International Journal of Disaster Risk Reduction 73 (2022) 102905

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Sea level rise induced impacts on coastal areas of Bangladesh and local-led community-based adaptation

Bishwajit Roy [a,g,*], Gil Pessanha Penha-Lopes [a], M. Salim Uddin [b,c,g], Md Humayain Kabir [d,e], Tiago Capela Lourenço [a], Alexandre Torrejano [f]

[a] Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa, 1749-016, Lisboa, Portugal
[b] Department of Geography and Environmental Management, University of Waterloo, Ontario, Canada
[c] Centre for Asian Climate and Environmental Policy Studies, Ontario, Canada
[d] Wegener Center for Climate and Global Change, University of Graz, Austria
[e] Institute of Forestry and Environmental Sciences, University of Chittagong, Bangladesh
[f] Centro de Estatística e Aplicações, Universidade de Lisboa, 1749-016, Lisboa, Portugal
[g] Bangladesh Institute of Social Research Trust, Dhaka, 1207, Bangladesh

A R T I C L E I N F O

Keywords:
Sea level rise
Community-based approach
Physiographic impacts
Coastal area
Bangladesh

A B S T R A C T

Bangladesh is as a low-lying country, susceptible to various Sea Level Rise (SLR) induced impacts. Previous studies have separately explored SLR effects on Bangladesh's coastal ecosystems and livelihoods, across multiple spatial and temporal scales. However, empirical studies acknowledging local population's perceptions on the causal factors to different SLR induced physiographic impacts, their effects at societal scale and ongoing adaptation to these impacts of SLR have not been able to establish a causal-linkage relationship between these impacts and their potential effects. Our study explores how SLR has already impacted the lives and livelihoods of coastal communities in Bangladesh and how these have been responded by adopting different adaptative measures. We applied a qualitative community-based multistage sampling procedure, using two Participatory Rural Appraisal (PRA) tools, namely Focus Group Discussions (FGDs) and Community Meetings (CM), to collect empirical data about SLR effects on livelihoods and implemented adaptation responses. Our study found that both man-made and natural causes are responsible for different physiographic impacts of SLR, and which seem to vary between place and context. Five major SLR induced impacts were identified by coastal communities, namely: salinity increase, rising water levels, land erosion, waterlogging and the emergence of char land. Salinity increase and land erosion are the two most severe impacts of SLR resulting in the largest economic losses to agriculture. Our results highlight how coastal communities in Bangladesh perceive the impacts of SLR and the benefits of different adaptation processes set in motion to protect them, via development projects and other local interventions.

1. Introduction

Climate change-induced Sea Level Rise (SLR) has been a major concern for coastal and low-lying areas of the world since these areas undergoes several morpho-dynamic processes due to several geomorphological, climate change and oceanographic factors [1,2].

* Corresponding author. Centre for Ecology, Evolution and Environmental Changes, Faculdade de Ciências, Universidade de Lisboa, 1749-016, Lisboa, Portugal.
E-mail address: ahirsust@gmail.com (B. Roy).

https://doi.org/10.1016/j.ijdrr.2022.102905
Received 29 September 2021; Received in revised form 7 March 2022; Accepted 9 March 2022
Available online 11 March 2022

Although global communities aim to keep the global mean surface temperature (GMST) below 1.5 °C by the end of the century [3], but the IPCC special report on the ocean and cryosphere highlighted that emission reduction strategy will not eliminate SLR and extreme sea level (ESL) risk to low-lying coasts and islands rather delta regions and resource rich coastal countries are expected to experience moderate to high risk in terms of land erosion, loss, flooding, salinization, and cascading impacts due to mean SLR and extreme weather events after 2050 [4]. The situation will be worsened because of the increasing exposure of population and human assets along the coastal area. The number of people living in low elevation coastal zones and their exposure to coastal flooding is highest in Asia and China, India, Bangladesh, Indonesia and Viet Nam [5–7] and this is likely to remain unchanged in future [7,8]. In Bangladesh, about 46% of its total population live within 10 m above sea level and approximately 50 million people live below 5 m above the mean sea level [9].

Considering the geomorphological characteristics, the coastal areas of Bangladesh can be divided into three zones: the western, the central and the eastern. These areas are an important source of different economic activities ranging from commercial, recreational, and subsistence fisheries to other agriculture activities and forest resources collection [10,11]. Agriculture by itself, is one of the primary economic activities of Bangladesh representing 14.23% of the country's GDP and employs around 40.60% of total labour force of Bangladesh [12]. This sector has been identified as one of the prime sectors for achieving the development goals of coastal areas and agriculture is the main economic activity of 40 million people living in the coastal zone [13]. Due to the global climate change induced SLR, agricultural activities in the coastal areas of Bangladesh have been incurring economic loss in terms of inundation by rising water level and salinity intrusion, reduction in crop production, loses of livelihood activities and resources degradation [14,15]. In future, due to the inwards salinity intrusion and resulting inundation by saline water, the availability of the crop field is going to decline in the coastal belt of Bangladesh [16]. Previous studies focusing on climate change and SLR impacts on agriculture in Bangladesh have projected further decreases of agricultural production [17–21].

A considerable number of empirical studies has been carried out on Bangladesh with respect to SLR induced impacts and associated extreme events. A few studies have specifically focused on the physiographic impacts of SLR such as land erosion and accretion [1,22–24] and others on inundation [25–30]. For example, Ahmed et al. [1] reported that among the coastal zones of Bangladesh, the central zone is highly susceptible to erosion being influenced by the different hydro-climatic factors including sea level rise. The higher variation of mean SLR along with varied degrees of river discharge contributes to the high rate of erosion [23]. Analysis of climatic scenarios found that the extent of inundated areas and the level of storm surge heights would be higher than that of the present days with the projected changes of SLR until the midst of 21st century [105]. Due to the low elevation and waterlogged wetlands, the northern parts of the Sundarbans in India - the largest mangrove forest located in Ganges-Brahmaputra-Meghna (GBM) delta – are high to very highly vulnerable due to the sea level rising and tropical cyclone induced storm surge inundation [31]. Many studies focused the socio-economic impacts of SLR as well as associated adaptation strategies to cope with those impacts [21,32–36]. Mehvar et al. [34] quantified the total loss of about US$ 0–1 million to US$ 16.5–20 million to different ecosystem services due to the different levels of relative SLR (RSLR) under different Representative Concentration Pathways (RCPs) until 21st century in the west coast of Bangladesh. Applying remote sensing and GIS tools, Moniruzzaman [35] quantified the amount of waterlogged area in the south-west coastal part of Bangladesh on a temporal scale and addressed the impacts of SLR on the socio-economic condition of the people in that area. Similarly, Islam et al. [38] have also found that a considerable amount of areas in the south-western part of Bangladesh have been suffering from waterlogging condition which has brought significant changes in the land use land cover of that area from 1973 to 2015. However, they did not mention about the causes or factors of such waterlogging condition in their study. Several studies have developed coastal vulnerability index for different parts of the coastal areas to detect the exposure of those areas under different SLR extremes [39–41].

Bangladesh government introduced policies and action plans namely Coastal Zone Policy (CZP) in 2005, Bangladesh Climate Change Strategy and Action plan in 2009 and formulated National Adaptation Program of Action (NAPA) in 2005 at national level to address the SLR induced impacts. Among these, NAPA and Bangladesh Climate Change Strategy and Action Plan (BCCSAP) have specifically addressed several adaptations needs and prioritized actions through community involvement for coastal zone management. Bangladesh is also a leading example for the implementation of community-based adaptation (CBA) measures among least developed countries [42]. The benefits of community-based adaptation activities are that it ensures the participation and inclusion of the poor and more vulnerable communities and people in the development of the projects and empower them to identify and provide feedback on the risks posed by climate change and associated risks [43]. With respect to adaptation, several community-based adaptation projects against climate and SLR induced impacts have also been implemented in Bangladesh [44–49]. Bangladesh government along with the international support implemented "Community Based Adaptation through Coastal Afforestation," which main target was to reduce the vulnerability of coastal communities through livelihood diversification by the active involvement in community based natural resources management [49]. Haque et al. [50] in their review article addressed the importance of community based approach to cope with the SLR impacts. They also addressed the limitation of different government policies with respect to community-based approach. Rahman et al. [36] assessed the salinity level in drinking water facilities in a south-western coastal district of Bangladesh and concluded that a community based approach through the involvement of different stakeholders could reduce the safe drinking water scarcity for that area caused by salinity intrusion of SLR. Abedin et al. [51] have also made similar recommendation to address salinity induced drinking water scarcity problems.

However, our literature review revealed there are significant gaps in the understanding of the cascading physiographic impacts of SLR (e.g., land erosion, water logging, inundation, emergence of char land) and their associated effects on farming from the community perspective, especially in the southwestern region of Bangladesh. Therefore, the main objectives of this study are: (i) to identify the community perceptions on the causal-linkage between the SLR physiographic impacts and associated causes to and effects of them at societal scale within the coastal areas of Bangladesh, and (ii) to explore the local-led climate change adaptive measures to cope with and adaptations to SLR induced challenges, with a focus on the agricultural activities and livelihood diversifications.

2. Profile of the study areas

This study has been carried out in Sutarkhali and Banishanta, two coastal Unions (lowest administrative unit in Bangladesh), both belonging to the Dacope Upazila (sub-district unit) of the Khulna District (Fig. 1). The total area of Dacope Upazila is 991.57 sq. km with 10 Unions including Banishanta and Sutarkhali. These two Unions are located on the coast of the Bay of Bengal and inundated by tidal waves of the largest river in Bangladesh - the Padma River [13,52].

Sutarkhali Union is located 25 km away from Dacope Sadar Upazila (Khulna district). Two major rivers - the Sibsa and the Sutarkhali - pass along the border of the Sutarkhali Union. Banishanta Union is located on the south-eastern side of the Dacope Upazila, bordering the Mongla Upazila (Bagerhat District) and along the bank of the river Passur. Other major rivers in Banishanta include the Sibsa, the Manki, and the Bhadra. Population wise, Sutarkhali Union consists of 18 *mohallas*[1] belonging to four villages with a total of 7463 households, while Banishanta Union has 23 villages with a total of 3398 households [53]. The major socioeconomic occupation of populations in this area is agriculture, followed by fishing and collection of non-wood forest products (NWFPs) from mangrove forests [13].

Main livelihood activities (subsistence activities) in the area consist of paddy crop cultivation,[2] supplemented with homestead vegetable gardening, livestock rearing, collection of forest resources from the Sundarbans Reserve Forest and fishing [54]. Crop farming was the main economic activity until 10–15 years ago, when deliberate flooding of crop fields with saline water for shrimp farming, along with erratic monsoon rainfalls and the more frequent landfall of cyclones, gradually altered the types of livelihood activities in this area [55].

The Dacope Upazila was selected as it is one of the most affected areas by SLR-driven salinity intrusion, in Bangladesh. The Sutarkhali and Banishanta Unions were selected based on their physical exposure to the dynamics of the sea estuary, their socioeconomic base and occupational diversity, and observed losses and damages due to SLR induced salinity intrusion, and cyclones.

In 2007 and 2009, both Unions were devastated by two major Cyclones (Sidr and Aila, respectively) that caused a massive loss in lives, livelihoods, and economic assets. Several coastal polders and river embankments were breached, with extensive physical and socioeconomic damages [56,57].

3. Research methods

A qualitative approach with multistage sampling procedure was used in this study. Several Participatory Rural Appraisal (PRA) tools were applied for data collection. A total of 7 Focus Group Discussions (FGDs) were conducted at the smaller sampling units with the participation of local people from the sampled villages (i.e., Villages/Mohollas). Additionally, two Community Meetings (CM) were organized, one in each Union. This set up allowed to incorporate additional perspectives from other stakeholders (e.g., governmental and non-governmental organizations) and thus complement the responses collected at the local community sampling units (Villages/Mohollas). Fig. 2 represents a schematic outline of the whole research process.

3.1. Focus group discussion (FGD)

The Focus Group Discussion (FGD), a participatory method based on qualitative data, has been extensively applied in social sciences for several decades [58]. The main purpose of applying participatory methods is that it facilitates the exploration and construction of knowledge for a particular phenomenon in smaller groups [58] and helps researchers to obtain a richer and more detailed information of past experiences [58,59]. FGDs have been widely used for examining the impacts of climate change and climate change adaptation in multiple settings and countries, including Bangladesh [10,60–63].

Each of the FGD sessions was organized following the methodology proposed by Breen [64]. All FGD were composed of participants of both genres from each respective area and the selection of participants was done using the snowball sampling approach [65]. Participants at each FDG were comprised of 12 people including subsistence farmers, small landholders and fishermen, elderly people, schoolteachers and members of the local administrative unit. An implementation guide was prepared in advance of each FGD. The guide contained a list of 20 semi-structured open-ended questions, a list of target stakeholders, and a training module for the FGD facilitators. The questions covered the following topics: perceptions about climate change; SLR and associated impacts; impacts on agricultural activities; measures and actions undertaken at the institutional level; and support received from governmental institutions.

The random sampling method with a sampling intensity of 20% was applied to the selection of villages for FGD. To do that, villages were randomly selected (from a list of all villages in each Union) until the reported sampling target (20%) was reached for both Unions. Four villages (out of 23) in Banishanta and three (out of 18 *mohallas*) in Sutarkhali were selected.

The two study areas have different local administrative structure, therefore sampling intensity at 20% means 20% out of the total local administrative units which are villages and *mohallas* for Banishanta and Sutarkhali union respectively.

[1] This is a non-administrative unit; developed by the Union parishad to facilitate the administrative work of the Union.

[2] In South Asia, the crop calendar is divided into three main seasons named as Kharif – I (March–May), Kharif – II (June–November) and Rabi (December–February) and the paddy crops grown in these seasons are referred to as Aus, Aman and Boro, respectively (Hoque et al., 2018).

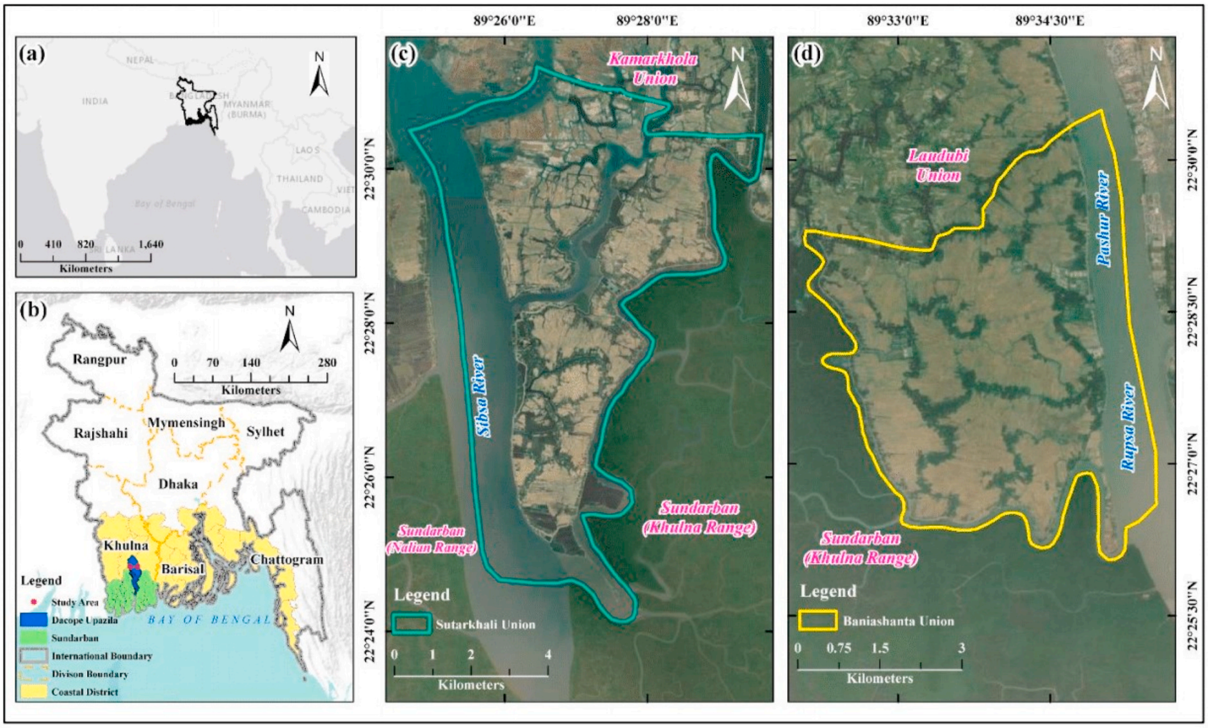

Fig. 1. Profile of the study area. The insert map (a) illustrates the location of Bangladesh (denotes in black color) in south Asia overlain in world light gray canvas base map. The map (b) displays the location of Dacope upazila* (Blue color) in Bangladesh where the study area (red color point) Banishanta (in the east) and Sutarkhali (in the west) union* located respectively overlain in world terrain base map. This map also denotes the divisional* boundary (Electron gold color), coastal district* (Autunite yellow color) and Sundarbans (Light apple color) location in Bangladesh map. The map (c) shows the location of Banishanta Union* (Yellow color) and map (d) represent the location of Sutarkhali union* (green color) overlain in the world imagery map. (*Union – Administrative boundary level −4, *Upazila – Administrative Boundary level-3, *District - Administrative Boundary level-2, *Division - Administrative Boundary level-1) (Source: WFP, 2013 and authors performed image analysis) https://geonode.wfp.org/layers/

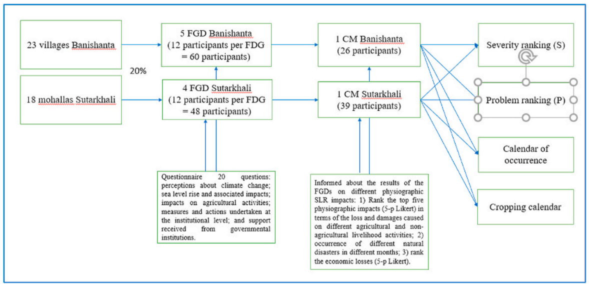

Fig. 2. A schematic diagram of the research process highlighting the data collection tools namely FGDs and community meetings (CMs) used to obtain community people's responses against the severity of different SLR induced physiographic impacts and associated problems and adopted resilience measures to cope with the impacts.

3.2. Community meeting (CM)

FGDs' findings were used in two Community Meetings (CMs), one for each of the studied unions. The objective of this meetings was to document additional views from an enlarged community perspective, as well as to validate, complement and cross-check the FGD findings.

Main components of the CM were: the perception of locals towards SLR induced impacts; causes and their subsequent effects on agricultural activity; vulnerable groups; and local-led adaptation measures. A problem tree analysis technique was applied in each CM where participants find solutions to the problems through the identification of the negative aspects of a given situation through the establishment of a relationship between the causes and effects by the observed problems [66,67]. These techniques have been extensively used in developing countries because of their role in logical framework analysis [66,68]. With the help of the local nongovernmental organizations (NGO), stakeholders involving local people, schoolteachers, NGO workers, local governmental institutions and community clubs from each case study area were invited on a fixed date to participate in the CM. No specific criteria were followed for the stakeholder's selection because the main target was to receive a holistic view of the residents from each study area towards SLR induced impacts, effects and associated measures to cope and adapt with the impacts. The number and type of participants in each Union's CM are presented in Table 1.

At arrival, participants were briefly informed about the purpose and agenda of the CM, as well as the activities to be carried out, and their expected roles. They were also clarified about the technical terminology related to the topic through a short presentation in Bengali (mother language).

3.2.1. Sea-level rise physiographic impacts

Additionally, they were presented with the FGDs results concerning the top-5 different physiographic SLR induced impacts. Then, they were asked to rank that top five physiographic impacts using a 5-point Likert scale (i.e., 5 – very severe to 1 – least severe) in terms of the loss and damages incurred by them on different agricultural and non-agricultural livelihood activities.

In order to assess how participants in CMs have experienced the physiographic SLR induced impacts and resulting effects in their respective Union, equation (1) was applied to identify the severity extent of those impacts.

$$\textit{Severity score } (S) = \frac{1}{N}\sum_{j=1}^{j=5}(nL)_j \tag{1}$$

where, N = Total number of participants, j is the level of severity (i.e. 5 - very severe; 4 – moderately severe; 3 – severe; 2 – less severe; 1 – least severe), n is the total number of people selected in jth category and L is the value of severity level (i.e. "very severe" = 5; "moderately severe" = 4; "severe" = 3; "less severe" = 2; "least severe" = 1).

The assumption was that the higher the severity score, the higher the risk posed by the physiographic SLR impacts. Fisher's Exact test was applied to compare the differences of responses for each physiographic impact between case study areas. The null hypothesis was that the distributions of attributed rankings were the same for Sutarkhali and Banishanta.

Participants were then randomly divided into five groups composed of different occupational groups distributed into five tables. Each group was consisted of at least six members. Each table discussed one of the five SLR induced impacts, following a world-café setting [69], where participants changed tables every 30 min thus allowing them to discuss all five impacts and complement what previous groups had concluded. Following the problem tree analysis technique [66,67], they were asked to write down the main causes responsible for each impact, its primary effects on their lives and livelihood activities, affected groups and adopted (or proposed) adaptation actions or measures to cope with those impacts.

3.2.2. Sea level rise and human induced agricultural problems

The comparative assessment on the economic losses in the livelihood activities between Sutarkhali and Banishanta was done using equation (2) (see below). We applied Independent Sample T-test to find out the differences towards the severity of different agricultural problems, between two case study areas.

$$\textit{Problem ranking } (P) = \frac{1}{N}\sum_{j=1}^{j=5}(nD)_j \tag{2}$$

where, P stands for problem ranking, N = Total number of participants, j is the extent of damage (i.e. 5 - very huge loss; 4 – moderately severe loss; 3 – severe loss; 2 – less severe loss; 1 – least loss), n is the total number of people selected in jth level and D is the value of the extent of damage (i.e. "very huge loss" = 5; "moderately severe loss" = 4; "severe loss" = 3; "less loss" = 2; "least loss" = 1).

3.2.3. Occurrence of climate hazards and adoption of cropping calendars by the communities

At the CMs, the participants also performed a snapshot of the perceived occurrence periods of the different climate hazards (disasters) for their case study areas, considering both past (5–10 years ago) and present (last 3 years) conditions.

First, major climate hazards experienced by the communities in the past and present temporal scales were agreed. Then, participants were instructed to write Yes (coded as 1 for analysis, meaning the disaster typically occurred in that month) or No (coded as 0 for analysis) on a monthly basis, considering both past and present conditions.

Secondly, participants were asked to describe if they had adopted a cropping calendar for their agricultural crops to cope with the negative impacts of the different climate hazard. As for the occurrence of climatic hazards, they were instructed to prepare a cropping calendar representing past (5–10 years ago) and present (last 3 years) conditions.

With respect to the temporal mapping of different hazards and cropping calendar, the perceptions of the participants between the two study areas were compared. The participants' assessment was decided by majority vote, that is, when >50% of the groups (tables) voted yes to the occurrence of the event or the cultivation of a crop during a specific month, it was considered that a majority of the participants agreed that the hazard or cultivation occurred in that month. It needs to be mentioned that when the majority vote couldn't be obtained, then (>25%) vote was considered to facilitate the comparative analysis between two areas. Results are visualized through a heat map.

4. Results

4.1. Community perceptions on major sea level rise induced physiographic impacts

The participants' discussion in groups at the CMs using problem tree analysis revealed that salinity increase, land erosion, the

Table 1
Number and types of stakeholders that participated in the Community Meetings at Sutarkhali and Banishanta study areas.

Representatives	Sutarkhali	Banishanta
Local people	14	7
NGOs staffs	6	4
Govt representative	1	2
School teacher	3	2
Farmers	8	5
Fishermen	5	3
Local administrative unit	1	1
Community club	1	2
Total	39	26

emergence of new char land,[3] water logging, and rising tidal water level are the major physiographic impacts of SLR to the coastal communities. Table 2 represents a brief outline of the causes, effects of different physiographic impacts of SLR, affected community/organization and associated measures implemented from the institutional levels as well as practiced by the communities from two case study areas based on the discussion of the participating five groups from each study area.

4.1.1. *Salinity increase*

According to locals, expansion of shrimp farms, letting saline water to get in through sluice gate by the shrimp farm owners and elite people from the respective areas, longer saline water retention for shrimp farming, increasing the height of tidal water in rivers and later overtopping the earthen embankments have increased the salinity problems in the areas. As a result of increasing salinity, especially the farmers and freshwater fish collectors/fishermen have been incurring economic losses through declining the production of agricultural crops and vegetables cultivated in the country yards, damage to the fruit trees in the yards, virus infestation and death of freshwater fishes etc. Furthermore, local people especially the children, older people, and pregnant women are getting affected by different kinds of health diseases such as diarrhoea, dizziness, and hypertension.

To cope with such situations, different adaptation measures such as repairing the dikes, dredging of the rivers, afforestation/reforestation on the dikes, storing the rainwater during monsoon in canals have been implemented by different organizations. However, when the institutional measures did not suffice, the local people are applying organic and inorganic fertilizers in the crop field to cut the salinity problems and increasing the agricultural productions, applying water purifying chemicals to ponds to decrease the virus attack in ponds and rivers. They are also participating in community-based awareness activities to alert shrimp farmers about the side effects of shrimp cultivation.

4.1.2. *Land erosion*

Participants from both case study unions reported similar causes such as increasing the height of river tide, unplanned extraction of sand from riverbeds and cutting down trees from the riverbank areas along with other causes. Among the other causes, locals from Sutarkhali reported about salinity increase, improper river dredging, and use of fishing nets, while participants from Banishanta stated about illegal settlements on the riverbanks and excessive rains as the major causes of land erosion in Banishanta. As a result of increasing erosion, people are losing their houses and properties, incurring economic loss by losing their cropland and have becoming shelter less. Therefore, after losing everything they are moving towards the city areas and increasing slums there. Moreover, participants also reported the infrastructural damages such as damage to roads and dykes, different types of development activities etc. These problems can be minimized through adoption of tidal river management activities such as river dredging, pulverization of riverbank areas, afforestation and reforestation activities along the bank area, awareness raising among people not to extract sand from bank areas, among others.

4.1.3. *Rising water level*

Participants from both areas noticed an increase in level of water in the rivers and sea in recent years. These changes in water level had been noticed by the increase of the height of the river tide and increased riverbank erosion. According to participants, the main causal factors for rising water level are siltation in the riverbed due to riverbank erosion. They are also aware about the melting of glaciers and ice in Antarctic and Greenland due to temperature rise which is causing SLR. Furthermore, due to the gravitational force during the ebb and tide, the water flow in the big rivers has been deteriorating by siltation in the meeting points of the big rivers also increasing the water level. As a result of rising water level, farmers are losing their cultivable cropland and low-lying croplands are getting inundated by saline water and cage aquaculture farmers are losing their aquaculture farms. General people are losing their settlements and household properties by overtopping and wreaking down of dikes and bridges caused by the increased flow and force of water through rivers coming from the sea. Especially the people from Banishanta have been experiencing the problems of dyke damage almost every year.

Communities from Sutarkhali and Banishanta are looking forward to governmental institutions for tidal river management activities such as river dredging, ruling of rivers, construction of concrete walls and/or giving concrete blocks along the built dikes and in

[3] Typically, the monsoon overflows rivers and carries significant amount of silt and deposits a huge part of that in the shallow water along the coastal belt, predominantly in the south-eastern region. This sedimentation in the form of coastal *chars* leads to new land formation, locally called Char (Shahed et al., 2016).

Table 2
Different causes, effects of sea level rise induced physiographic impacts perceived by locals from Sutarkhali and Banishanta and associated adaptation measures/actions available in the areas.

	Banishanta Union	Sutarkhali Union
Salinity increase		
Causes	• Rise of tidal water level and stagnant of saline water for long • Expansion of shrimp/fish farm • Breaching of dykes by the elite people for shrimp farming • Less freshwater flow from upstream and prolonged dry season	• Increase of tidal water level. • Expansion of shrimp/fish farm • Less freshwater flow from upstream • Sustenance of saline water for extended period.
Effects	• Damage/decline of crops productivity • Decline vegetable production. • Fish mortality • Declining soil fertility • Spreading of human diseases and crop pests	• Damage of crops/decline of crop productivity. • Death of sweet water fishes • Damage of fruit trees in home garden • Health diseases • Lack of drinking water
Affected community/ organization	• Farmers, businessmen (fish), children, pregnant woman, different livestock businessmen	• General people, livestock, children, old people, pregnant woman, farmers
Actions/measures	• Building dykes and holding rainwater by digging canal • Using insecticides/pesticides • Producing and using organic fertilizers • Afforestation/reforestation • Seminar and training for awareness • Renovation of sluice gate	• Building dykes • Increasing river flow by dredging • Afforestation/reforestation • Increasing people awareness • Holding sweet water by digging canal
Rising water level		
Causes	• Climate change and improper construction of dykes and sluice gates • Siltation in the riverbed and river estuary • Melting of glaciers and ice due to rising temperature • Reduction in duration and speed in river tide 20 years ago.	• Riverbank erosion induces the siltation of riverbed. • Melting of glaciers and ice due to rising temperature • Excessive rain accelerates the land erosion.
Effects	• Damage of crops • Inundation of low-lying land by saline water • Disruption of settlements and properties through overtopping of the dykes • Lack of sweet water reduces the crop productivity. • Chances of breaking down the dikes. • Lack of pure drinking water	• Crop damage • Inundation of crop land • Disruption of settlements and properties by breaking down the dykes. • Intrusion of saline water in crop lands • Causing floods
Affected community/ organization	• Farmers, fishermen, and local formal and informal organizations	• Farmers, general people, cultivable land, children and older people
Actions/measures	• Constructing high and wide dykes • Awareness raising of local people. • Tidal river management • Removing the illegal settlements on dykes • Planting more trees along riverbanks/dykes.	• Building up high dykes • River dredging • Awareness raising • Ruling the rivers
Waterlogging/inundation		
Causes	• Decreasing water flow of rivers and lack of proper drainage management • Excessive raining and flooding • Emergence of char land • Conflicts and collision between people • Limited number and unplanned construction of sluice gates • Lack of public consultation in decision making	• Absence of proper water drainage/extraction channel • Decreasing the flow of river • Unplanned dykes' construction • Expansion of shrimp farms • Lack of connection between sluice gates, canals and rivers.
Effects	• Damage to the crops/crop production • Spread of diseases and declining soil fertility. • Scarcity of pure drinking water and death of livestock due to drinking saline water • Disruption in communication infrastructures • Death of sweet water fishes by saline water	• Damage to the crops • Communication problem • Damage to the seedlings planted in crop lands. • Decrease of grazing land for livestock
Affected community/ organization	Farmers, livestock, children and old people, pregnant woman, fishermen	• Farmers, general people, livestock
Actions/measures	• Canal excavation Proper channel for water drainage • Reconstruction of sluice gates • Cultivating salt tolerant rice varieties	• River dredging • Re-excavation of the canals • Construction of the sluice gates in right place

(*continued on next page*)

Table 2 (*continued*)

	Banishanta Union	Sutarkhali Union
Land erosion		
Causes	• Increasing the force and velocity of tidal water	• Increase in water level and salinity
	• Excessive rain	• Filling up the riverbed and improper river dredging
	• Extraction of sand from riverbank	• Cutting trees and unplanned excavation of soil from the riverside
	• Illegal settlement on Char land of river or on riverbank	• Use of fishing net.
	• Cutting down trees from riverbank	• Increasing the speed of river tide
Effects	• Losing of houses and cropland, and increasing slums in towns	• Land erosion
	• Damage of roads and rural infrastructure	• Damage of crops
	Declining crop lands and grazing lands for livestock	• Losing of crop lands, houses and properties
Affected community/ organization	• Farmers, general people, landowners, government	• General people, roads, cultivable lands, sweet water fishes, farmers
Actions/measures	• Planting trees on riverbank	• Controlling river erosion
	• Building up high, good, and sustainable roads	• Constructing dykes
	• Concrete walls along the road/dikes	• Afforestation/reforestation on the dykes
	• Controlling river erosion	• Prevention of cutting trees from riverbank.
	• Providing training on riverbank/erosion prevention	• Concrete wall along the river dikes
	• River dredging	• Proper river dredging activities and awareness creation
Emergence of char land		
Causes	• Dams on rivers/unplanned dyke construction	• Less speed in river current
	• Controlling the pathway of river	• Effect of siltation
	• Receiving or carrying of sediments by tide water and natural process in delta formation	• Throwing garbage in the river
	• Throwing garbage on rivers	• Filling up rivers
	• Setting up houses, factories, and markets by encroaching the riverbank	
Effects	• During tide, level of water goes higher.	• Decreasing the flow of rivers
	• Damage of crops due to interrupted irrigation facilities.	• Increasing the water level
	• Lack of grazing land for livestock and disruption in movements of fishes	• Crop damage due to interrupted irrigation facilities
Affected community/ organization	• Farmers and fishermen	• Farmers and fishermen
Actions/measures	• Dredging of rivers and canals	• River dredging
	• Dikes should not be built on rivers.	• Heightening the dykes in coastal areas
	• Garbage should not be thrown on rivers	• River ruling
		• Garbage should not be thrown on rivers.

some cases re-construction of the dikes along the rivers. Where possible, they are repairing the broken dykes, planting trees and grasses by themselves for stabilizing the dykes. Furthermore, they have also been conducting awareness activities through community clubs and with the help of NGOs for the people who breach the dykes for personal benefits.

4.1.4. *Emergence of char land*

People from Banishanta discussed about this problem more than that of the Sutarkhali and they also have different perception in terms of the severity to this impact. The main causes of this impact are unplanned dike construction, controlling the river flow by improper embankments, siltation of the rivers by the transported sediments from the upstream river bodies and lack of speed in the river current. Furthermore, participants from Banishanta reported that people throw garbage and build up shops and markets by filling up the rivers with sand and these also intensified the process of char land creation. As a result of this, during high tide the level of water goes higher, causes problems in irrigation activities, changes the pathway of river. These problems could be dealt through dredging of the rivers and canals, making people aware about the drawbacks of throwing garbage in the rivers.

4.1.5. *Waterlogging*

Regarding waterlogging, participants from both unions had different point of view for the causes for this impact. According to the Sutarkhali people, unplanned dike construction, improper management of sluice gate and no connection between sluice gate and canal linked with rivers were the causal factors to this problem while Banishanta people reported about poor management of drainage system, lack of sluice gates to bypass the water, emergence of char land as the main causes of waterlogging conditions. Participating groups from Sutarkhali mentioned about crop damage, disruption of communication system and dying of seedlings planted in the cropland. Due to the waterlogging condition, soil fertility had been deteriorating resulting in poor crop production, causing death of sweet water fishes in the canals due to saline water, scarcity of pure drinking water, death of the livestock, among other consequences, were the observed effects of waterlogging in Banishanta. These problems could be managed through construction of sluice gates in the proper place and excavation and re-excavation of canals and properly channelling them to nearby water bodies. Moreover, dredging of the rivers can also minimize the waterlogging problem and providing salt and water tolerant seed varieties to farmers can decrease their economic losses.

4.2. Perceived level of severity towards different sea level rise induced physiographic impacts

In the CMs, participating groups exhibited different responses in terms of severity level towards five major physiographic impacts of SLR. Table 3 represents their perceived level of severity along with the Fisher's p-value and Fig. 3 represents percentages of the various level of severity attributed to various physiographic impacts of both case study areas.

The participants from Sutarkhali scored less severity value than Banishanta to the SLR induced physiographic impacts. We did not reject the hypothesis that the severity perception distribution is the same for both areas in the cases of salinity increase and rising water level. However, evidence to say that the distribution of severity perception was varied between the two areas for the rest of the impacts. Among the major challenges, salinity increase was scored as the most severe impacts (4.85) and water logging as the least severe impact for both Sutarkhali and Banishanta. After salinity increase, land erosion (3.08) and rising water level (2.85) were the second most severe impacts respectively for Sutarkhali, while in case of Banishanta union, rising water level (3.58) and land erosion (3.54) were found as the second and third major impacts from the participants of Banishanta Union respectively.

Salinity increase was the most severe perceived impact of SLR in both case study areas. About 89% participants from Sutarkhali Union and more than 92% participants from Banishanta expressed their deepest concern to the effects of this physiographic impact. After salinity increase, land erosion was the second most perceived severe physiographic impact of SLR in the case study areas. About 34% participants from Banishanta and approximately 36% participants from Sutarkhali considered it as the most severe and moderately severe impact, respectively.

Participants from both areas noticed an increase in level of water in the rivers and sea in recent years. However, it was not identified as severe problem as salinity increase and land erosion by the respondents. About 41% from Sutarkhali identified it as the severe and 46% participants from Banishanta thought it as moderately severe impact of SLR.

People from Banishanta discussed about this problem more than that of the Sutarkhali and they also had different perception in terms of the severity to this impact. About 39% participants from Banishanta considered this as the moderately severe problem, while 41% from Sutarkhali considered it as the less severe impact of SLR. Among all the physiographic impacts, waterlogging was perceived as the least severe problem by populations in both case study areas, with 51% participants in Sutarkhali and more than 46% participants in Banishanta and listing it as the least severe impact of SLR.

4.3. Community perceptions on sea level rise and human induced agricultural problems

Sea level rise induced impacts had been generating different problems for the farmers to continue their agricultural activities. Table 4 lists the major problems along with the ranking. An increase in salinity, pest attacks in rice and excessive fertilizer use were the major problems reported for agricultural activities in Sutarkhali. Excessive salinity in soil has forced farmers to increase the amount of fertilizer in rice field every year. As a result of doing so, the organic matter content in their crop field had been deteriorating. Moreover, unavailability of good quality seeds and insecticides were the third biggest problem perceived by the respondents from this area. On the other hand, pest attack in rice followed by salinity increase, poor quality of seeds, and decreasing soil fertility respectively were the most highly ranked problems in Banishanta. Interestingly, we did not find any significant difference from the independent sample *t*-test against the most severe agricultural problems between two case study areas. An independent sample *t*-test reported a significant difference for pest infestation in vegetables, virus attack in water resources, poor quality seeds, and waterlogging between Sutarkhali and Banishanta Union.

4.4. Community perceptions about the occurrence of climatic hazards

Five different main types of climatic hazards were identified by participants at the CMs. Additionally, participants provided their perceptions about past and current periods of occurrence and a perceived yearly calendar of occurrence was drawn for each hazard (Fig. 4). We noticed that for most of the climatic hazards, participating groups couldn't properly mention the occurrence period for the 5–10 years back.

Participants in both study areas reported cyclones as the climatic hazard that affects them most. All five stakeholder groups (tables) at Sutarkhali CM, and 4 groups (out of 5) at Banishanta reported that the occurrence period and duration for this disaster increased recently, in at least half of the year (Fig. 4a). Participating groups between case study areas had different perceptions about the

Table 3
Sea level rise induced physiographic impacts and their level of severity according to the perception of local people from Sutarkhali and Banishanta Union.

	Sutarkhali (N = 39)	Banishanta (N = 26)	
	S	S	Fisher's p Value
Salinity increase	4.85	4.85	0.655
Land erosion	3.08	3.54	0.004
Rising water level	2.85	3.58	0.065
Emergence of char land	2.23	3.00	0.034
Waterlogging	1.95	2.23	0.000

Note: S is the weighted average severity score given by the participating groups from Banishanta and Sutarkhali, and N is the sample number from each union.

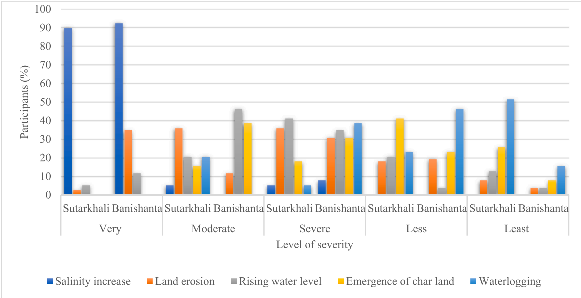

Fig. 3. Severity scoring of different SLR physiographic impacts in Banishanta and Sutarkhali as percentage (%) of responses by CMs participants.

Table 4
Major agricultural problems perceived by the farmers along with the problem ranking.

	Sutakhali	Ranking	Banishanta	Ranking	T- value	df
Salinity increase	5	1	4.6	2	0.571^{ns}	64.66
Pest infestation in vegetables	2.6	4	4	3	−3.731***	38.01
Excessive fertilizer	3.8	2	2.4	6	-0.595^{ns}	37
Insecticides	2.8	3	2.8	5	0.638^{ns}	64.92
Pest attack in rice	3.8	2	4.8	1	-0.532^{ns}	56.84
Virus attack in water resources	2.6	4	3	4	3.495***	49.98
Lack of good quality seed	2.8	3	4	3	−6.015***	52.11
Soil fertility decrease	2.6	4	4	3	0.513^{ns}	59.47
Waterlogging	2.6	4	2	7	4.87***	51.66
Excessive rain	1.8	5	1.4	8	-1.757^{ns}	30.69

Note: ^{ns} – Not significant. Values in *** represents significance at $p < 0.05$.

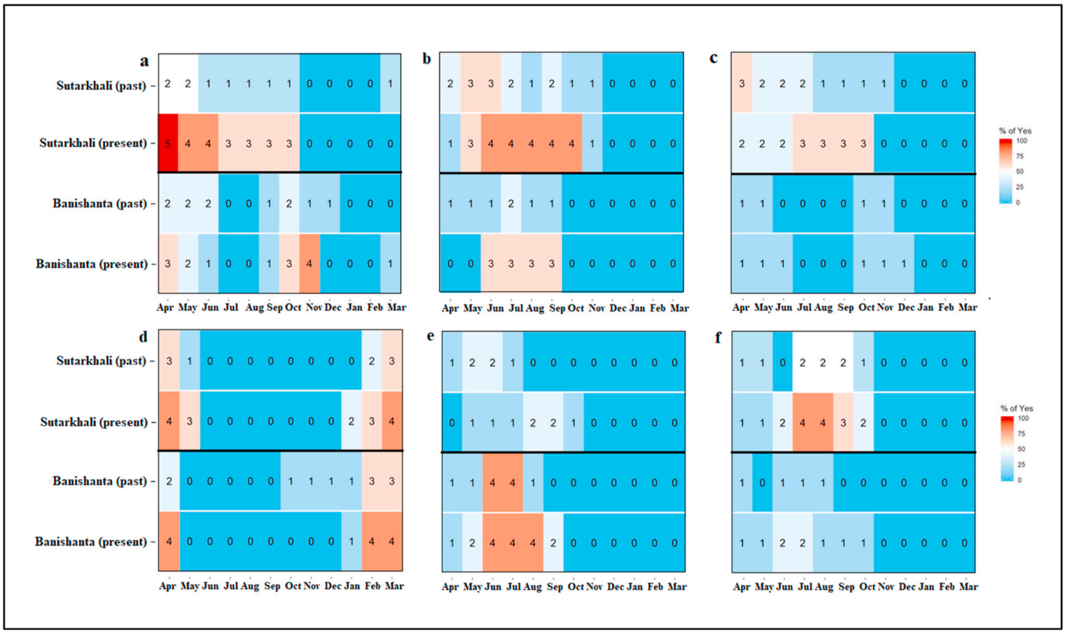

Fig. 4. Graphical presentation of changes in occurrence period of different climatic hazards (a) cyclone; (b) floods; (c) storms; (d) droughts; (e) excessive rain; (f) storm surges at a temporal scale based on the perception of people from both case study areas.

occurrence period of this disaster. Stakeholder groups in Sutarkhali reported the cyclone occurrence period at the present time prevails between April–October while in case of Banishanta, it's at first during the months of April–May and then again in the months of October–November. However, we couldn't reach in a conclusion regarding the occurrence period of this hazards in the past (5/10 years ago) because less than 50% groups from both case study areas could detect or remember the occurrence period of this climatic hazard.

Floods were reported by 4 groups from Sutarkhali and 3 groups from Banishanta (Fig. 4b). Participants from both case study areas possessed similar response for this disaster for the current time but have very disparate responses for the past. According to the groups of Sutarkhali, the occurrence of the floods season had extended from May–June to May–October. People from the Banishanta reported that flooding season occurs from June–September. Considering the contribution of less number of groups, it seems that the storm season seems to be non-existent in Banishanta.

Out of the 5 groups, 3 groups from Sutarkhali contributed to make mapping of storms climatic hazard on temporal scale (Fig. 4c). According to them, the storm season now occurs during July–October which used to be only in April. But no conclusion could be made for Banishanta since only one group contributed to the mapping of this disaster at temporal scale.

Like floods, the participants from both areas are in almost total agreement about current occurrence period but have different response for the past (Fig. 4d). Out of the 5 groups, 4 groups from Sutarkhali mentioned that the drought season has elongated significantly from March–April to February–May. According to the groups from Banishanta, the drought period seemed to prevail only two months (February–March) and at present it extended one month more (i.e., February–April).

Participants from both areas have different opinions about the occurrence period for the excessive rain. Moreover, it is difficult to pinpoint a time for this event especially for Sutarkhali since only two groups have mentioned this disaster. However, after focusing on the qualitative aspect of the study, it seemed that rainy season has shifted from May–June to August–September (Fig. 4e). On the other hand, Banishanta people had a very clear indication of occurrence period of this hazard. According to them, the rainy season expanded from June–July to June–August.

Participants from Sutarkhali seemed to experience this event more than those from Banishanta. Out of 5 groups, 4 groups from Sutarkhali and only 2 groups from Banishanta mentioned about storm surges (Fig. 4f). Considering the contributions of all the groups from Sutarkhali, it can be concluded that the storm surge season is the same for both past and current time: July–September. However, no conclusion could be reached for Banishanta since only 2 groups mentioned this disaster.

4.5. Adoption of cropping calendar to minimize the impacts to agricultural activities

Agriculture and other aquaculture activities are the main livelihood activities of populations in the coastal regions of our case study areas. Participants in the study were asked to describe the adoption of cropping calendars and other actions to deal with the negative impacts of the different climate disasters. Results are presented bellow for each agricultural crop considered. Fig. 5 represents the cropping calendar for different types of agricultural crops.

4.5.1. Rice

There are mainly two types of rice crops namely *Boro* and *Aman* cultivated by farmers from the case study areas.

Considering *Aman* rice cropping, the perceptions of the respondents seem to be very similar to each other (Fig. 5a). The general perception according to the majority vote is that the growing season for *Aman* has shortened slightly in study areas. In Sutarkhali *Aman*[4] cultivation got shorter from June–November to June–October and in Banishanta, *Aman* cultivation shifted to later in the year, from June–October to July–November.

Participants shared that they have been cultivating *Aman* for some time and have recently started cropping *Boro* rice (Fig. 5b) to increase the income. Since this crop has recently been cultivated by the community and only two groups from both case study areas mentioned about the cultivation period of this crop, therefore we couldn't reach in a concrete solution for the cultivation period of this crop. However, considering the contribution of the participating groups, it could be said that in Sutarkhali, *Boro* rice is cultivated between January and March at both time scale, while in Banishanta, most of the groups shared that the cropping season prevails between December–April.

4.5.2. Vegetables

Populations in these areas cultivate different vegetables in their homestead garden and fruits and cabbage in the crop field during the summer. Fig. 5 c represented the changes in cropping time for these types of crops. We notice a variation in responses for this type of crops by the groups of Sutarkhali. The general perception according to the participating groups is that the season used to happen in September–March, but now starts sooner in August. However, in Banishanta, the season does not seem to have changed, and is mentioned to occur from November to January.

4.5.3. Aquaculture

Out of 5 groups, 3 groups from Sutarkhali and two groups from Banishnata responded about the period of the aquaculture activity. Fig. 5 d showed that in Sutarkhali, aquaculture activities happen during September–January for either period analysed. In Banishanta, there is not enough agreement among the groups to correctly define the aquaculture period as most of the cells have less than 50% vote for yes; but 2 groups out of 5 shared that the season lasts between April to September.

5. Discussion

5.1. Perceived coastal sea level rise induced impacts and effects

Sea level rise induced physiographic impacts have numerous perceived impacts on the lives and livelihoods of populations across our study areas. The use of the problem tree analysis technique in the CMs helped to elucidate the impacts and effects of each of these

[4] Aman and Boro is a kind of cereal (Rice) food plant usually cultivated in December–January and in March–May respectively.

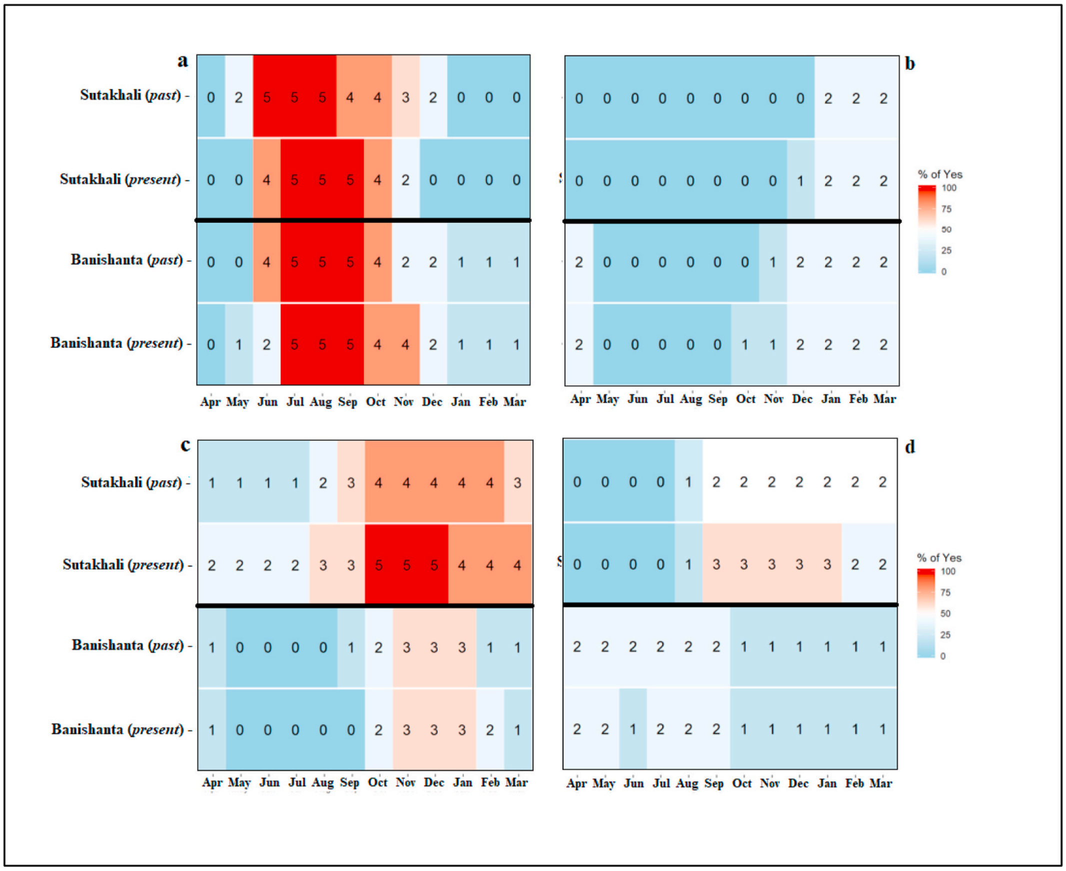

Fig. 5. Schematic presentation of adopted cropping season for different agricultural activities/crops (a) Aman rice, (b) Boro rice, (c) Vegetables, and (d) Aquaculture practiced in both case study areas.

impacts. First, it allowed to explicitly consider the role of local anthropogenic activities along with the impacts of global changes such as sea level rise. Notably, the coastal embankment program carried out in the area, and that aimed to restrict salinity intrusion in the dry season, drain excessive rainwater, and allow freshwater irrigation flow to polders in the wet season [104], is perceived to have failed to provide its expected outcomes. In fact, population's perception is that it rather contributed to rapid land use changes and human settlement activities that have increased vulnerability [54–56,99–101]. Therefore, consideration of community perception is crucial for the successful implementation of the adaptation measured planned at the institutional level. Chowdhury et al. [70] addressed that generation of inclusive policies including communities, good governance and proper budget allocation are the vital components for tackling with the climatic hazards induced impacts. Additionally, the rapid expansion of shrimp farming and associated activities inside the polders has replaced agricultural lands and is responsible for increasing soil salinity [57]. Polders impeded sedimentation within the embanked region and resulted in land subsidence [23]. In addition, physical deterioration and unreliable operation of sluice gates caused prolonged inundation during the monsoon period [102,103]. On the other hand, climate related hazards, such as storm surges and pluvial flooding have reduced the number of agricultural lands causing salinity increase, and the diversion of the upstream river 'Mathabhanga' from the river Ganges has led to a decrease in the water flow increasing the rate of siltation downstream [60].

Our findings are in line with Islam et al. [71] that modelled the increase in salinization of shallow groundwater in the south-eastern coastal area of Bangladesh using observed data. The authors found that concurrent climate change and land use changes directly affects the groundwater salination in this region. Besides, they predicted that increased inundation events associated with increase in shrimp farming, will cause rapid salinization of groundwater in this region, and hence make it less available for drinking water and irrigation. On the upside, the authors pointed out that more robust land use and integrated water management practices could mitigate some of these impacts [71].

Islam and Paul [15] found that climate change and induced SLR are the emerging threats to coastal agriculture of Bangladesh. They argued that effective adaptation strategies associated with high awareness levels may significantly reduce the vulnerabilities of agriculture considering the adverse impacts of climate change and SLR in Bangladesh.

Community perceptions vary across their geographical and social contexts [10,72,73]. Hasan and Kumar [72] conducted a comparative study on farmers' perceptions in farm productivity over the past 10 years. They found that a majority (64%) of study respondents believed that climate change was responsible for decreases in farm productivity. They also showed that dry period salinity, flood and coastal inundations were the main impacts of climate change adversely affecting crop productivity in Bangladesh. Their study suggested that to better adapt agricultural activities, government agricultural extension organizations and other relevant agencies should promote updated climate knowledge and information among farmers. Hasan and Kumar [72] noticed that observed climate data were mostly aligned with the farmers' perception with respect to temperature, rainfall, floods, droughts, and salinity. Positive correlations were also found among the perception of climate change, the perception of vulnerability and the number of adopted adaptation practices. Interestingly, Shameem et al. [74] explored that local people were aware of the changes in hydro-climatic parameters and that in relation to on short-term variability, the correlation between scientific evidence and local perceptions was high. This risk perception at individual, group or community level plays an important role in providing effective early warning system to indicate that most of the risk management actions are in order and encourage people to implement that actions [75].

5.2. Perceived best practices and local-led adaptations

To reduce the loss and damages due to the recurrent coastal flooding, construction of structural flood control measures has been taken since the colonial period, such as construction of polders, reshaping of the pattern of human settlements and land use which is widely known as "levee effect" [76]. Adnan et al. [77] claimed that polders have provided protection against storm surges and fluvio-tidal events with moderate severity but that have, however, exacerbated pluvial flooding and promoted potential flooding impacts during the most extreme storm surges in Bangladesh. Often, the failure of structural measures due to overtopping or breaching of embankment leads to increase in flood damages in southwestern part of Bangladesh [78].

Poor socio-economic conditions of the coastal communities also exacerbate flood vulnerability and risk [79,80]. This climatic hazard is not only occurring in the southwestern part of the country, but also in the south-eastern part. Over the coastal region of Bangladesh, SLR increases the likelihood of tidal flooding hazard. The authors predicted that the central part of the Bangladeshi delta will potentially experience severe fluvial flooding under the scenarios of 0.5 m of SLR in Bangladesh. A recent study reported that the tidal and fluvial flooding is an important phenomenon which needs to be taken into consideration for the better understanding of hydrodynamics of the Bengal delta [81]. Hence, it will play a vital role for a sustainable delta management to ensure stable livelihood and food security in Bangladesh.

Similarly, Kabir and Baten [82] found that, the local communities of Khulna, Satkhira and Bagerhat districts in South-Western Bangladesh have spontaneously promoted several social innovations using their innovative ideas and traditional knowledge. For example, local populations have developed a unique adaptation practice called 'Community Mangrove Aqua-Silviculture (CMAS)' to cultivate some floral and faunal species of the Sundarbans mangrove ecosystem. Particularly for adapting to SLR induced tidal flooding, villagers in the flood prone areas, (e.g., Barishal division), build their houses on a raised land and plant trees surrounding their houses to protect from flood inundation [83]. However, adaptation during and after flooding has a strong positive correlation with the income level, availability of food, educational level of the villagers, and flood forecasting. In line with this recent literature on adaptation and climate risk management, we found that local coastal communities have been developing several adaptation practices to cope with the challenges they faced, and that these are very much correlated with their own risk perception.

Coastal population in Bangladesh, as many around the world, perceive and try to predict imminent hazards by observing different environmental indicators and traditional practices. This means they take actions for disaster prevention, mitigation and adaptation accordingly to their existing traditional knowledge and practices. Particularly, to adapt to changing trends in disasters such as cyclones, floods and droughts in coastal areas of Bangladesh, populations spontaneously change their housing structures using their traditional knowledge, search new suitable jobs, migrate, emigrate, rear alternative livestock, borrow money from relatives and micro-credit lending organizations, take national and international relief and diversify their livelihoods [10,84]. However, holistic empirical research on indigenous adaptation practices of coastal people to manage natural hazards are critical to enable comprehensive policy-making by providing insight about context and enabling implementation processes connected to national disaster management policy, and national adaptation planning [85].

Coastal plantations act as a natural defence against cyclone induced tidal surges and storm surges. Local people were found planting deep-rooted tree species around their homestead along with other adaptive measures. White [76] claimed that the percentage of wind speed reduction is significantly higher at plantation coast than barren, and ship breaking yard coast. Kabir and Baten [86] listed a total of 50 adaptation practices in southwestern coastal areas of Bangladesh. Among these, based on their sustainability analysis, they reported that growing different local rice varieties, proper pond water management, rainwater harvesting, lowering house roof, and raising plinth are the more sustainable adaptation practices. Such findings corroborate our own analysis in respect to perceived adaptation practices.

Salinity increase is a major causal factor lowering paddy cultivation in the coastal areas of Bangladesh [87]. Several initiatives were taken by the government and NGOs and our study revealed that most paddy farmers have transformed their rice cultivations into less-laborious shrimp farming to secure more revenue in shorter periods, since this is an activity that can be done with salty water. For example, studies have demonstrated that rice farmers would suffer a higher rice yield loss (23%) under saline water conditions compared with the shrimp farming (16%) and salt producers (14%) [88].

Adaptation to climate change induced hazards by applying traditional socio-ecological knowledge and local-led adaptation strategies were found to be very crucial for coastal communities to live with high levels of uncertainty regarding their livelihoods. Our study explored respondents' perceptions of changes in climate and extreme events, and local adaptation measures. These have shown strong corelation with the observed meteorological data. Households and communities in the study areas were found to take a range of farming and non-farming adaptation practices, for example, adopting new salt and water tolerant crop varieties, adjusting sowing and planting time, homestead garden redesigning, planting trees around the households, and internal migration. Corroborating our research, Akter and Ahmed [89] identified that adaptation in agriculture is essential due to climate change induced salinization and extreme climate events. Moreover, local-led adaptation strategies are very context specific and highly dependable on individual local community farming practice, fisheries, resources availability and regional climate settings [89,92]. In a similar context, Uddin et al. [10,84] documented that coastal communities in Bangladesh were found resilient and adapting continuously by transforming their livelihoods to cope and adapt with the shocks from disasters and livelihood threats. Consequently, Alam et al. [91] explored that the local knowledge was key for adaptation in response to the perceived impacts of riverbank erosion due to climate change. Their research advocated for improved access to financial and technical support for appropriate strategies appears to be crucial to implement locally-led adaptation processes [91].

In a livelihood analysis research by Uddin et al. [10] revealed that coastal communities were continuously adapting with changing scenarios, transforming their livelihoods and enhancing resilience to climate change induced disasters. However, respondents in our study areas reported that very few attempts were made to provide good sources of drinking water at the household level and for paddy irrigation facilities. They also argued that there was a significant interface between local perceptions and the socio-agro-ecological factors changing the dynamics of coastal hazards, social vulnerability, and communal crisis. Rakib et al. [92] found that local people using their traditional knowledge to cope with and adapt at multi-levels of these crises under vulnerable conditions. However, policy emphasis requires attention to local contexts to achieve social and environmental sustainability under adverse climatic conditions in the coastal communities [89]. In addition, Rahman and Mori [93] revealed insufficient communication prior to the implementation of local-led adaptation projects by NGOs and development partners were found to be the underlying cause of this lack of successful and community engaged implementation in the coastal areas of Bangladesh. Whereas Sujan et al. [95] emphasized on financial and technical capacity building and proper local-level policy guidelines for local-led adaptation strategy adoption and scale-up is critical for climate change adaptation in the coastal areas of Bangladesh [94]. In line with this, respondents to our study reported that previous mismatches between perceived risks, autonomous adaptation levels and national or even local policymaking have led to the perception that policies do not achieve their desired goals, and sometimes even work against local risk management.

6. Conclusions

Our study demonstrates that SLR has been intensifying both physical impacts and agricultural problems for the case study areas. Due to different types of impacts like salinity increase, water logging, land erosion the agricultural production is decreasing gradually and making the people economically vulnerable.

Our problem tree analysis presents the perceived causes for each of the impacts along with the economic loss to the people caused by them. We found that both natural and man-made factors are responsible for these physiographic impacts. And, as a result of them, people are incurring agricultural damages such as losing agricultural land, decreasing agricultural production, economic losses in aquaculture activities especially for the salinity increase, increasing the height of tidal water and land erosion.

Furthermore, mapping of the climatic hazards by the community exhibited how much shift has occurred at temporal scale by different hazards and how the communities are adapting with these changes through the cropping calendar. Adoption of a cropping calendar and doing agricultural activities according to it demonstrates the improvement of the resilience capacity of these communities.

Different strategies have been deployed over the time by the governmental, non-governmental organization along with community people to decrease the impacts induced by these impacts. This includes the construction of dams and dikes and afforestation and reforestation along the river dikes to protect the cropland and freshwater fisheries, household settlements; tidal river management, renovation and increase of the number of sluice gates, restoration of the water canal to increase the flow of freshwater into the croplands, holding rainwater during the off season, awareness activities about the drawbacks of shrimp farm expansion, among others.

However, the existing measures could not provide the desired outcomes to the coastal communities since most of the cases were designed without considering local context, existing community-led adaptations, and local-community perceptions. Therefore, during developing new policies, development planning and implementation of adaptation measures against SLR induced impacts, it is critical to consider community perception towards different measures and evaluate them under different evaluation criteria to receive the expected outcomes of development measures. These efforts would be required to complement and refine the adaptation measures for the specific sites considering the socio-economic and geographical context, and further disentangle the contributions of SLR induced challenges to the degradation of farming and fishing practices in these climate and socio-economic vulnerable areas. In turn, this information would be helpful to better plan and design practical responses to address the impacts induced by each challenge, and their connections with climate change and climate change induced SLR.

The results reported in this article are based on the local participant's understanding and perceptions of climate change and its effects, their experiences and how they rank the observed problems in two coastal areas of Bangladesh. Therefore, generalizations based on the study are of limited scope and should be made with caution. Data collection was also limited into Focus Groups Discussions and Community Meetings were used where local people were interviewed to represent the entire study areas. Future research should be pursued with a focus on livelihood insecurity that arises due to the different SLR induced impacts and effects, and the role of indigenous knowledge to SLR induced vulnerability management. Furthermore, the inclusion of a qualitative quantification of the SLR induced physiographic impacts on temporal scale based on community perceptions as well as perception of the famers towards available local-led adaptation measures could provide better information for designing future climate change adaptation policies and guidelines. The afore-mentioned are the important gaps and should be considered to get into the root of the problems and find out solutions to manage SLR induced problems. Nonetheless, our research work helps to find out the causal-linkages relationship between SLR induced physiographic impacts and associated effects of them on agriculture and other human activities in the study areas.

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.

Acknowledgements

This work was supported by Fundação para a Ciência e a Tecnologia (FCT, Portugal): BR doctoral grant PD/BD/128210/2016; GPL contract number IF/00940/2015; cE3c project UIDB/00329/2020. The third author (M. Salim Uddin) research was funded by a Social Sciences and Humanities Research Council (SSHRC, Canada) Post-Doctoral Fellowship (# 756-2019-02920). We would also like to express gratitude to all the officials of BASD local office Banishanta, Mongla for their continuous support in different logistical purposes and the anonymous reviewers for their valuable feedback. Last but not the least, the residents of Banishanta and Sutarkhali Union who have been the core part of this research work and helped to complete the research work by their active participation in Community and FGD meetings.

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