well as qualitative surveys, involving 77 local residents comprising 32 adult women and 35 adult men. Parameters were developed for the surveys along with the participants who were given a list of inductive, predefined 'core options', which they were allowed to modify and redefine. A total of 16 parameters were finalised with four criteria each through this process and '*scores*' of 20, 15, 10 and 5 were assigned to each criterion where 20 indicated the worst conditions for resilience and 5 the best through a participatory process. A comprehensive list of conditions for appraisal of resilience from the perspective of the residents was developed and not from the perspective of the researchers. The 16 parameters were grouped in two different manners. Firstly, these were grouped by their nature which yielded two categories, geophysical conditions (pragmatist) and secondly policy and governance (see Tables 1 and 2). The second classification was based on temporality – pre-disaster, in-disaster and post-disaster (see Appendix I) (see Table 3).

Details of the parameters in their respective temporal category along with respective sets of criteria against their scores are explained in detail in Annexure I.

**Table 1**
Physical parameters.

| |
|---|
| Village elevation |
| Erosion & land loss (2000–2015) |
| Key ecoclimatic determinants/Slow onset impacts of climate change |
| Disaster cycle/Immediate impacts of climate change |

**Table 2**
Policy and governance parameters.

| |
|---|
| Material poverty (*Consumption US$0.5/person/day)* |
| Condition of Embankment (Between 2010 and 2016) |
| Roads and river transportation |
| Distances and time to access a disaster shelter during a disaster |
| Early warning: Knowledge |
| Early Warning: Communication |
| Mitigating Actions |
| Evacuation and support |
| Migration for recovery |
| Politics over Aid, Relief and rehabilitation |
| Loss & Damages (material, health, education, livelihood) |
| Resilience governance |

**Table 3**
Factors that the community feels undermine their resilience the most.

| Factors undermining resilience the most (Descending from most severe to least severe) | Scale of 100 |
|---|---|
| Politics over Aid, Relief and rehabilitation | 0.86 |
| Loss & Damages (material, health, education, livelihood) | 3.46 |
| Condition of Embankment (Between 2010 and 2016) | 3.89 |
| Mitigating Actions | 4.32 |
| Disaster cycle/Immediate impacts of climate change | 4.32 |
| Erosion & land loss (2000–2015) | 6.06 |
| Early Warning: Communication | 6.92 |
| Village elevation | 7.79 |
| Resilience governance | 9.09 |
| Key ecoclimatic determinants/Slow onset impacts of climate change | 11.25 |
| Early warning: Knowledge | 11.68 |
| Migration for recovery | 15.15 |
| Distances and time to access a disaster shelter during a disaster | 16.01 |
| Roads and river transportation | 21.64 |
| Material poverty (Consumption US$0.5/person/day) | 51.51 |
| Evacuation and support | 76.62 |

Questions asked in the semi-structured interviews are detailed in Annexure II.

## 5. Findings: high resilience during disasters but critically low in post-disaster periods

The quantitative survey found that perceived resilience in the region was much lower than what people needed (see Fig. 1). The average level of resilience in a scale of 0 (worst resilience scenario) to 100 (best resilience scenario) was at 14.3 (Fig. 2). However, differences disaggregated across three temporal scenarios — pre-, in- and post-disaster — was quite intriguing. Resilience was the highest during the disaster at a score of 30.22 (out of 100) and lowest in post-disaster scenarios at a score of 8.97 (Fig. 3) – both unique findings. Lowest scores were obtained in *'politics of relief'* and *'loss and damages'* respectively – both a feature of post disaster scenario (see Table 1). The exceptionally high score in in-disaster scenario could be attributed to the highest score in evacuation and support among all parameters. This reflected the success of achieving zero casualty even during recent national disasters in the form of two very severe cyclones in 2020 and 2021 respectively. It indicates precision, timeliness and accuracy of early warnings issued by the Indian Meteorological Department (IMD). Locals also indicated that a significant number of disaster shelters had been constructed in the region over the past decade with global aid, federal funding, local government and NGOs.

Geophysical parameters in the region are continually transforming under the impacts of recurrent smaller perturbations followed by rapid ecoclimatic shifts that produce renewed policy and governance challenges. Across human habitations below the sea-level (GPS reading at the centre of the village), embankments[2] were found to be much weaker structurally and villages recorded high land loss from erosion. Interspersed with major extreme weather events such as tropical cyclones, these smaller but more frequent disasters undermined collective resilience the most (Fig. 4), causing recurrent damages to the built environment – most critically the embankments along with personal property, key infrastructure such as roads, health and education facilities, communication networks. These episodic events also produce acute livelihood losses in the form of crop failures, loss of fishing activities, salinisation of soil,

[2] That make human habitation possible in the region saving the islands from intrusion of hightides, floodwaters and storm surges. For details, see Ghosh 2018).

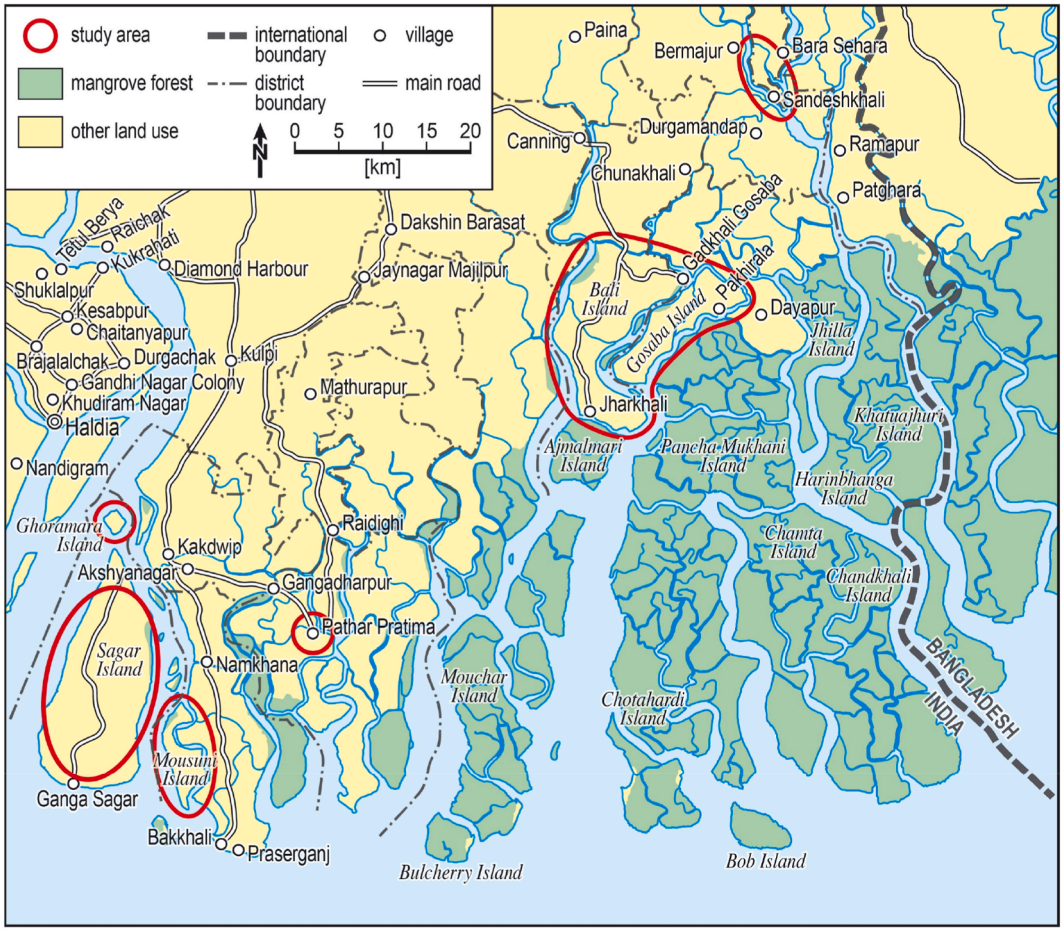


**Fig. 1.** Map of the study site, the Indian Sundarbans along the Bay of Bengal (Source [10]: 23).

death and physical injuries to the cattle and livestock. While slow-onset changes from climatic shifts aggravate these impacts, the community attributed their poor resilience to recurrent smaller and larger disasters (see Fig. 5).

### *5.1. Beyond saving lives: actionable knowledge to bolster resilience*

#### *5.1.1. Scientific knowledge: vacuum, out of context and incomprehensible*

Accuracy and timeliness of the early warnings neither helped residents in enhancing their resilience nor it helped local managers in developing a temporally spaced resilience plan to secure livelihoods, savings and personal properties. The seeming puzzle of high resilience during disaster events but lowest level of resilience in the post-disaster scenarios was attributed to three main reasons.

a) Unavailability of specific kinds of knowledge required by different actors
b) Framing of the knowledge in user-friendly information packages
c) Communication about a wide range of parameters

These particularly concerned weather and climate information – early warnings, forecasts and projections; knowledge about climate change and its possible impacts and finally how these impacts can interact with different sub-regions within the Sundarbans. These three aspects also determined the extent of loss and damages, ineffective individual and collective responses as well as poor policy and governance towards bolstering recovery and resilience. Interviews with scientists, local managers and the respondents also indicated that the weakness emanated from unavailability of the kind of 'knowledge' required to inform resilience governance, address specific vulnerabilities (gender and children for example), help climate-proof development at the local and regional scales.

The knowledge, information and communication gaps begin with the early warning system (EWS) itself. Local managers said that the early warnings merely included information about wind speed, time and area of the landfall of the storm. However, they needed information about how the storm will affect the ocean behaviour, said a disaster manager in Sagar, the biggest and most populous island in the Sundarbans:

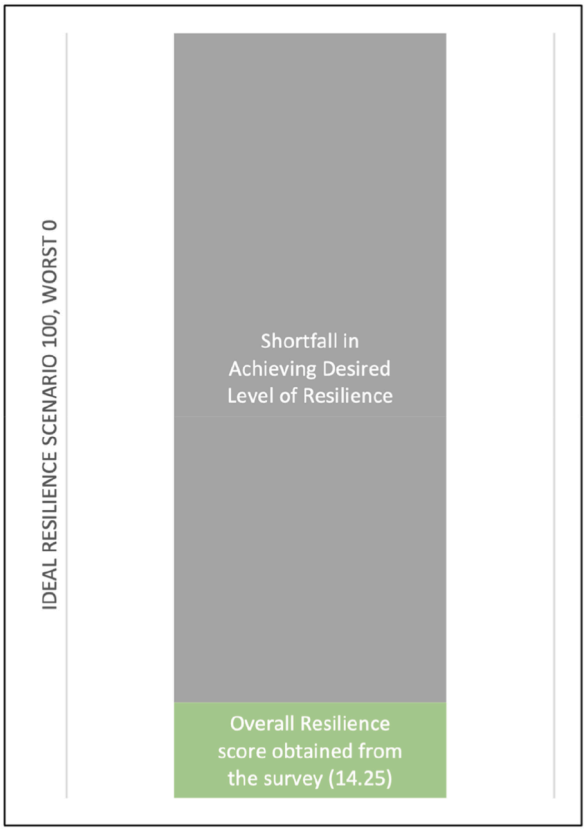


**Fig. 2.** Overall resilience score as obtained by the survey.

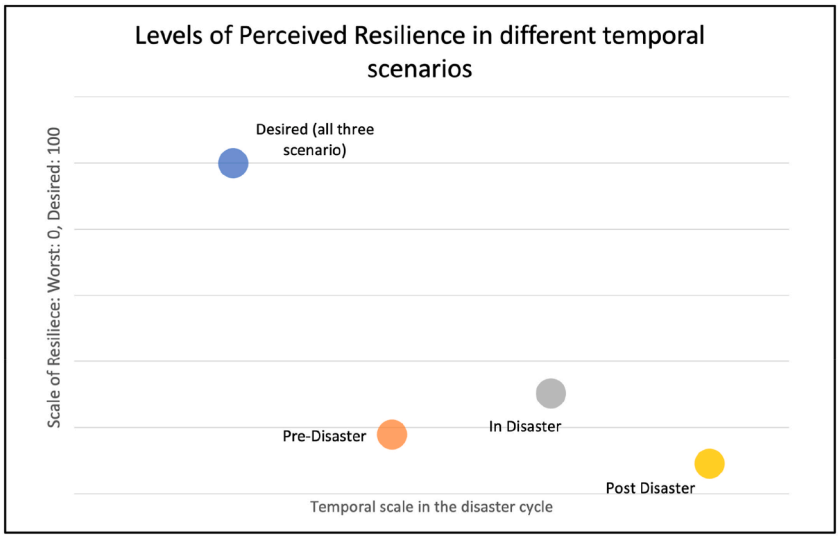


**Fig. 3.** Comparative levels of perceived resilience in various disaster scenarios in the Sundarbans.

> "We need to know possible height of the storm surges so we understand whether it will overturn the embankments and breach them. That makes a major difference in the outcome of a storm. For example a cyclonic storm coinciding with the Perigean spring tide will have completely different outcome than one without."

Interviewed local residents also echoed an acute need of 'useable information'. A key informant in Mousuni, the fastest eroding island in the Sundarbans, said:

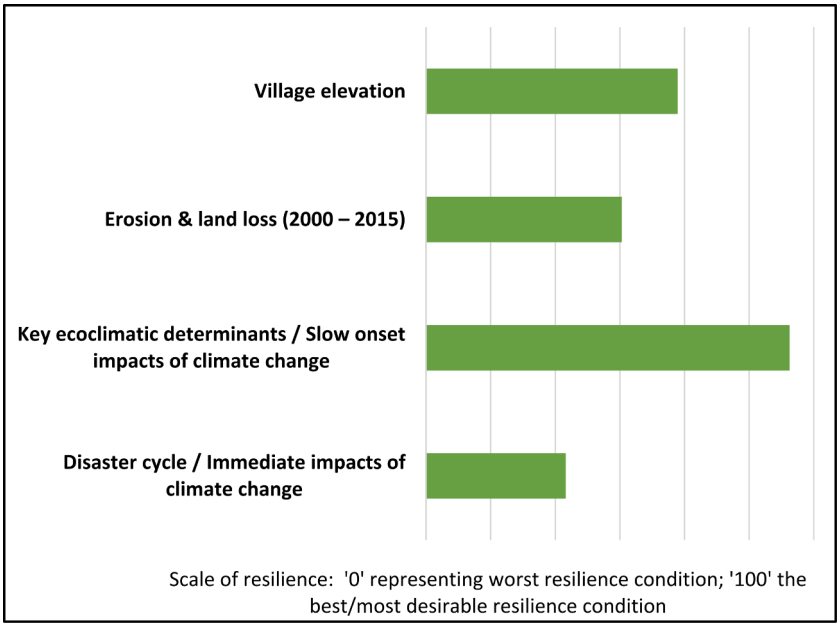


**Fig. 4.** Resilience as undermined by geophysical parameters.

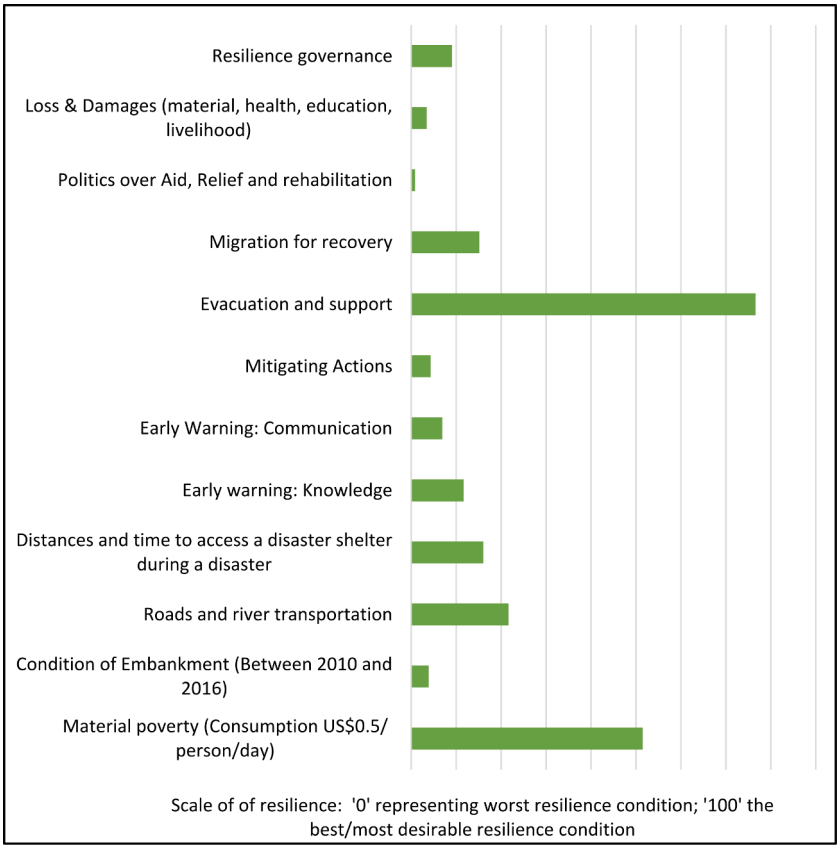


**Fig. 5.** Resilience Scores of Policy and Governance parameters.

> "A very severe cyclone, wind speed of 100 or 150 km/hour or certain centimetre or millimetre of rain do not convey any meaning to us, neither does it help us decide our actions. Can someone not simplify what a 'very severe cyclone' is?"

This would have enormous implications for collective action as well, reaffirmed participants of a focus group conducted in the Gosaba village, eastern periphery of the Sundarbans in India. They said:

> "Since we have lived in the region with storm surges and cyclones for generations, we have adapted and know how to negotiate these. We need precise information about what to expect. While we must avoid grave physical harm, loss of property, livelihoods and cattle at all costs, we also must not unnecessarily panic or make unreasonable plans (such as evacuating)."

Inquiry with the ocean scientists working in the region revealed that such a warning was only possible if both the meteorologists and the oceanographers collaborated to develop a mathematical model. This model – integrating oceanic conditions, wind speeds, rainfall events – was not available or could not be developed because of a diverse range of methodological, institutional and organisational entanglements, said geologists and ocean scientists. A senior oceanographer at a renowned local university said:

> "Only this model, which is not available with us and has never been thought of as a requirement, can provide such information. Technically it is possible to develop but there are a range of procedural barriers."

The mathematical model could also integrate weather events such as storm surges, monsoon rains, Perigean Spring Tides to forecast the resultant oceanic behaviour which becomes the most important determinant of the impacts of a specific event on humans and nonhumans and the nature and extent of the eventual disaster. But this necessitated regular local area audits and updated database of various physical conditions and parameters across vulnerable areas. Prospects of such a tripartite knowledge coalition involving local government agencies, federal government agency and local universities was bleak. Jurisdictional boundaries, authority and power struggles were found to be main barriers. IMD was a federal agency while universities and the local area governance was a responsibility of the state government of West Bengal. A senior bureaucrat at the state secretariat, responsible for district-level mitigating actions, said:

> "IMD has always been unwilling to collaborate with these institutions which have specific capabilities. They are not interested in offering more accurate, place-specific, customised or actionable forecasts because they feel it is not within their domain. Such information helps local area governance that is within the jurisdiction of the state government. IMD being a federal agency is not concerned about it."

This model could also inform resilience building at a protracted temporal scale by strategizing how to support and diversify local livelihoods, provide better education and healthcare facilities and services at specific locations, said local administrators and bureaucrats. A block development officer in Sandeshkhali, the eastern boundary of the Sundarbans sharing international border with Bangladesh, said:

> "While were interact and negotiate with people at a local level to understand their realities, how these would interact with the changing climate and ecoclimatic shifts is never integrated in developing forecasts along a temporal scale."

Another senior bureaucrat who retired recently said that the region needed forecasts or scenarios similar to the ones issued by the Intergovernmental Panel on Climate Change or IPCC. He said:

> "We must break down the impacts of climate change from the global levels that IPCC issues to local levels such as the Sundarbans, already proven to be an acutely vulnerable sociological system. This is where science is failing us. It is not producing actionable knowledge encompassing different projections about the future of the region through collaborations between disciplines, institutions and individuals. Thousands of institutional and individual research projects have been carried and are still undertaken every year on the region – across natural, social and physical sciences. Unfortunately, no comprehensive understanding about the future – segregated into different scenarios for different regions – is provided to people like us who work on the ground at the level or policy and governance. Science and our knowledge systems are failing to inform policy and the people."

#### *5.1.2. Looped livelihood losses: limits of knowledge reached*

Inability to recover from cycles of temporally squeezed smaller disasters interspersed with mega disaster events was the most severe incapacitating factor for all the respondents across 20 villages. Regular storm surges, even from seasonal events such as Perigean Spring Tides, destroyed embankments, inundated villages, damaged built structures and poisoned the agricultural fields as well sweetwater ponds unlike riverine flooding.

A fisher in the coastal village of Mousuni in Namkhana subdistrict said:

> "The only viable option for us in such cases is migrating out for unskilled jobs. It takes over a year or more to recover losses in most years. By the time we recover, there is another disaster."

Salinisation of soil affected the local economy more acutely as cultivation is only possible when salinity of the soil is washed off by monsoon rains over seasons.

A farmer said:

> "On average, it can take up to two years and till such time, we have to resort to the government's income guarantee scheme.[3] We are also clueless about what we can cultivate next, how and when. Our traditional knowledge is failing us as we never experienced such a dramatic environmental and ecological changes. Our knowledge system cannot cope with the rate of environmental changes. On top, no one asks us about what we know, if we need to learn some new farming skills or if any equipment can help. We need products such as saline resistant crops but the government has not provided any."

One of the reasons behind compromised resilience, said an agrobiologist, was consistent push for high-yielding varieties developed by the federal State in the 1960s which led to gradual decline of traditional varieties which possessed a range of characteristics towards adaptability as these were developed through experiments carried out over generations to suit different ecological, social and cultural conditions. He said:

> "Paddy with high degree of salt resistance were available among the traditional varieties that farmers cultivated earlier. With the consistent push for high-yielding paddy all these varieties are lost."

#### *5.1.3. Socio-culturally alienated: knowledge and its framing*

Along with climatic, geophysical and ecological contexts, social and cultural context in communicating knowledge and information undermined seriously affected resilience. A disaster manager in Namkhana block said:

> "The warnings are issued by the scientists at the IMD and is coined in a scientific language, in English or Hindi. It often fails to make any sense even to us. Apart from the absence of any local context this is a major challenge for the people."

A meteorologist admitted that the current content of the early warning in particular and weather forecast in general was often intangible or even incomprehensible. She said:

> "The rainfall categories of IMD such as 'heavy', 'very heavy' and 'moderate' are all in English language and are unfortunately intangible. Even the quantum of possible precipitation is issued in metric scale (mm or cm). For the end-user, it does not translate into actionable information."

Fishers and farmers interviewed claimed that they preferred forecasts (and early warnings) issued by the Bangladesh Betar, the country's State-owned radio station. The warnings are in Bengali language and the information is more actionable in the local sociocultural context, revealed discussion in a focus group in Gosaba subdistrict. Administrators also reiterated saying they needed information about areas that will be affected more and ones that might be safer so that evacuation or relief distribution could be planned, essential supplies maintained and communication networks be designed.

Issuing more precisely framed early warning messages compatible with regional linguistic and cultures was beyond their capacity, said a senior meteorologist in the Kolkata regional headquarters of the IMD.

> "We are physical scientists and not trained communicators. Many of us do not even speak the local language as we come from different parts of the country into this federal organisation. There needs to be local social scientists, communicators and administrators who can work with us to make the messages more precise. But the institutional mandate does not allow such a collaboration or even employing full-time social scientists with an understanding of local cultures and societies."

Senior bureaucrats reiterated the need of designated mediators to interpret the scientific, technological information and subsequently re-frame the same for the residents in across different locations and the local managers therein. A district-level administrator said:

> "Local managers know the local conditions best and must be looped into framing and contextualising the forecasts and the warnings along with the scientists. Residents even in the same island have very different vulnerabilities and these messages must address specific vulnerabilities for specific communities in the pre- and post-disaster phases respectively."

### *5.2. Knowledge access: reinforcing power structures, not informing governance*

Inequitable access and distribution of knowledge and information created an entangled landscape that heavily undermined resilience of certain groups (such as tribals) in two ways. Firstly, by tilting the balance of power disproportionally in favour of those with access to information to take timely action. Secondly, it compromised access and entitlements to resources for those without the access to information (typically marginal communities) at different scales (see Table 4, politics over aid and relief undermine community resilience the most).

#### *5.2.1. Control over resources deepening existing vulnerabilities*

Differential access to information, determined by the prevailing power structures, particularly affected the marginal communities and specific vulnerable groups such as women and children. The power struggles seemed nestled in how and what kinds of information is made accessible, whom it is shared with, how the communication is mediated and what information is withheld from whom. Interestingly, the power struggles were hierarchical, between federal and regional governance; between local area governance and the communities and also between different groups within the community. A senior bureaucrat interviewed described the nature of entangled power dynamics between the federal and regional government:

[3] Mahatma Gandhi National Rural Employment Guarantee Act 2005, 100 days of paid unskilled/semi-skilled and skilled work.

**Table 4**
Linking knowledge and communication to produce actionable information for different actors and objectives.

| NATURE OF KNOWLEDGE, INFORMATION & COMMUNICATION | RESILIENCE UNDERMINED | |
|---|---|---|
| | **PRODUCTION** | **COMMUNICATION** |
| SCIENTIFIC | Absence of coupled model between meteorology and oceanography | Locally comprehensible and actionable forecasts (language and meaning) |
| | What products and services would local livelihood need? Livelihood support (New seeds, agricultural techniques), aquaculture | Locally contextualized forecasts for different stakeholders – local residents, managers, farmers, fishers, students |
| | Impacts of climate change along the temporal scale across different parts of the region | Framing projected scenarios and forecasts for specific end-users and for specific purposes (local area development, DRR, household-level planning) |
| SOCIOECONOMIC | Nature and entanglements of structural violence and power structures | Inequitable access to actionable information in a timely manner |
| | Who are the most vulnerable and why? Who will be the most affected and why? | |
| GOVERNANCE | How to structure and organize health and education services for human development | DRR delinked from education and health facilities |
| | Nature of assistance to different communities | Rescue, evacuation to competent authorities |
| | Transportation (both road and water) | Information flow between different agencies |
| | How to ensure equitable access to disaster shelters | Inform, assist and support communities and households |
| | Mainstreaming climate change, DRR and resilience into sustainable development paradigm | How to engage policy actors, administrators, managers, local communities in developing shared meaning |

> "For example, declaring a severe cyclone as a 'national disaster' has implications for the amounts of compensations offered for various losses and damages, which is much higher generally. If it is a declared a State-level disaster, the compensations are much lower. However, this information is never shared with the community and additional federal funds are siphoned off,"

At the level of community, knowledge politics produced power struggles that determined access to and space in disaster shelters. GIS readings on paths connecting different settlements and disaster shelters within an island revealed that the most vulnerable – living in close proximity of the coast or riverbanks, on the embankments[4] – had to cover longest distances to reach a shelter. During a disaster, despite being the worst affected, they often failed to find place by the time they managed to reach these facilities on their own. Those who live closer to these shelters – typically the wealthier – occupied these spaces first, pushing the marginal out in the 'competition' over space. Information about an impending disaster is not shared early enough with the most marginal, nor does the rescue and evacuation follow patterns of socio-spatial vulnerabilities but aligns with social power structure.

A family of tribal fishers in Sandeshkhali village shared their experience:

> "By the time, carrying whatever little we manage to save, we arrive at the flood shelter, these are full to capacity. We are turned away for reaching late and then return to the embankments and somehow construct temporary shelters and live in these informal settlements amidst high risks."

Such power struggles have grave implications for resilience, as families who stay in the state-owned disaster shelters recover quicker, receive most of the aid and relief including daily meals, clothes, and compensations for structural damages.

Construction of road and waterways – that constitute vital evacuation infrastructure – were political decisions. Legislators and administrators more powerful had greater influence on where, when and how such infrastructure will be built. Apart from the local micropolitics, the urban elite's agenda seemed determined the nature of infrastructure in the Sundarbans. Being a globally renowned tourist destination, there are robust road and water ways connecting major tourism facilities including a regular helicopter service for tourists traveling to *Gangasagar*, a nationally significant tourism destination with an average footfall of 3.5 million tourists annually.

A local state official said:

> "Forget about helicopter, a simple water ambulance or basic speed boats are not available for the local residents for health, weather or any other kinds of emergency. In disaster situations, whether erosion, storms or cyclones; man-animal conflicts – the locals self-organise relief or seek assistance from their respective social networks. The State only promotes tourism and lease out land to mega private facilities without realising that it is an ecologically fragile area and too much of tourism will affect its sustainability. Local population are anyway at the mercy of the god."

#### *5.2.2. Capabilities compromised: disaster cycle jeopardising human development and household-level resilience*

Knowledge and information gaps failed to inform two other critical areas that heavily undermined community resilience, the residents and local managers pointed out. Firstly, mobilisation of healthcare during and post disaster phases essential for humans and cattle (veterinary healthcare) were a key area of concern that affected recovery and productivity. Secondly, reinstating education services – the most neglected area in the aftermath of disasters – severely jeopardised human development both in terms of availability

[4] As it is a state-owned commons, where people – after losing their homes to inundations or storms – move to.

and quality of education and affecting health of the children as schools provide mid-day meals[5] and suspension of schools often means sacrificing one meal for the children, particularly those from the marginal families.

Rangabelia village in Gosaba has one of the best healthcare facilities in the entire region, which however, have been developed by NGOs working with the community. A doctor working in the local hospital said:

> "Poor healthcare facility also causes loss of man-days and incomes, and the cycle just keeps reproducing itself. Mid-day meals served at schools is an important source of nutrition for the local children, particularly those from the marginal communities such as the tribals. Indefinite suspension of school severely jeopardises the health of the children."

Unavailability of mid-day meal had other financial implications and additional burdens on the women of the households (Fig. 6). A mother of two teenagers, in the remote village of Lahiripur in Gosaba sub-district, said:

> "This puts heavy financial burden on the family as there are more mouths to feed and more meals to cook. During disasters, food availability is seriously hampered anyway – vegetables, eggs, meat, oil – everything becomes scarce and more expensive. As a mother, I feel helpless when mid-day meals are suspended indefinitely, often stretching up to three months every time there is a disaster."

Women suffered both much higher and more acute physical and psychological stress. A mother of three in the village of Satjelia Island in Gosaba subdistrict said:

> "Our responsibilities include caregiving (for children and the old). We also have to earn for the family while our men migrate. On top there is destruction of the physical structure, livelihood insecurities and loss of cattle – all producing high levels of stress.

Loss and damage of textbooks, stationaries and uniforms – a common household experience caused by structural damages to the living spaces – could not be recovered by the households as they could not afford to repurchase these materials.[6] Damages to the teaching learning materials (TLM)[7] at the institution is never replaced within the school year, said head teacher at a high school in Mousuni Island. Disruption of human development processes affected both skill developments in young adults, comp prospects of accessing skilled and better-paid labour markets at a later stage. However, knowledge about health and education requirements is universally available with community members, administrators and policy actors. However, it did not inform policies or governance because of the power struggles that rendered meaning and value to the knowledge and how to make it actionable.

## 6. Discussion

### *6.1. Recalibrating knowledge production: plurality and synthesis simultaneously*

Existing vulnerability indices range from the global [56,58]; federal and national levels [59] – Brazil) [60], – Indonesia); regional [30,45,61–63,65,66]; and local such as cities and municipalities [67,68]. However, treating vulnerability as a subject of scale or geographical units against which it is measured – villages, districts, towns – as opposed to that of communities, households and individuals fails to bring people into the central focus. This, argues Saja et al. (2019), not only shifts the burden of adaptation and coping to the community as a neoliberal instrument but also suffers heavily from ambiguity for its failure in connecting specific gaps (knowledge, information, action) towards resilience building. Most existing indices also undermine the role of agency, denying the targets of resilience-building and adaptation a scope to participate in the very process of vulnerability reduction [45,69]. Fig. 7 demonstrate how absence of participation at various scales and levels significantly compromises knowledge production for resilience. Ignoring social learning and community assessment about structural hierarchies and unequal vulnerability distributions borne by negatively affected individuals kept reproducing drivers that undermine resilience and justice [70]. In such cases, policies are not translated into higher quality decisions (ibid.), because of the knowledge, information and action gaps created at different levels (see Fig. 6) (see Fig. 8).

Findings of this study proposes a participatory, scalable, dynamic, bottom-up and real-time process to address specific knowledge, communication and action gaps, to co-produce in climate services (see Fig. 7), that is assuming much greater importance [164–166] [71], as it tailors "information products to user needs, with less attention towards the service environment itself" [161]. It can also help connect spatial themes such as land use, transportation and village boundaries to access risk within the hazard zone, evacuation plans as well as temporal themes such as livelihood support, enhancement of human capital [167] [72], especially in the context of frequent and multiple disaster scenarios as experienced over the past decade in the Sundarbans. Fig. 7 attempts to connect these seemingly disparate domains – livelihood support, transport infrastructure, educational facilities, public health, access to disaster shelters for different communities, who receive timely, comprehensible early warnings, who have higher resilience and will require less institutional support in a disaster situation. Such knowledge and information are critical for high adopting quality decisions towards resilience-building [21,22]; [167]. Furthermore, to reduce the intensity and frequency of risks, integrating social and environmental systems [73] and disaster management with development processes is critical [10,74–76].

[5] Mid-day meals are free cooked meals provided to all school children, under the provision of law in India, which has proved instrumental in improving the nutritional status of children between 2001 when it was ordered to be implemented nationwide and now (2020).

[6] Provided free of cost to children from the school.

[7] Teaching learning materials or TLM as these are officially used to describe textbooks, reference books and different kinds of stationaries that are supplied by the government to the schools and to the students free of cost.

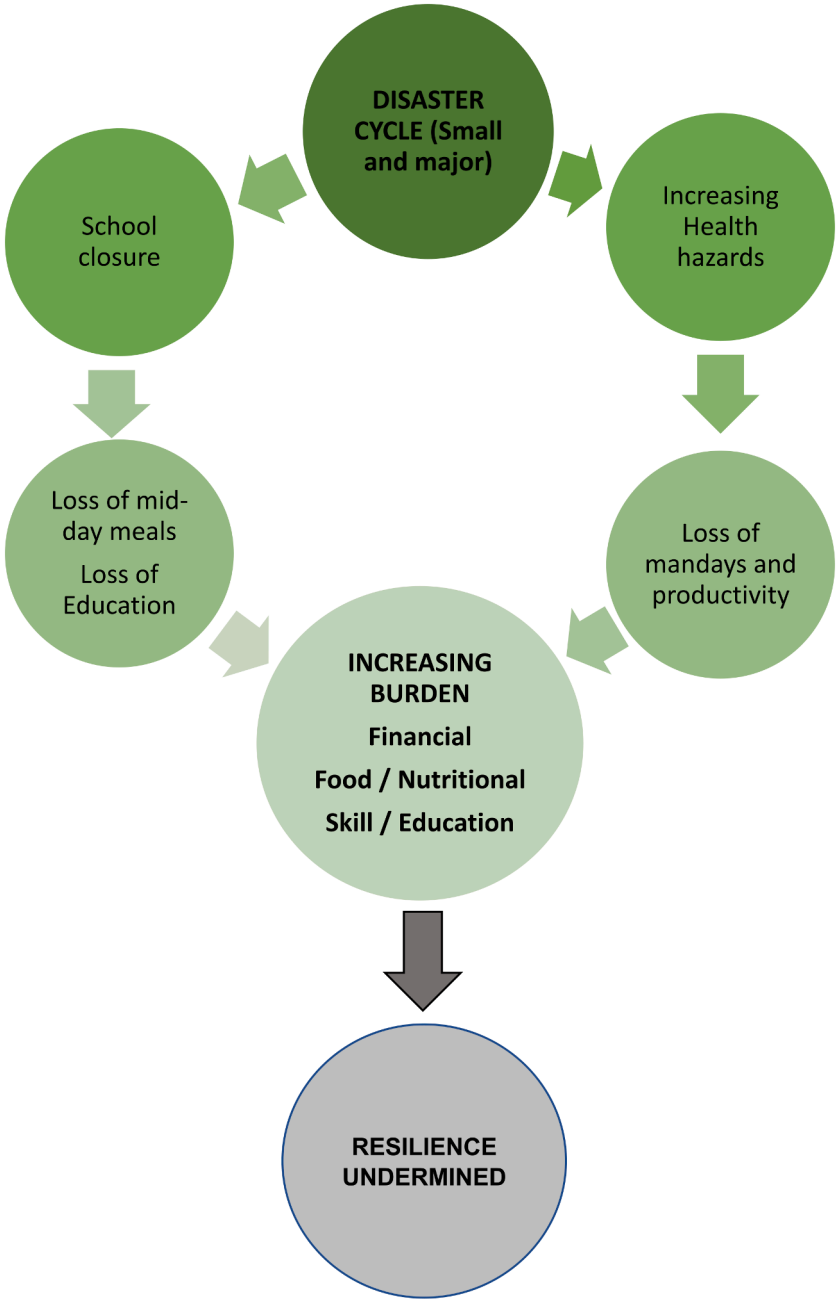


**Fig. 6.** How the disaster cycle affects human development and jeopardise household level resilience.

### *6.2. Risk governance within a resilience framework: from 'individual' vulnerabilities to 'co-produced' resilience*

Achieving a paradigmatic shift towards sustainable transformation, a key condition of development in the Anthropocene, is only possible through robust socioecological resilience across regions that are particularly vulnerable from the impacts of a rapidly changing climate. However, a key concern that emerged from this study concerns the discursive alienation over meanings of 'sustainable development', 'adaptation', 'resilience', 'ecosystem conservation' and resulting conflicts in governance and polices. Scholastic understanding of the term 'resilience' are variegated at best – [168] discusses historical etymology of the term; [169]analyses its conceptual relations to vulnerability and adaptive capacity [46]; explain politics of resilience for planning, [170]critique resilience policies and activism, among numerous other studies. Even within single geographic fields such as disaster risk reduction (DRR), climate change adaptation (CCA), humanitarian aid or spatial planning, resilience elicits different meanings, contexts and applications – mirroring the diversity of meanings that even governments and organizations in different parts of the world find in the concept [168, 171–173].

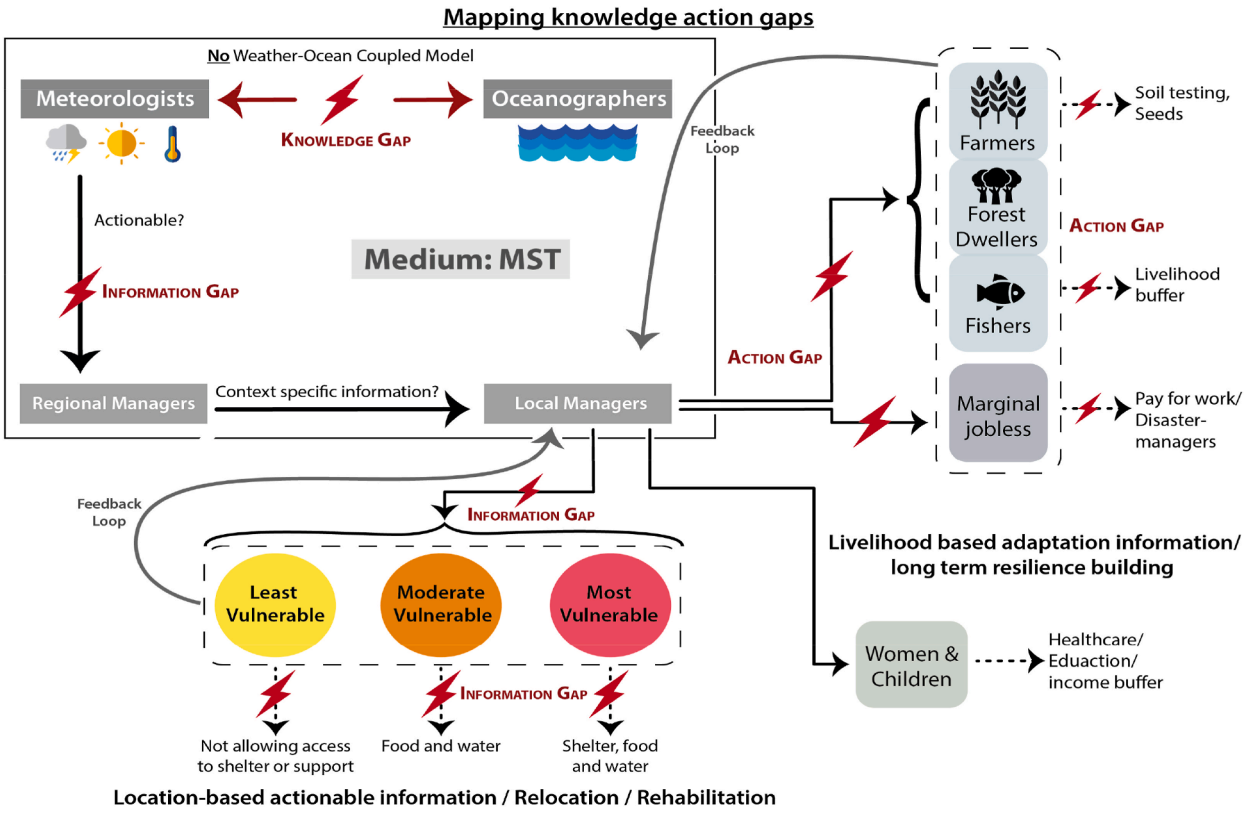


**Fig. 7.** Mapping knowledge-information-action gaps in disaster management in the Indian Sundarbans.

There is also considerable contestation over the connection between vulnerability and resilience concepts in theory. While some consider resilience as the flipside of vulnerability [29]; [174,175] others describe vulnerability as a socio-economic process rather than a 'state' [169] [77], with the process view then extending to resilience. Findings of this study emphasise the importance of developing a shared and mutually respectful approach to diverse meanings of resilience for different actors, an area ignored by existing vulnerability indices. Majority of these indices e.g., Refs. [67,68]; [176] [56,60–63,65,66,71,78], extract and employ diverse kinds of physical indicators to derive their respective indices. Characterised by a 'temptation' to complicate matters by having a high degree of details, these indices often become un-operational at the local level, limiting their practical applications [80]. This study urges to shift to two entirely new dimensions to bolster socioecological resilience: addressing knowledge gaps concerning actionability, socioecological contexts and community specifications, along with developing socio-culturally nuanced framing of the produced knowledge and its communication.

Power struggles over meanings obstruct contextually calibrated knowledge and implementation of the sub-sets of components that shape resilience [81], inevitably leading to what [181] lists – subjective choice of variables problems of measurement, averaging and weighing procedures, aggregation problems, and political aspects. We argue that instead of aiming for a universal and all-encompassing understanding of resilience, the discursive diversity can be employed as a productive tool of informing socioecologically contextual and diversely designed policy approaches based on epistemic plurality and multiple realities. By involving different 'agents' to actively contribute to knowledge production itself, shared meanings and values along the spatio-temporal scales can be developed, discursive alienations of vulnerability assessments can be addressed and specific resilience can be built that is informed by multiple parameters such as specific communities, their locations, socioeconomic profiles, eco-climatic conditions and others. Simplicity, however, will have to be central to foster concerted action at all levels, so that the frameworks and indices are used in actual problem-solving instead of becoming a mere academic exercise and discussion (Ibid). Visualisation (Fig. 7) is a key tool to achieve the simplicity and actionability as it shows designated spaces of participation of different stakeholders and agents that facilitate developing shared meanings while reflexivity allows refining scenarios and shared meanings in a process-continuum.

## 7. Conclusion

Findings of this study suggest that reducing ideas of vulnerability and resilience into 'scalar' parameters can achieve limited success in mitigating newer forms of risks induced by climate change. Instead, local adaptive skills, knowledge and context-based learning from micro and situated contexts can be translated into actionable components and can enable resilience and recovery through participatory approaches. Contextual, comprehensible, networked and actionable knowledge is key to enhance resilience of communities with disproportionately high levels of vulnerability from snowballing negative impacts of climate change. The case of Sundar-

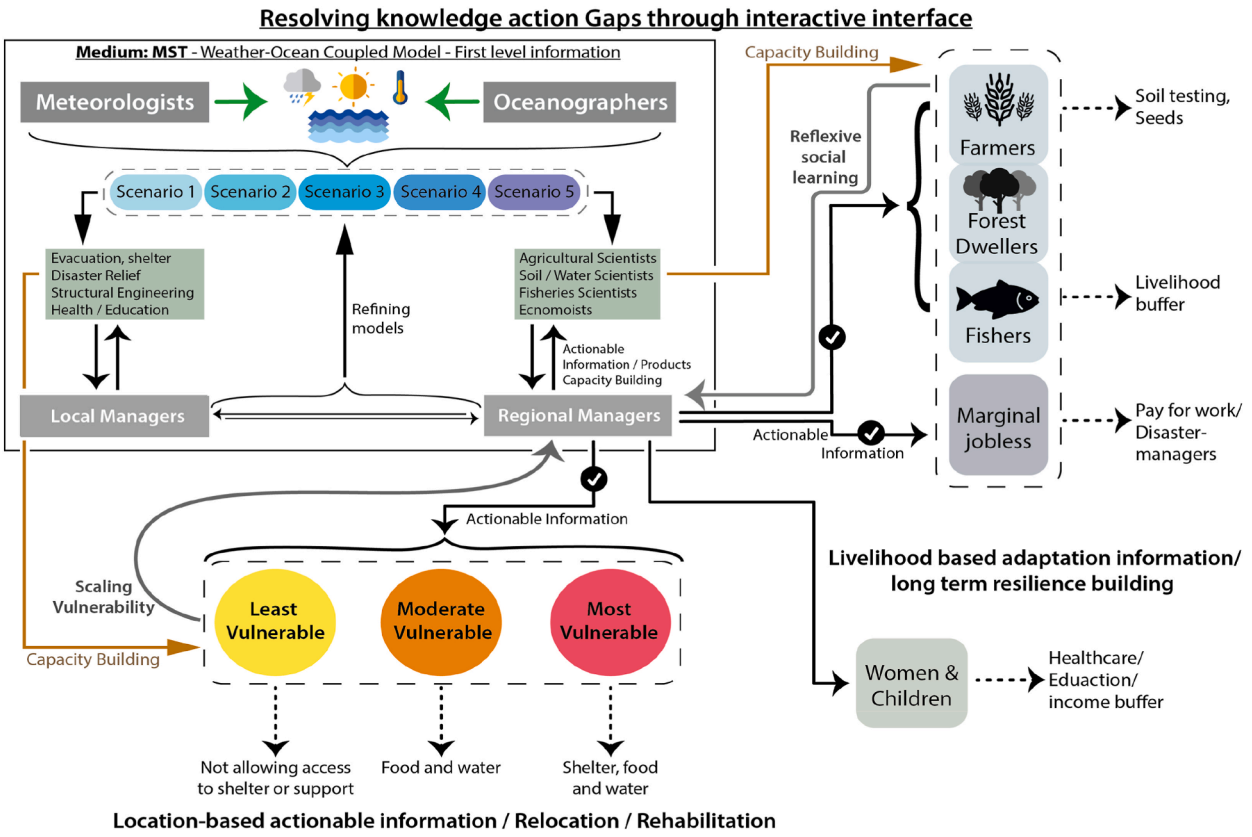


**Fig. 8.** Disaster Action Framework: A Schematic diagram.

bans revealed absence of a coupled model between meteorology and oceanography (knowledge gap), customised and targeted information for various stakeholders (communication gap) and finally, how existing power structures determine access to information and knowledge. The combination critically impairs resilience of communities, failing to provide either structural, material and livelihood securities or human development services in the form of healthcare and education. However, at the same time, we find resilience to be a discursive construct with diverse meanings and values across communities, stakeholders, actors and institutions. Integrating multiple resilience 'realities' during production of actionable knowledge and in its framing and communication is key to localise resilience and its constituents. Simultaneously, translating and mediating the knowledge into clearly defined actionable information for different end-users and ensuring its access in a timely manner are equally important, the study finds. This necessitates acknowledging politics, power, inequality and agency in the resilience building process and how science is produced; to prevent the neoliberal ideology to misappropriate resilience as a profiteering tool [177–179]. Wide participation in the complex processes of knowledge co-production, customised framing and communication of the knowledge and reflexivity are critical to connect different social strata, local governance and hierarchies that create lived environments [34,82,83]. 'Fetishizing the sublimity of beautiful (scientific) data' [84]: 155) and 'enticing fantasy of total knowledge' [85]: 6), this study finds, are rather futile. Instead, forming knowledge coalitions can help develop localised interventions, empowering households and communities, synthesising and integrating the 'small, diverse kinds of data' arranging 'people and property into time and space' [86]: 40, [87,95]. Conceptualising resilience as a flexible, open-ended, socioecologically contextual and continuous process is vital by creating spaces where encounters between social, communication and geospatial science can take place and develop new capacities for communities, systems and platforms.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

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