Environmental Development 45 (2023) 100813

Contents lists available at ScienceDirect

Environmental Development

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

Prioritization of sectoral adaptation strategies and practices: A case study for Bangladesh

Mahiuddin Alamgir [a,*], Md Nasir Uddin [b], M. Mehedi Hasan [c], Xiaojun Wang [d], Mohammed Sanusi Shiru [e], Shamsuddin Shahid [e]

[a] School of Civil Engineering, Jiujiang University, Jiujiang, 332005, Jiangxi, China
[b] Bangladesh Centre for Advanced Studies (BCAS), Dhaka, 1212, Bangladesh
[c] Department of Economics, Naogaon Government College, Naogaon, 6500, Bangladesh
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing, 210029, China
[e] Department of Water and Environmental Engineering, School of Civil Engineering, Universiti Teknologi Malaysia (UTM), 81310, Johor Bahru, Malaysia

ARTICLE INFO

Keywords:
Climate change
Prioritization
Sectoral adaptation
Multi criteria analysis
Bangladesh

ABSTRACT

Climate change adaptation has become a more serious issue to vulnerable countries like Bangladesh. The study areas, as one of the important food baskets of the country, has been experiencing wide-ranging extreme event (flood, riverbank erosion, cold wave, less and erratic rainfall, and prolonged droughts). Here severe affected sectors are agriculture; fisheries; livestock; housing; and drinking water, sanitation and public health. Through participatory Multi-Criteria Analysis (MCA), the adaptation strategies were prioritized based on the overall preferences of multiple stakeholder opinions at different level (community/village, upazila/sub-district, and district/regional level). Therefore, using MCA methods of the study areas helped their ideas from different level actors/stakeholders to improve the adaptation strategy, practices and drivers leading to vulnerability. The study found that most priority of adaptation measures of different sector i. e Agriculture; Fisheries; Livestock; Housing; and Drinking Water, Sanitation and Health sector; are Maize, and Sathi Fosol (mixed and relay culture); Livelihood Diversification; Adhi system (shared rearing of livestock); Rising plinth level, and Solar energy, and Ensure safe drinking water, and Enhance health facility and community clinic activities, respectively. The various mechanisms for coping and adaptation practices of different communities were identified in this study. The study suggests further support from the government. Study recommends a combination of the local and scientific knowledge, allocation of resources to the poor, technological transfer and innovative adaptation approaches for Bangladesh.

1. Introduction

The need for adaptation to climate change has gained more attention in recent times due to increased evidence of increasing temperature (Berrang-Ford et al., 2021; Pörtner et al., 2022) and erratic rainfalls (Shahid, 2011; Ray et al., 2021) in many parts of the globe. These changes have increased the dryness in many areas causing increased aridity and droughts (Dai, A. 2011; Hua et al., 2022) and wetness in others leading to increased frequency and intensity of floods (Douglas et al., 2008; Billi et al., 2015; Venkatappa et al.,

* Corresponding author.
E-mail address: malamgirutm@gmail.com (M. Alamgir).

https://doi.org/10.1016/j.envdev.2023.100813
Received 26 September 2021; Received in revised form 27 October 2022; Accepted 5 February 2023
Available online 15 February 2023

2021). In addition, the projections that the climate system regardless of decreases in greenhouse gases emissions will undergo changes in the future because of the thermal inertia of oceans and atmospheric conditions (Manabe and Stouffer, 1993; Matthews and Caldeira, 2008; Ussiri and Lal, 2017) gave rise to more studies on adaptation to climate change. Among many sectors, the agricultural and water resources sectors are the most vulnerable to climate change (Aryal et al., 2020; Kourgialas, 2021).

The trend of climate change adaptation (CCA) followed a hierarchical top-down approach with the use of a range of global scenarios (Lo et al., 2020). The inputs to the global climate models are the greenhouse gas emissions, whose output serves as the input to the impact models (IPCC, 2014). Due to the inability of this so called top-down approach to address the lower level needs in response to the changing environmental conditions, they are widely criticized (Urwin and Jordan, 2008; Butler et al., 2015; Lo et al., 2020). Therefore, there has been increased interest in the methods of adaptation such as the 'community risk assessment (CRA)' which is bottom-up driven and very critical at the local scale (Van Aalst et al., 2008; Rashid and Khan, 2013; Eicken et al., 2021). The bottom-top approach in comparison to the top bottom approach for climate change adaptation has its basis on applying the knowledge of the local climate change impacts and local circumstances, in which stakeholders' perceptions and capacities are viewed as crucial for the development of effective response strategies (Pörtner et al., 2022; Azadi et al., 2022; Nago, and Krott, 2022).

Among the several sectors, the water resources and agricultural sector will be the most affected by the impacts of climate change (Whitehead et al., 2018; Islam et al., 2018; Lu et al., 2019; Hasan et al., 2019). Adger (2006) noted that the development and implementation of effective adaptation measure is paramount in order for governments to consider risks relating to climate change and opportunities while developing planning and policy decision-making processes. Adaptation of the agricultural sector to climate change requires expansion of crop variability and, proper irrigation management, as well as large investments in farmers, scientists and private development organizations (Rosenzweig and Parry, 1994; Aryal et al., 2020; Rattis et al., 2021). Therefore, sustainable adaptation is essential for viable agricultural practices, and needs to be prioritized. However, this area has received little attention till date. Eriksen et al. (2011) defined sustainable adaptation as a set of actions contributing to socially and environmentally sustainable development pathways encompassing social justice and environmental integrity. Local capacity strengthening alone doesn't effectively reduce climate change vulnerability (Thomas et al., 2019; Susskind and Kim, 2022) it is therefore imperative to combine local capacity with measures encompassing socially marginalized groups, considering them in decision-making processes which affects them and making such matter, even under economic development needs (Eriksen et al., 2011). To be considered for this are; physical development of lands which influences climate risks and reduces land rights of the poor (Coirolo and Rahman, 2014; Parven et al., 2022).

Adaptation, rather than a list of actions, is a process and measures which addresses particular climate change impacts (Eriksen and Brown, 2011; Owen, 2020; Abbass et al., 2022). Actions and measures implications are crucial to be holistically examined in social and environmental context recognizing tradeoffs and negative outcomes potentials, both spatially and temporally (Eriksen et al., 2011; Thomson et al., 2019). The challenge of adaptation in the least developed countries compared to the developed ones are more arduous as a result of lower adaptive capacity originating from disrupted sustainable development (IPCC, 2014). For example, Rawlani and Sovacool (2011) noted that designing of viable adaptation options for climate change resilience through community based adaptation is required in Bangladesh, particularly as past studies have reported the negative impacts of lack of sufficient adaptation measures on crops that are important for food security for human population (Lobell et al., 2008; Rashid, and Khan, 2013; Roy et al., 2022). Therefore, at farm levels, designing of strategies for adaptation implementation needs to be such that critical evaluation and prioritization relative to the most critical climate risks in the different communities are used for adaptation options.

In order to address climate change related issues, the Government of Bangladesh (GoB) formulated two national documents namely, Bangladesh National Adaptation Programme of Action (NAPA) in 2005 (MoEF, 2005) and Bangladesh Climate Change Strategy and Action Plan in 2009 (MoEF, 2009). In these documents are strategies and actions encompassing six key thematic areas, namely, i comprehensive disaster management, ii. Food security, social protection and health; iii. Capacity building and institutional strengthening, iv. Mitigation and low carbon development, v. Research and knowledge management, and vi. Infrastructure. Additionally, the GoB made developmental strides in adaptation measures for development and use of water resources sustainably. Consequently, the National Water Management Plan (NWMP) of Bangladesh (MoWR, 2001) was developed, along with other key national policies and priorities. The NWMP serves as a guide to implementing the National Water Policy (NWP) (MoWR, 1999). Climate change is recognized by both NWMP and NWP as one of the critical factors for future water demand and supply. Moreover, recent agricultural and natural resources policies considers these policies as guidelines as the increasing impacts of climate change affects Bangladesh.

According to (Kriegler et al., 2012; O'Neill et al., 2014) climate change analysis from a socio-economic scenario is essential for collaborative efforts amongst researchers in adaptation, integrated assessment and impacts and vulnerability areas. Hence, multi stakeholders participatory approach is paramount for development of reliable adaptation options for mitigating climate extremes impacts in such a way that the risks are understood, adaptation responses are identified, and risk reduction prioritization are implemented (Bhadwal et al., 2013; Cvitanovic et al., 2021; Werners et al., 2021; Wheeler and Lobley, 2021; Allan et al., 2022).

Based on content analysis and focus group method (FGM) among farmers, Tripathi and Mishra (2017) found that agricultural and farming practices are being changed by farmers e.g. changing cropping patterns; short duration crops' cultivation; changing sowing and harvesting times; investing in agroforestry and irrigation; and intercropping. Indigenous floating agricultural techniques have been found to be suitable for adaptation to climate change and the sustainable development of communities in Bangladesh (Ayers et al., 2014; Chowdhury, and Moore, 2017; Bhandary, 2022). Adaptation options in the agricultural sector were explored using Climate Smart Village (CSV) approach (Aggarwal et al., 2018; Zougmoré et al., 2021). It was shown that the CSV approach has of high potential in explicating the best practices, services, and climate smart agricultural technologies.

In this present study, findings from consultations with stakeholders and identification of adaptation options using participatory adaptation tools were used at different levels for the ranking of identified adaptation options. Also, a third phase of the consultation of

the stakeholders at regional levels, in which participatory prioritization tools were used for the ranking of the adaptation options identified and organizing of feedback from the stakeholders on the priorities and prioritization criterion was conducted. In addition, the prioritization exercise drawing was selected through the scientific literature review and consulted with primary stakeholders participation. This study attempts to deepen our understanding of adaptation approaches, strategies and activities in the context of the lower Teesta basin in Bangladesh in different sectors, where agriculture and fishery are the main livelihoods practiced, along with other sectors.

2. Study area

This prioritization study was conducted under three upazila (sub-district) namely Dimla in Nilphamari; Hatibandha in Lalmonirhat; and Kaunia in Rangpur District in the Teesta floodplain of Bangladesh (Fig. 1). The village level prioritization workshops were held in the same village's participation in the previous assessment phase from the stockholders consultation (Alamgir et al., 2018). Mainly, the Teesta alluvial fan extends out from foot of the Himalayas, flows through the two states of Indian (West Bengal and Sikkim) through Bangladesh and enters the Bay of Bengal (BBS, 2017). Often, the region is affected by recurrent floods, riverbank erosion and drought (Brammer, 1990; Shahid and Behrawan, 2008; Paul et al., 2020; Mondol et al., 2021; Kumar et al., 2022). Rangpur division is highly populated and the mostly poor and underdeveloped compared to other divisions of the country (BBS, 2017). The Teesta basin areas are surrounded by five districts of the Rangpur division which are Kurigram, Nilphamari, Lalmonirhat, Gaibandha, and Rangpur. About 78% of the total population of the Teesta River basin areas live in rural areas and the remaining 22% is urban (Hassan et al., 2020). The people are tremendously dependent on Teesta river water for agriculture, fisheries, and their livelihood purposes (Ferdous and Mallick 2019; Dilshad et al., 2019; Ahmed et al., 2022), but the river often has less water during the dry season (November to May) and too much water in monsoon (June to September) (Sarker et al., 2011; Afroz and Rahman, 2013). The major crops grown in the Lower Teesta basin in Bangladesh are rice, wheat, potato, maize, jute and tobacco. Fertile alluvial soil and tropical weather with seasonally variable rainfall have given rise to a rich tradition of agriculture throughout the year. Agricultural production is governed by moisture supply from rainfall and soil storage, and erratic rainfall and dry soils adversely affect yields production. Different cropping seasons experience damage; significantly caused by droughts in the northern western part of Bangladesh (Alamgir et al., 2015; Mohsenipour et al., 2018). Approximately 80%–85% of the households in the study areas are directly or indirectly involved in agriculture. Livestock production is already reduced due to a lack of food during a drought and flood. Also, the risks producers face, not only affect food security directly, but indirectly as well, as agricultural development is constrained; by the prevention of investments and access to credits, resulting in reduced economic activities (see Fig. 2).

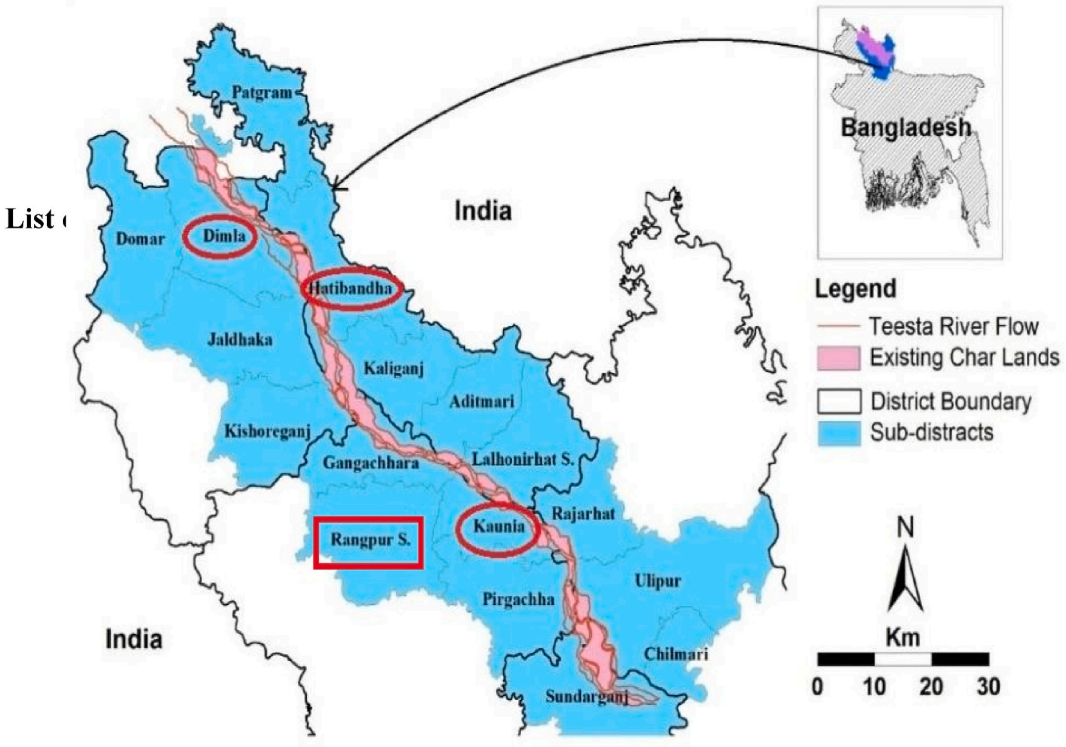

Fig. 1. District (red rectangular) and Upazilas (red circle) where prioritization workshops were conducted. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 2. Prioritization adaptation process through the Multi Criteria Analysis (MCA) method at different places.

3. Methodology

3.1. Identification of adaptation options

A literature review was conducted to identify key adaptation approaches in the Teesta floodplains. Several literatures were examined to understand the key adaptation factors from peer review journal articles, working papers, project reports, policy and government strategic documents etc. Participatory assessments of climate stress, drivers and conditions leading to vulnerability were used for the identification of possible adaptation measures in the study areas. Different Participatory Research Appraisals (PRA) were

Table 1
Adaptation measures in different sectors identified from literature review.

Adaptation measures	Adaptation potential
Agriculture Sector	
Short rotation rice verity	Suitable to overcome both flood and drought. It allows farmers produce three crops per year
Flood tolerant rice verity	Can survive during flood and high yielding
Storm tolerant rice verity	Survive during storm and reduce loss due to erratic rainfall
Maize cultivation in char lands	Drought tolerant. Maize is also very effective to cope with sand deposition
High yielding potato	Increase income and thus enhance adaptive capacity.
Mixed and relay culture	Reduce loss of crop due to climate extreme. Enhance food and nutrition security of the household
Crop Insurance	Crop-specific insurance to compensate income loss due to vagaries of weather
Information based Crop Agro-advisory	Climate information based value added agro-advisories to the farmers
Fisheries Sector	
Intensive aquaculture in pond	Increase fisheries production
Livelihood diversification for fishers	Increase income and enhance adaptive capacity
Cage and pen culture	Adaptation to increased flood
Use of lime and medicine in the pond	Protect fish from increase temperature
Livestock Sector	
High yielding fodder	Feeding of cattle during flood
Shared rearing of livestock	Increase income to cope with critical climate stress moment
Veterinary treatment	Protect livestock from heat and cold
Housing Sector	
Raising plinth	Protect house from flood
Cluster house	Resettlement of people affected by riverbank erosion
Kitchen gardening	Increase household income to cope with critical climate stress moment
Homestead Plantation	Protect house from storm and adaptation to heat wave
Solar energy	Enhance energy security
Disbursement of public land (khas land)	Resettlement of people affected by riverbank erosion
Biogas	Enhance energy security
Tube well	Ensure safe drinking water and sanitation

applied so that the adaptation needs are captured and the adaptation strategies that are important from a macro-perspective are identified (Chambers, 1994; McNamara and Buggy 2017; Omondi, 2020). The participatory assessment was based on focus group discussions, mostly with farmer groups from the three selected villages (union).

3.2. Enrichment of list of identified adaptation options

Vulnerabilities of the different communities were stressed, the adaptation options are identified; through both sectoral and cross-sectoral approaches. Summaries of the key adaptation options put forward for prioritization in different sectors are given in Table 1.

Prior to the beginning of the prioritization exercise, the list of the identified adaptation options that were identified during the participatory assessment of drivers and conditions leading to vulnerability were said to be reviewed by the stakeholders. This allowed for enrichment of the existing list by the stakeholders; and in some instances, two or more similar (or linked) options were merged into one for facilitating the prioritization exercise. Participatory prioritization exercise was conducted after the enrichment of the adaptation options.

3.3. Multi stakeholder workshop

There are three multi-stakeholder levels e.g. primary stockholder (farmer, fisherman, wage earners), secondary stakeholder (governmental, department, NGOs), and tertiary stockholder (policy makers) under the different adaptation activities has been conducted, but at the regional (secondary stakeholder) and national levels (tertiary stockholder), stakeholders play a vital role in policymaking and resource allocation to different sectors. The views and opinions of the stockholders often differ in adaptation planning prioritization. The field exercises to engage the stockholders to prioritize adaptation options in the key sectors were based on four criteria which are; appropriateness, effectiveness, coherence/synergy, and sustainability. The list of workshops at different locations, the dates, and the number of participants are presented in Table 2.

The workshops involved several stakeholders, sectors and scales, making reaching a consensus arduous. The study applied multi stakeholder-multi level approach for facilitating adaptation to climate change. Multiple stakeholders of various technical and non-technical pieces of knowledge were brought together for a joint discussion about adaptation needs and strategies. The multi stakeholder-multi level approach was used across three different administrative levels i.e. community/village, upazila (sub-district), and district/regional levels.

3.4. Prioritization of adaptation options in key sectors

As there can be multiple value conflicts and a high degree of uncertainties in climate change cases, this study employs the Multi Criteria Analysis (MCA) method for the assessment of climate change adaptation options (Bell et al., 2001; Janssen and Van Herwijnen, 2006; Ebi, and Burton, 2008; Golfam et al., 2019; Baláž et al., 2021). In this study, the MCA uses stakeholders' judgments on the importance of the various criteria for resolving the problem. The criteria for prioritization were set based on expert opinion. The criteria are;

(1) *Appropriateness:* How feasible is the implementation of a given adaptation option in the current administrative, institutional and bio-physical contexts? Is it commensurate with the nature and magnitude of the impact it intended to manage?
(2) *Effectiveness:* How good is the given option in enhancing the capacity of a system to adapt and achieve its objectives? Does it reduce the impacts, exposure, or risks? Is it profitable in terms of cost and benefit?
(3) *Coherence/Synergy:* Does the given options align with policy, system, and development goals? Can the adaptation option enhance and strengthen the outcome of existing policies and initiatives?
(4) *Sustainability:* Will the option be sustainable in the long term? Is it responsive and flexible to changing future conditions? Will it allow for adjustments due to unforeseen changed conditions and can it be implemented with flexibility? Can it operate and perform under a wide range of uncertainties and future climatic scenarios?

The adaptation options were given weight (0–3) for scoring and ranking the most suitable adaptation options based on community discussion. For score ranges (0–3); 0 stands for no; 1 stand for low; 2 stands for medium; and 3 stands for high.

The participants shared their views, insight and perspectives to assess the appropriateness, synergy, and suitability of the selected

Table 2
Name of the location, and date where prioritization workshops were conducted at different levels.

Place	Date	No of participants
Singhamari Union, Hatibandha, Lalmonirhat	October 25, 2017	25
Hatibandha, Lalmonirhat	October 26, 2017	30
Purbochatnai Union, Dimla, Nilphamary	October 28, 2017	26
Dimla, Nilphamary	October 29, 2017	30
Balapara Union Kaunia, Rangpur	October 31, 2017	24
Kaunia, Rangpur	November 1, 2017	22
Parjatan Motel, Rangpur	November 21, 2017	50

adaptation options. In some cases, they have different opinions and debates about the appropriateness and suitability of the adaptation options in the context of climate stress, socio-economic conditions, market forces and government policy and support for agriculture, infrastructural development and rural livelihoods. Aside from ranking the options that were achieved through the MCA method, discussions on the various adaptation options were also recorded.

4. Results and discussions

There is a strong connection between agriculture and climate, as the climate has a significant influence on agricultural production and is a significant factor in food production variability (Selvaraju et al., 2011; Mairura et al., 2021; Kumar, and Sharma, 2022). Sectoral adaptation options and practices are described as follows.

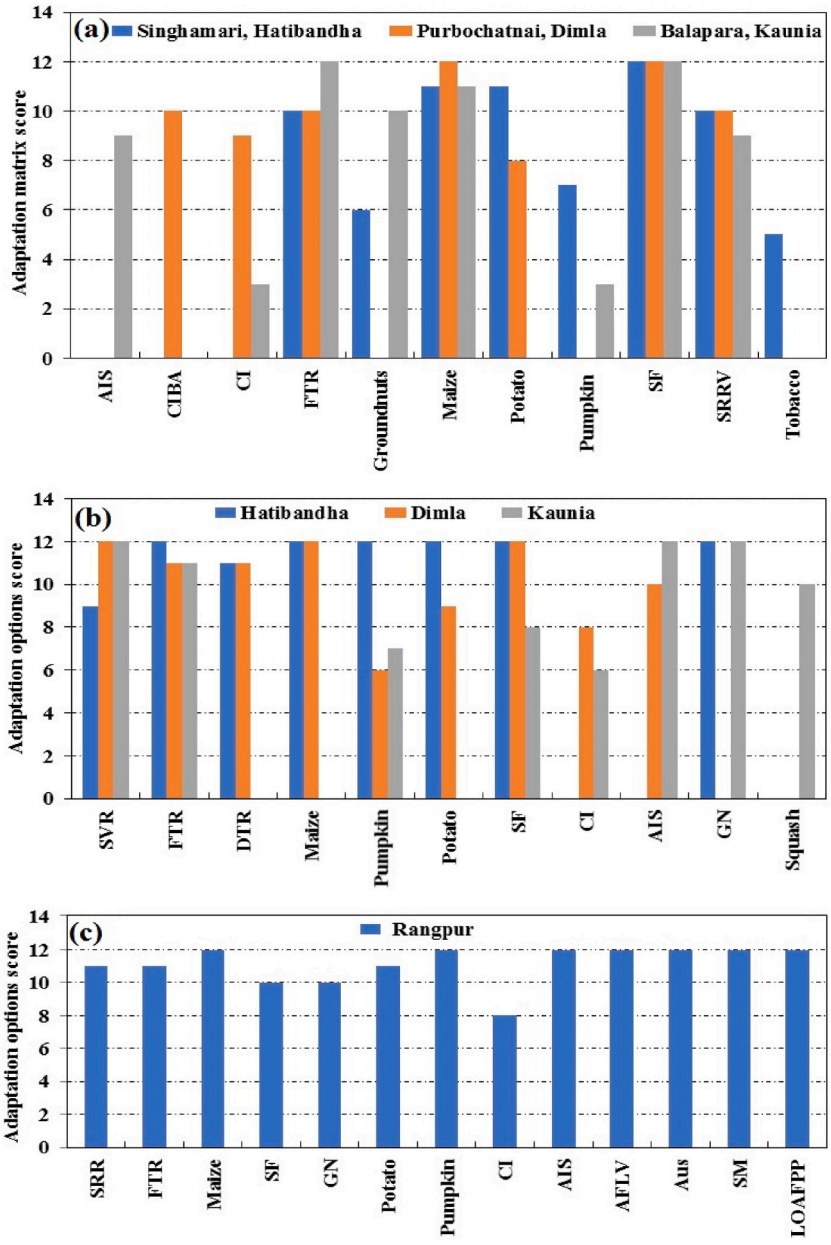

Fig. 3. Adaptation options of agriculture sector preferred by the (a) community, (b) Upazila, and (c) District level.

4.1. Agriculture sector

4.1.1. Community/village level

The option to cultivate maize in the char lands was most preferred option for the community in the areas. Sand deposition drastically hindered cultivation of crops on chars. Growing staples on such degraded and barren land was difficult. Farmers cultivating char have shifted to the cultivation of potato, maize, onions, and peanuts, which have higher profit margins. This is also the case for Boro rice which even though has high yield, has been replaced with the cultivation of maize due to the deposition of sand on lands used for chars (sand deposit bar). The farmers solicited governments' intervention in giving financial support and creating markets to attain more sustainable agricultural practices. Mixed and relay culture (Sathi Fosol) was a beneficial option at all of three locations for reducing risk and ensuring household food security. While most often, Rabi maize is mono-cropped, it is intercropped with early maturing vegetables and potatoes by many farmers. Because peas do not compete with maize for nutrients, sunlight, and space, they are also intercropped with maize.

Using newly improved rice varieties (e.g., short rotation, varieties that are tolerant to flood) was seen to be another preferred option. Like across the country, rice is the dominant crop in the areas. Generally, they allow farmers to grow maize and other winter crops. Thus adopting 'short duration Aman rice' cropping pattern gives farmers the opportunity to get four crops on the same land annually, which is seen as a good option. Cultivation of flood tolerant rice varieties has become popular in the region to enhance rice production and ensure food security despite climate change impacts in recent years. The farmers have been continuing transplantation of seedlings of the flood-tolerant variety (SWARNA, BRRI dhan51, BRRI dhan52, BINA 11, and BINA 12) rice and are getting high yield. However, these varieties take 120–130 days to be harvested and farmers said it will be more beneficial if flood tolerant rice varieties are also short rotation. In the areas, it was found that there is a lesser preference for drought tolerant varieties, as during drought, farmers can use groundwater irrigation (Fig. 3a). shows that in the agricultural sector, 'Sathi Fosol (SF)' and 'Flood Tolerance Rice (FTR)' received a high scores from the Balapara union of Kaunia upazila. However, Maize and SF received high scores from all unions. Though it was observed that farmers largely prefer the option of adoption of improved rice varieties, they mentioned that sometimes they lack confidence in the adoption of new techniques as they perceive them as risky. Thus, adequate government support including demonstrations, training, and capacity building are needed for substantial changes in farming practices. Also highlighted was the need for financial support from the government for new technologies adoption.

The option of sandbar cropping was discussed. This approach has been tested with pumpkin by many non-governmental organizations (NGOs) in the areas. The sandbars are the common property (government) as barren resources and are not utilized for any gainful or productive purposes. Using this option, barren sandy land can be made productive to compensate for the loss of land due to riverbank erosion. Farmers get very high yield pumpkin, but they are less market value products. Farmers have to sell huge quantities of pumpkin at a very minimal prices every year. In addition to pumpkin, other crops including; onions, strawberry, lettuce, capsicum, squash, parsley, melon etc. Are being harvested on a trial basis. Among these crops, capsicum, strawberry and squash, are high value crops and are preferred by the communities. However, these crops' seedlings are not available in the areas. Another problem of sandbar cropping is access of sandbars by poor farmers. Sandbars are owned by the government; however, local powerful people acquire them illegally causing blockage for access by poor and vulnerable people.

The advantages of having a better forecasting system for information about weather and agro-advisory services were also well understood. More information on the weather (particularly that are extreme, such as floods) were preferred under any setting. However, the reliability of the information was the only constraint seen here. The community urged accurate and precise information. The question raised in Purbachatnai was that if farmers lose crops because of wrong advice due to inaccurate information, who will take the responsibilities? 'Crop insurance' was the least preferred option by the community. Though they acknowledge that it can be an important option to protect their interests, it was still ranked low due to feasibility issues and trustworthiness issues in insurance providers.

4.1.2. Upazila/sub district level

For agricultural sector adaptation estimation, this study found that the highest adaptive level was for flood tolerant rice varieties from peoples perceptions under three upazilas. Besides, the short variety rice has almost the same score (Table 4). These areas have favorable conditions to cultivate Sathi Fosol (mixed and relay culture), according to the participants. However, maize cultivation was found to have a positive impact on two upazilas (Hatibandha and Dimla), whereas the Kaunia upazila faces the opposite scenario. Hatibandha and Kaunia upazilas farmers have more interest in cultivating groundnut whereas Dimla shows no interest. Furthermore, it was found that Agricultural Information Services (AIS) is well practiced in Dimla and Kaunia but not in Hatibandha because the farmers from Dimla and Kaunia Upazila's are getting support from different NGO's who are working on AIS in this area. Therefore, AIS is needed among farmers for the agricultural system of other upazila. On the other hand, huge amounts of ground nuts are cultivated in Hatibandha and Kaunia, but in Dimla farmers are not interested in the crop because this area's soil characteristics are not favorable for it. All kinds of adoption options can help to compensate for the climate change impacts and the agricultural sector variability. Participants in these locations showed low levels of preference for potato and pumpkin because of their lesser market value. Despite the huge production of these crops, they are mostly unsold. They urged to find out some indigenous verities which may be available in other areas. For example, one of the local journalists (Hatibandha) said *"we don't need relief or any help from everywhere anymore, only we need left side of embankment of Teesta (Badh, locally called) and digging of the river"*. The participants from the workshop showed their willingness to adopt some adaptation measures to reduce risk factors such as crop insurance, and agro-advisories which can be run by the government through technical and financial services. In the agricultural sector, 'Flood Tolerance Rice Variety (FTRV)', 'Short Rotation Rice (SRR)', 'Sathi Fosol (SF)', and 'Pumpkin' options scores ranged between 9 and 12 under all upazials (Fig. 3b).

4.1.3. District level

Maize cultivation is the top ranked adaptation option in the agricultural sector among the districts in the areas (Table 3). Maize is very good at coping with sandbar deposition. Maize crop can adapt during drought and farmers have shifted from rice to maize cultivation during the dry season because it requires lesser water. According to the participants, maize is profitable and has high market demand, so maize cultivation on char land areas was the most preferred adaptation option in the agricultural sector. Nowadays, farmers are cultivating pumpkin in char land of the area. The participants at this location have shown low levels of preference for cultivating potato and pumpkin because of their less market value and difficulty to preserve. Crop diversification, specially, 'Sathi Fosol (mixed and relay culture)' is the most popular and effective practice in the region, because this type of crop is planted even before the first crop is harvested. Moreover, farmers are cultivating groundnuts, squash, and potato in this area. Agriculture Information's Service (AIS) is the more popular service to yield better crop production, so farmers are taking advantages of them. To enrich the agricultural sector, farmers are using local variety and high technology to cope with floods. The participants of the workshop advised that soil management, and operational land access for poor/extremely poor people is another option to be promoted by the government for sustainability in the agricultural sector through technical and financial services (Fig. 3c). During district level consultation we considered 13 adaptation options in agricultural sector, from which seven options received high scores of 12 while the rest of the six options get scores between 8 and 11 (Table 4).

4.2. Fisheries sector

4.2.1. Community/village level

Livelihood Diversification (for example, handcraft, small scale business and animal husbandry) was considered the most beneficial option for income enhancement; for example, milk was already a source of income for many in the village. Community members urged that livelihood diversification should be promoted by the government, for example, cheaper loans for raw materials purchase,

Table 3
Top prioritization of multi and cross sectorial adaptation options preferred by the community, upazila (sub-district), and regional/district level stakeholders.

Prioritized adaptation options	Sector
Community/village level	
Maize cultivation in the char land	Agriculture
Promotion of livelihood diversification activities	Cross-sectoral
Afforestation/plantation	Habitat
Crop diversification (mixed and relay culture)	Agriculture
Solar Energy	Cross-sectoral
Improved rice verity (short rotation, flood tolerant)	Agriculture
Tube well for safe drinking water and sanitation	Habitat
Upazila/sub district level	
Maize cultivation in the char land	Agriculture
Flood tolerance rice	Agriculture
Promotion of livelihood diversification activities	Cross-sectoral
Crop diversification (mixed and relay culture)	Agriculture
Solar Energy	Cross-sectoral
Improved rice verity (short rotation, flood tolerant)	Agriculture
Raising plinth level	Habitat
Cluster house	Habitat
Afforestation/plantation	Habitat
District/regional level	
Maize cultivation in the char land	Agriculture
Flood tolerance rice	Agriculture
Crop diversification (mixed and relay culture)	Agriculture
Pumpkin cultivation in char lands	Agriculture
Agriculture Information's Service (AIS)	Agriculture
Soil management	Agriculture
Integrated fish culture (ditch and dyke)	Agriculture
Establishment of fish sanctuary	Agriculture
Enhance basin water holding capacity	Agriculture
Implementation of fish law (task force)	Agriculture
Promotion of livelihood diversification activities	Cross-sectoral
Shared livestock raising (adhi system)	Cross-sectoral
Raising plinth level	Habitat
Afforestation/plantation	Habitat
Integrated flood management	Habitat
Tube well	Habitat
Distribution of public (khas) land	Habitat
Solar Energy	Habitat
Enhance health facility and community clinic activities	Health and sanitation
Ensure safe drinking water	Health and sanitation

Table 4
Prioritization adaptation matrix of Hatibandha Upzila, Lalmonirhat; Dimla Upzila, Nilphamary; Kaunia Upazila, Rangpur; and Rangpur Division for agriculture sector.

Adaptation measure	Multi Criteria Analysis				
	Appropriateness	Effectiveness	Synergy	Sustainability	Total
Hatibandha Upzila, Lalmonirhat					
Short rotation (Amon BINA-7)	2	1	3	3	9
Flood tolerance rice (Sorna)	3	3	3	3	12
Flood tolerance rice (Bidhan)	2	1	2	1	6
Drought tolerance rice (BRRI-48)	3	3	3	2	11
Maize	3	3	3	3	12
Almond	3	3	3	3	12
Pumpkin	3	3	3	3	12
Potato	2	2	3	2	9
Sathi Fashol	3	3	3	3	12
Dimla Upzila, Nilphamary					
Short rotation rice verity	3	3	3	3	12
Flood tolerant rice verity	3	2	3	3	11
Storm tolerant rice verity	3	2	3	3	11
Maize cultivation in char lands	3	3	3	3	12
Potato	3	1	3	2	9
Mixed and relay culture	3	3	3	3	12
Vegetables in fellow land (pumpkin, onion)	3	1	2	0	6
Crop insurance	3	0	2	3	8
Climate information based agriculture	3	3	3	1	10
Kaunia Upzila, Rangpur					
Short rotation rice PARI, BINA-7, BRRI-34,39,49 and 62	3	3	3	3	12
Flood tolerance rice BRRI 39, 52, BINA-14	2	3	3	3	11
Maize F1, NK-40 (HYV)	3	3	3	3	12
Almond	3	3	3	3	12
Pumpkin	3	1	2	1	7
Squash	3	3	2	2	10
Crop Insurance	3	2	0	1	6
Agriculture Information Service	3	3	3	3	12
Sathi Fashol	2	2	2	2	8
Rangpur Regional/Divisional					
Short Rotation Rice	3	2	3	3	11
Flood Tolerant Rice	3	2	3	3	11
Maize	3	3	3	3	12
Sathi Fashol (Mixed and Rally Crops)	3	2	2	3	10
Ground Nut	3	3	2	2	10
Potato	3	3	2	3	11
Pumpkin	3	3	3	3	12
Crop Insurance	3	0	3	2	8
Agriculture Information's Service	3	3	3	3	12
After Flood Local Variety/Technology	3	3	3	3	12
Rice (Aus)	3	3	3	3	12
Soil Management	3	3	3	3	12
Farmer Job	3	3	3	3	12
Land Operational Access for Poor/Extreme poor	3	3	3	3	12

improved livestock breeds, adequate training for handicraft etc. Community members showed their low level preference for aquaculture as the areas are high risk due to flooding which washes away the fishponds. Also, in the dry season there is not enough water for pond aquaculture.

Groundwater could be a source of water for pond aquaculture during the dry season. However, being sandy soil, the water holding capacity of the areas is less and community members think that it will not be economically beneficial. Participants also discussed the feasibility of cage culture in the open water bodies particularly in the river Teesta. Cage culture is not practiced in the areas for now. Community members showed interest in it and urged technological and financial support from the government. In the fisheries sector "Livelihood Diversification (LD)" adaptation option received score (11) under bunionsnion except Balapara union (12) (Fig. 3a).

4.2.2. Upazila/sub-district level

Participants from three upazila showed less interest to practices 'Integrated fish culture e.g.'ditch and dyke' and 'pen and cage' options because of geographic location (scarcity of water during dry season) and condition, so, such kind of culture is not feasible in this area. 'Livelihood Diversification' is the topmost priority for all upazilas (Fig. 3b). They think that cage and pen culture is promising, but showed considerable doubt about its feasibility. However, the participants argued that traditional fish culture can be protected from diseases by using lime and medicine in the pond which helps to enhance production. In the fisheries sector, from the participants, height score was found of 'Livelihood Diversification (LD)' among all upazilas. 'Using Chemical (UC)' option received 12

and 9, in the Hatibandha and Dimla respectively. Moreover 'IFC (pen and cage)' and 'IFC (ditch and dyke' got scores between 4 and 8 to three upazials 12 (Table 4).

4.2.3. District level

According to the participants (fisheries officers, fishermen, and others) at the workshop, fishermen are most vulnerable to changing climate due to the reduction of fish cultivation in the river and floodplain. Integrated fish culture (ditch and dyke) received the highest priority from the participants (Fig. 3c). Similarly, participants placed emphasis on the fisheries sector such as 'establishment of fish sanctuary', 'enhancement of basin water holding capacity', and 'implementation of fish law (task force)' to increase fish production in this area. Nevertheless, at upazila and community level, participants identified this as the best adaptation option of 'livelihood diversification'. Because during the dry season, fishermen are migrating to Rangpur (division) or Dhaka (capital city) to earn money where they mostly pull rickshaw (tricycle), they think that 'cage and pen culture' option is promising but showed considerable doubt about its feasibility. However, the participants discussed that traditional fish culture in this field can be protected from diseases caused by climate variability by using lime and medicine in the pond which enhances production. According to participants, in the fisheries sector all adaptation options received high scores (12) except 'Short Migration (SM)' and 'Short Term Fish Culture (STFC)' with scores 10 and 8 respectively (Table 5). From this workshop, participants helped enhance new adaptation options for the fisheries sector which are 'Task force', 'Early Warning System of Flood and Drought (EWSF&D)', and 'Enhancement of Basin Water Holding Capacity (EBWHC)'.

4.3. Livestock sector

4.3.1. Community/village level

Shared livestock raising (Adhi system) was the widely preferred option at all the three locations (Fig. 3a). Because of limited capital, poor farmers engage in shared livestock rearing arrangements. Normally female members of households' play vital role in livestock rearing. Hence, this option can also empower women economically. The owner and the person to rear agree on the terms of sharing offsprings from the livestock or products (milk) or both. Shared livestock rearing lift household income levels.

Communities also emphasized protecting the livestock during extreme climate events, in particular during floods. During flooding, households have to leave their homestead temporarily in search of shelter on higher grounds or in flood shelters, which are both, likely to be on the mainland. They take whatever they can with them, including their livestock. Hence, raising the plinth of livestock shed as a preparatory measure is a very good option. Improved shelter by raising the plinth of livestock shed is the second most prioritized option in the areas. However, the soil texture in the char area is a challenge for doing so.

Communities have also shown interest in the option of high yielding fodder production in the highlands. During climatic hazards, particularly times of flooding, a shortage of fodder happens, hence, high yielding feed crops in high land is a good option to cope. Most common varieties are Nephiare and Jumbi grass. Farmers can also sell the surplus at the market. Community members also mentioned the importance of preserving fodders for monsoon season. Fig. 3a shows that the livestock sector received a score 12, the 'Shared livestock raising (adhi system)' and HYV (High Yield Variety) adaptation options has the second highest scores of 11 under each union (Table 4).

Table 5
Cumulative score of adaptation measures given by the multi-stakeholders in different sectors.

Adaptation measures	Community	Upazila	Regional
Agriculture Sector			
Flood tolerant rice	32	34	11
Maize	36	24	12
Sathi fosol (*mixed and relay culture*)	36	32	12
Short rotation rice verity	29	33	11
Livestock Sector			
High yielding fodder	24	22	12
Shared rearing of livestock (*adhi system*)	32	27	12
Veterinary treatment	19	36	10
Livestock shelter	18	35	9
Fisheries Sector			
Livelihood diversification	34	36	12
Housing Sector			
Rising plinth level	33	32	12
Solar energy	33	32	12
Cluster house	30	31	6
Tube well	21	31	12
Drinking Water, Sanitation and Health sector			
Flood tolerant sanitation	–	–	11
Enhance health facility and community clinic activities	–	–	12
Ensure safe drinking water	–	–	12
Health facility to marginal people	–	–	11
Ensure hot cloth for child and poor people	–	–	8

4.3.2. Upazila/sub district level

Livestock treatment received the highest adaption scores among the livestock sector. In addition, livestock shelter was highly emphasized by the participants (Fig. 3b). The participants also showed their preference for high yielding fodder production because of its economic return. They discussed that high yielding fodder cultivation is not feasible for the area. The participants didn't show their interest of shared livestock raising (adhi system) in the Kaunia area. However, we found the highest score from the participant was for shared livestock raising (adhi system) at both Hatibandha and Dimla upazila. Poor people can lead their livelihood by adhi system from the well of the owner to relief from economic stress. So, both the owner and the occupant benefit through this system. Furthermore, raising the plinth level of the cow shed got more prioritization from the Hatibandha and Kaunia's participants, whereas in Dimala upazila participants showed less interest. In the livestock sector, the 'Livestock Treatment (LT)' option got the highest score of 12 at three locations. On the other hand, 'Livestock Shelter (LS)' score received 12, except Kaunia which received 11 (Table 4).

4.3.3. District level

From the workshop participants agreed with 'high yields fodder' production as the most prioritized in the livestock sector (Fig. 3c). Another option; 'shared rearing of livestock', appeared as a good practice in Rangpur region because poor people can earn some money by raising cows orgoatst owned by rich people during economic crisis periods. In this way, both the owner and leaseholder can benefit. From the view of the expertise of the workshop, 'Livestock Insurance', 'Artificial Infertility (AI) System', and 'Building local market' may become suitable adaptation options in this sector. From the participants, 'High Yielding Fodder (HYF)' and 'Adhi system' options received highest score (12), followed by the two options 'Fodder Preservation (FP)' and 'Artificial Infertility (AI) System' which received score (11)', and other four options having scores between 8 and 10 (Table 4).

4.4. Habitat sector

4.4.1. Community/village level

'Raising the plinth' of the house was ranked the as top adaptation option in the habitat sector. During flood, poor people living on the char lands have to leave their homes temporarily to shelters on higher ground on the mainland. They take whatever they can with them, including their livestock. Leaving anything behind have the risk of theft or loss to the river. Raised plinths protect people and their belongings from flooding. The raised plinths also act as temporary shelters for other households in the village along with their livestock as they take shelter on raised plinths during the floods. 'Solar energy' is the second most preferred option for the community stakeholders. It expands the renewable energy source in remote areas and people can light electric bulbs with the energy. However, community stakeholders mentioned that solar panels are still expensive for the poor to afford even though there is a government subsidy. They urged that financing for solar projects should be expanded.

The community members have awareness of the multiple benefits of plantation (source of firewood, water conservation, reduced soil erosion etc.). However, community stakeholders are of the opinion that more information from authorities on which species to be planted without effects on the environment is required. Community urge; large scale plantation should be a publicly funded activity on government owned land and preferred there is no requirement for any investments from them, and benefits could be accrued by the communities. The option of agroforestry was also discussed, it is one of the least preferred options as farmers felt such intervention results in the competition of the agro forests with the cultivated crops resulting in stunted growths of crops planted under the shade of trees.

Allotment of cluster houses (Gucchogram) was seen as an effective option to resettle the riverbank erosion of landless people. The community people discussed that the government Gucchogram project is too little to handle the problems of all displaced persons. If NGOs initiate the same kind of project, many families can be assisted under it. Disbursement of public owned land (Khas land) was less preferred by the community members as a maximum of the public owned lands are in erosion prone areas. To reduce pressure on firewood sourcing, improved cooking stoves and biogas technologies are used all over the country. However, community stakeholders showed less preference for these technologies as currently there is no scarcity of firewood, and these technologies cannot handle the problems of energy during flooding. It was found that the identified options were more of reactions to the changes than preventive or were anticipatory and within the needs of the communities in the near future. There is correlation between the proposed adaptation options and the impacts experienced due to climatic hazards and communities are focused on the provision of quick short term reprieve from such impacts. The communities' stakeholders' welcome the adoption of newer technologies (for example improved rice varieties) and/or cropping techniques (such as mixed cropping) so long it doesn't affect their yields and profits. The improved services according to the stakeholders must come with adequate demonstration of the benefits obtainable from the new approaches, and in newer varieties cases, the provision of the seeds and other needed inputs should be in adequate quantities and at the right time.

Apart from these options that were prioritized, for flood management and riverbank protection, community stakeholders demanded more embankment and capital dredging in the river be done. Particularly, in the Hatibandha upazila of Lalmonirhat district, where communities have demanded a flood protection dam to protect their lives, properties, and cultivable lands. In the housing sector (Fig. 3a), from the participants (Singhmari and Purbochatnai), we found high scores from two adaptation options 'Plantation in Highland (PH)' and 'Rising Plinth Level (RPL)' with scores of 12 each. 'Solar energy', 'Cluster house', 'Bondhu Chula', and 'Tube well' got scores that ranged between 9 and 11 under all union (Table 4).

4.4.2. Upazila/sub district level

The participants discussed that raising the plinth level of houses is essential for all upazila because sandy soil is washed away in each flood season; this is the major challenge of that area.

They argued that plantation in the homestead can protect their houses from climate extremes such as floods and heat waves. The participants commented that to reduce the vulnerability of homeless people during floods, cluster houses (gucchogram) are essential to protect them at upazila level. Bondhu chula, biogas, and solar energy are newly promising options in the housing sector for adaptation among those upazilas. According to participants, 'distribution of public (khas) land' can also be a good adaptation option in the housing sector to landless people.

In the housing sector 'Plinth Raising (PR)', 'Solar energy', 'cluster house',' khas land', and 'biogas' received score 8 to 12 under those upazila. 'Plinth Raising (PR) and 'Plantation Highland (PH)' for Kaunia received score of 12, whereas in Hatibandha upazila score 12 was received by both 'Solar energy', and 'cluster house' adaptation option (Table 4).

4.4.3. District level

The outcome of the workshop shows that participants found that 'raising the plinth of houses' is essential option because flood level of lower Teesta basin can increase in the future. However, they mentioned that because of sandy soil, it is not highly appropriate to protect riverbank erosion. So, they agreed to 'plantation in highland' and the communities prefer than 'homestead plantation'. Plantation in the homestead can protect the houses from climate extreme event such as floods and heat waves. They said that disbursement of public land to the homeless could be a good option. However, it has many socio-political barriers to implement. Renewable energy communities have shown high levels of preference for solar energy than biogas. 'Safe drinking water and sanitation', and 'tube well' are the most important. Moreover, flood shelter and flood awareness also got very high priority. In the workshop, we considered 13 adaptation options in housing sector (Fig. 3c) from there, eight options received high scores of 12 while the remaining five options has scores between 6 and 10 (Table 4).

4.5. Drinking water, health and sanitation sector

In this workshop, the participants were mostly educated rather than those of upazila and community levels. So, they suggested adding 'Health and sanitation' as other adaptation options for which they care about. 'Drinking water, sanitation', and 'health' are the serious issues of that areas during both monsoon and dry season. During flood periods people are affected by food or waterborne diseases like diarrhoea, typhoid, and fever. So, they agreed to raise plinth levels of tube wells for safe drinking water. Enhanced health facility and community clinic activities also received very high priority. In this sector 'Enhance Health Facility and Community Clinic Activities (EHFCCA)', and 'Ensure safe drinking water' got highest scores of (12).'Rising Plinth Level of Tube well (RPL Tube well)', 'Flood Tolerant Sanitation (FTS)', and 'Health Facility of Marginal People (HFOMP)' gained second top score (11) (Table 5).

In agriculture sector, 'Maize' and 'Sathi fosol' received highest scores under community (36), and regional (12) levels, but in upazila level 'Maize' and 'Sathi fosol' got score 24 and 32 respectively (Table 5). 'Flood tolerant rice' got score (34) under upazila level. Based on expert opinions, community experience, and lessons learned from the workshop 'Maize' and 'Sathi fosol' can be considered as good adaptation option in the agricultural sector.

The 'adhi system' is the topmost adaptation option in livestock sector at all levels, that's why this option received scores of 32, 27, and 12 under community, upazila and regional level respectively. 'High yielding fodder' was found to have high score (12) at regional level. Therefore, 'adhi system' may be effective adaptation option to community, upazila, and regional levels of livestock sector. 'Livestock shelter' received highest score (35) at upazila level, but at community level got score (18), whereas regional (9) has less importance (Table 5). More interestingly, 'Livelihood diversification' received highest score at community (34), upazila (36) and regional (12) level in the fisheries sector. Therefore, there is no other option to adopt this sector, except this option (Table 5).

In housing sector, 'Rising plinth level' and 'Solar energy' options received almost the same scores of (33) and (32) respectively at both community and upazila levels. In addition, regional level score was (12) under both options. Whereas 'cluster house' has scores at community (30), upazila (31), and regional (6), meaning that at regional level less attention is paid to 'cluster house' as adaptation option (Table 5).

At regional level, participants agreed to supplement new adaption option e.g. 'Drinking water, sanitation, and health' under this option, and they considered five adaptation options, where 'Enhance health facility and community clinic activities', and 'Ensure safe drinking water' option scores were (12) in both cases (Table 5). So, those two adaptation options are topmost priority in this sector.

5. Conclusion

This study was conducted in three sub-districts of the northern part of Bangladesh, specifically to the Teesta floodplain ranges. These are highly climate vulnerable areas. In this present study, findings from consultations with stakeholders and identification of adaptation options using participatory adaptation tools were used at different levels for the ranking of identified adaptation options. This research employs the Multi Criteria Analysis (MCA) method for the assessment of climate change adaptation options. In this study, the MCA uses stakeholders' judgments on the importance of the various criteria for resolving the problem. There is a strong connection between agriculture and climate, as the climate has a significant influence on agricultural production and is a significant factor in food production variability. We found different outcomes from agriculture; fishery; livestock; habitat; drinking water, health and sanitation sectors.

Based on their perceived drivers and conditions leading to vulnerabilities to climate change, the community stakeholders, upazila, and district level identified and prioritized a set of sectoral, multi-sectoral, and cross-sectoral adaptation measures. Differences in vulnerability were perceived from the differences in priorities set by stakeholders at the different levels across the studies. A more integrated approach to stakeholder engagement is needed through adaptation process. Flood protection and riverbank erosion

management received highest priorities from the participants, while agriculture and health and sanitation were considered most important. There are different perspectives and priorities considered based on the stakeholders' working experience, institutional responsibility and global point of views. Finally, community and upazila level people wants immediate action to be implemented but regional level stockholders are thinking on a long term basis with different views and perspectives for planning, capacity building, resource allocation and better implementation. This paper presents a case study on prioritization of adaptation options from Bangladesh. Some of the outcomes of the study still needs further deliberation after implementation, especially for the different sectors, which have different demands for adaption, and also the investment, public awareness, local government support which are important factors for the future implementation.

Author contribution statement

Mahiuddin Alamgir: Analyzed and interpreted the thematic concept and design of the manuscript and wrote the paper. **Md Nasir Uddin:** Conducted many workshops and participated in several fieldwork at different stakeholder levels. **M. Mehedi Hasan:** Information collection from different sectoral sources includes relevant reports, journal articles, working papers, Governments and NGOs sources, and also revised the manuscript. **Xiaojun Wang:** Critical analysis of the manuscript. **Mohammed Sanusi Shiru:** Contributed to review this study. **Shamsuddin Shahid:** Several reviews have been conducted and research gaps have been explored regarding sectoral adaptation strategies and practices.

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.

Acknowledgement

We are grateful to Bangladesh Centre for Advanced Studies (BCAS) for providing financial support for this study. We are also thankful to the anonymous reviewers and editors for their helpful comments and suggestions.

References

Abbass, K., Song, H., Khan, F., Begum, H., Asif, M., 2022. Fresh insight through the VAR approach to investigate the effects of fiscal policy on environmental pollution in Pakistan. Environ. Sci. Pollut. Res. 29 (16), 23001–23014.
Adger, W.N., 2006. Vulnerability. Glob. Environ. Change 16 (3), 268–281.
Afroz, R., Rahman, M.A., 2013. Transboundary river water for Ganges and Teesta rivers in Bangladesh: an assessment. Glob. Sci. Technol. J. 1 (1), 100–111.
Aggarwal, P.K., Jarvis, A., Campbell, B.M., Zougmoré, R.B., Khatri-Chhetri, A., Vermeulen, S.J., Loboguerrero, A.M., Sebastian, L.S., Kinyangi, J., Bonilla-Findji, O., Radeny, M., 2018. The Climate-Smart Village Approach: Framework of an Integrative Strategy for Scaling up Adaptation Options in Agriculture.
Ahmed, Z., Alam, R., Ahmed, M.N.Q., Ambinakudige, S., Almazroui, M., Islam, M.N., Chowdhury, P., Kabir, M., Mahmud, S., 2022. Does anthropogenic upstream water withdrawal impact on downstream land use and livelihood changes of Teesta transboundary river basin in Bangladesh? Environ. Monit. Assess. 194 (2), 1–15.
Alamgir, M., Mahejabeen, M., Hassan, S.M.T., Syed, M.A., Mallick, D., 2018. Climate Change Adaptation Strategies and Practices in the Lower Teesta Basin in Bangladesh.
Alamgir, M., Shahid, S., Hazarika, M.K., Nashrrullah, S., Harun, S.B., Shamsudin, S., 2015. Analysis of meteorological drought pattern during different climatic and cropping seasons in Bangladesh. J. Am. Water Resour. Assoc. 51 (3), 794–806.
Allan, A., Barbour, E., Nicholls, R.J., Hutton, C., Lim, M., Salehin, M., Rahman, M.M., 2022. Developing socio-ecological scenarios: a participatory process for engaging stakeholders. Sci. Total Environ. 807, 150512.
Aryal, J.P., Sapkota, T.B., Khurana, R., Khatri-Chhetri, A., Rahut, D.B., Jat, M.L., 2020. Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Environ. Dev. Sustain. 22 (6), 5045–5075.
Ayers, J.M., Huq, S., Faisal, A.M., Hussain, S.T., 2014. Mainstreaming climate change adaptation into development: a case study of Bangladesh. Wiley Interdiscip. Rev.: Clim. Change 5 (1), 37–51.
Azadi, H., Siamian, N., Burkart, S., Moghaddam, S.M., Goli, I., Dogot, T., Lebailly, P., Teklemariam, D., Miceikienė, A., Van Passel, S., 2022. Climate smart agriculture: mitigation and adaptation strategies at the global scale. In: Climate-Induced Innovation. Palgrave Macmillan, Cham, pp. 81–140.
Baláž, V., Dokupilová, D., Filčák, R., 2021. Participatory multi-criteria methods for adaptation to climate change. Mitig. Adapt. Strategies Glob. Change 26 (4), 1–22.
BBS, 2017. Bangladesh Bureau of Statistics. Monthly Statistical Bulletin, Ministry of Planning. Government of the People's Republic of Bangladesh, Dhaka, pp. 49–69.
Bell, M.L., Hobbs, B.F., Elliott, E.M., Ellis, H., Robinson, Z., 2001. An evaluation of multi-criteria methods in integrated assessment of climate policy. J. Multi-Criteria Decis. Anal. 10 (5), 229–256.
Berrang-Ford, L., Siders, A.R., Lesnikowski, A., Fischer, A.P., Callaghan, M.W., Haddaway, N.R., et al., 2021. A systematic global stocktake of evidence on human adaptation to climate change. Nat. Clim. Change 11 (11), 989–1000.
Bhadwal, S., Groot, A., Balakrishnan, S., Nair, S., Ghosh, S., Lingaraj, G.J., van Scheltinga, C.T., Bhave, A., Siderius, C., 2013. Adaptation to changing water resource availability in Northern India with respect to Himalayan Glacier retreat and changing monsoons using participatory approaches. Sci. Total Environ. 468, S152–S161.
Bhandary, R.R., 2022. Climate mainstreaming via national climate funds: the experiences of Bangladesh and Ethiopia. Clim. Dev. 14 (4), 311–320.
Billi, P., Alemu, Y.T., Ciampalini, R., 2015. Increased frequency of flash floods in Dire Dawa, Ethiopia: change in rainfall intensity or human impact? Nat. Hazards 76 (2), 1373–1394.
Brammer, H., 1990. Floods in Bangladesh: geographical background to the 1987 and 1988 floods. Geogr. J. 12–22.

Butler, J.R.A., Wise, R.M., Skewes, T.D., Bohensky, E.L., Peterson, N., Suadnya, W., Yanuartati, Y., Handayani, T., Habibi, P., Puspadi, K., Bou, N., 2015. Integrating top-down and bottom-up adaptation planning to build adaptive capacity: a structured learning approach. Coast. Manag. 43 (4), 346–364.
Chambers, R., 1994. The origins and practice of participatory rural appraisal. World Dev. 22 (7), 953–969.
Chowdhury, R.B., Moore, G.A., 2017. Floating agriculture: a potential cleaner production technique for climate change adaptation and sustainable community development in Bangladesh. J. Clean. Prod. 150, 371–389.
Coirolo, C., Rahman, A., 2014. Power and differential climate change vulnerability among extremely poor people in Northwest Bangladesh: lessons for mainstreaming. Clim. Dev. 6 (4), 336–344.
Cvitanovic, C., Shellock, R.J., Mackay, M., van Putten, E.I., Karcher, D.B., Dickey-Collas, M., Ballesteros, M., 2021. Strategies for building and managing 'trust'to enable knowledge exchange at the interface of environmental science and policy. Environ. Sci. Pol. 123, 179–189.
Dai, A., 2011. Drought under global warming: a review. Wiley Interdiscip. Rev.: Clim. Change 2 (1), 45–65.
Dilshad, T., Mallick, D., Udas, P.B., Goodrich, C.G., Prakash, A., Gorti, G., Bhadwal, S., Anwar, M.Z., Khandekar, N., Hassan, S.T., Habib, N., 2019. Growing social vulnerability in the river basins: evidence from the hindu kush himalaya (HKH) region. Environ. Dev. 31, 19–33.
Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., Campbell, J., 2008. Unjust waters: climate change, flooding and the urban poor in Africa. Environ. Urbanization 20 (1), 187–205.
Ebi, K.L., Burton, I., 2008. Identifying practical adaptation options: an approach to address climate change-related health risks. Environ. Sci. Pol. 11 (4), 359–369.
Eicken, H., Danielsen, F., Sam, J.M., Fidel, M., Johnson, N., Poulsen, M.K., Lee, O.A., Spellman, K.V., Iversen, L., Pulsifer, P., Enghoff, M., 2021. Connecting top-down and bottom-up approaches in environmental observing. Bioscience 71 (5), 467–483.
Eriksen, S., Aldunce, P., Bahinipati, C.S., Martins, R.D.A., Molefe, J.I., Nhemachena, C., O'brien, K., Olorunfemi, F., Park, J., Sygna, L., Ulsrud, K., 2011. When not every response to climate change is a good one: identifying principles for sustainable adaptation. Clim. Dev. 3 (1), 7–20.
Eriksen, S., Brown, K., 2011. Sustainable adaptation to climate change. Clim. Dev. 3 (1), 3–6.
Ferdous, J., Mallick, D., 2019. Norms, practices, and gendered vulnerabilities in the lower Teesta basin, Bangladesh. Environ. Dev. 31, 88–96.
Golfam, P., Ashofteh, P.S., Rajaee, T., Chu, X., 2019. Prioritization of water allocation for adaptation to climate change using multi-criteria decision making (MCDM). Water Resour. Manag. 33 (10), 3401–3416.
Hasan, M.M., Alauddin, M., Sarker, M.A.R., Jakaria, M., Alamgir, M., 2019. Climate sensitivity of wheat yield in Bangladesh: implications for the United Nations sustainable development goals 2 and 6. Land Use Pol. 87, 104023.
Hassan, S.T., Hussain, A., Rahman, A., Gorti, G., Nyima, K., Luitel, M., et al., 2020. Critical Climate Stress Moments: Evidence from the Teesta River Basin in India and Bangladesh.
Hua, L., Zhao, T., Zhong, L., 2022. Future changes in drought over Central Asia under CMIP6 forcing scenarios. J. Hydrol.: Reg. Stud. 43, 101191.
IPCC, 2014. Climate Change 2014-Impacts, Adaptation and Vulnerability: Regional Aspects. Cambridge University Press.
Islam, A.T., Shen, S.H., Yang, S.B., 2018. Predicting design water requirement of winter paddy under climate change condition using frequency analysis in Bangladesh. Agric. Water Manag. 195, 58–70.
Janssen, R., Van Herwijnen, M., 2006. A toolbox for multicriteria decision-making. Int. J. Environ. Technol. Manag. 6 (1–2), 20–39.
Kourgialas, N.N., 2021. A critical review of water resources in Greece: the key role of agricultural adaptation to climate-water effects. Sci. Total Environ. 775, 145857.
Kriegler, E., O'Neill, B.C., Hallegatte, S., Kram, T., Lempert, R.J., Moss, R.H., Wilbanks, T., 2012. The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. Global Environ. Change 22 (4), 807–822.
Kumar, A., Mondal, S., Lal, P., 2022. Analysing frequent extreme flood incidences in Brahmaputra basin, South Asia. PLoS One 17 (8), 0273384.
Kumar, A., Sharma, P., 2022. Impact of Climate Variation on Agricultural Productivity and Food Security in Rural India. Available at: SSRN 4144089.
Lo, K., Li, H., Chen, K., 2020. Climate experimentation and the limits of top-down control: local variation of climate pilots in China. J. Environ. Plann. Manag. 63 (1), 109–126.
Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, R.L., 2008. Prioritizing climate change adaptation needs for food security in 2030. Science 319 (5863), 607–610.
Lu, S., Bai, X., Li, W., Wang, N., 2019. Impacts of climate change on water resources and grain production. Technol. Forecast. Soc. Change 143, 76–84.
Mairura, F.S., Musafiri, C.M., Kiboi, M.N., Macharia, J.M., Ng'etich, O.K., Shisanya, C.A., Okeyo, J.M., Mugendi, D.N., Okwuosa, E.A., Ngetich, F.K., 2021. Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. Weather Clim. Extrem. 34, 100374.
Manabe, S., Stouffer, R.J., 1993. Century-scale effects of increased atmospheric CO2 on the ocean–atmosphere system. Nature 364 (6434), 215–218.
Matthews, H.D., Caldeira, K., 2008. Stabilizing climate requires near-zero emissions. Geophys. Res. Lett. 35 (4).
McNamara, K.E., Buggy, L., 2017. Community-based climate change adaptation: a review of academic literature. Local Environ. 22 (4), 443–460.
MoEF, 2005. National Adaptation Programme of Action (NAPA). Ministry of Environment and Forests, Dhaka. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh.
MoEF, 2009. Ministry of Environment and Forests, Government of the People's Republic of Bangladesh. Bangladesh Climate Change Strategy and Action Plan 2009. Ministry of Environment and Forests, Dhaka.
Mohsenipour, M., Shahid, S., Chung, E.S., Wang, X.J., 2018. Changing pattern of droughts during cropping seasons of Bangladesh. Water Resour. Manag. 32 (5), 1555–1568.
Mondol, M.A.H., Zhu, X., Dunkerley, D., Henley, B.J., 2021. Observed meteorological drought trends in Bangladesh identified with the Effective Drought Index (EDI). Agric. Water Manag. 255, 107001.
MoWR, 1999. Ministry of Water Resources, Government of the People's Republic of Bangladesh, National Water Policy (NWP). Available at:
MoWR, 2001. Ministry of Water Resources (MoWR). Overview of Water Resources Management and Development in Bangladesh. Ministry of Water Resources, Government of Bangladesh, Dhaka (GoB).
Nago, M., Krott, M., 2022. Systemic failures in north–south climate change knowledge transfer: a case study of the Congo basin. Clim. Pol. 22 (5), 623–636.
O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim. Change 122 (3), 387–400.
Omondi, L.A., 2020. Learning together: participatory rural appraisal for coproduction of climate change knowledge. Action Res. 1476750320905901.
Owen, G., 2020. What makes climate change adaptation effective? A systematic review of the literature. Global Environ. Change 62, 102071.
Parven, A., Pal, I., Witayangkurn, A., Pramanik, M., Nagai, M., Miyazaki, H., Wuthisakkaroon, C., 2022. Impacts of disaster and land-use change on food security and adaptation: evidence from the delta community in Bangladesh. Int. J. Disaster Risk Reduc. 78, 103119.
Paul, B.K., Rahman, M.K., Crawford, T., Curtis, S., Miah, M.G., Islam, M.R., Islam, M.S., 2020. Explaining mobility using the community capital framework and place attachment concepts: a case study of riverbank erosion in the lower meghna estuary, Bangladesh. Appl. Geogr. 125, 102199.
Pörtner, H.O., Roberts, D.C., Adams, H., Adler, C., Aldunce, P., Ali, E., et al., 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. IPCC Sixth Assessment Report.
Rashid, A.M., Khan, M.R., 2013. Community based adaptation: theory and practice. In: Climate Change Adaptation Actions in Bangladesh. Springer, Tokyo, pp. 341–362.
Rattis, L., Brando, P.M., Macedo, M.N., Spera, S.A., Castanho, A.D., Marques, E.Q., Costa, N.Q., Silverio, D.V., Coe, M.T., 2021. Climatic limit for agriculture in Brazil. Nat. Clim. Change 11 (12), 1098–1104.
Rawlani, A.K., Sovacool, B.K., 2011. Building responsiveness to climate change through community-based adaptation in Bangladesh. Mitig. Adapt. Strategies Glob. Change 16 (8), 845–863.
Ray, S., Das, S.S., Mishra, P., Al Khatib, A.M.G., 2021. Time series SARIMA modelling and forecasting of monthly rainfall and temperature in the South Asian countries. Earth Syst. Environ. 5 (3), 531–546.
Rosenzweig, C., Parry, M.L., 1994. Potential impact of climate change on world food supply. Nature 367 (6459), 133–138.

Roy, P., Pal, S.C., Chakrabortty, R., Chowdhuri, I., Saha, A., Shit, M, 2022. Climate change and groundwater overdraft impacts on agricultural drought in India: vulnerability assessment, food security measures and policy recommendation. Sci. Total Environ. 849, 157850.
Sarker, D.C., Pramanik, B.K., Zerin, A.I., Ara, I., 2011. Climatic impact assessment: a case study of Teesta Barrage irrigation project in Bangladesh. Int. J. Civ. Environ. Eng. 11 (1), 99–110.
Selvaraju, R., Gommes, R., Bernardi, M., 2011. Climate science in support of sustainable agriculture and food security. Clim. Res. 47 (1–2), 95–110.
Shahid, S., 2011. Trends in extreme rainfall events of Bangladesh. Theor. Appl. Climatol. 104 (3), 489–499.
Shahid, S., Behrawan, H., 2008. Drought risk assessment in the western part of Bangladesh. Nat. Hazards 46 (3), 391–413.
Susskind, L., Kim, A., 2022. Building local capacity to adapt to climate change. Clim. Pol. 22 (5), 593–606.
Thomas, K., Hardy, R.D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J.T., Rockman, M., Warner, B.P., Winthrop, R., 2019. Explaining differential vulnerability to climate change: a social science review. Wiley Interdiscip. Rev.: Clim. Change 10 (2), 565.
Thomson, A.M., Ellis, E.C., Grau, H.R., Kuemmerle, T., Meyfroidt, P., Ramankutty, N., Zeleke, G., 2019. Sustainable intensification in land systems: trade-offs, scales, and contexts. Curr. Opin. Environ. Sustain. 38, 37–43.
Tripathi, A., Mishra, A.K., 2017. Knowledge and passive adaptation to climate change: an example from Indian farmers. Clim. Risk Manag. 16, 195–207.
Urwin, K., Jordan, A., 2008. Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Global Environ. Change 18 (1), 180–191.
Ussiri, D.A., Lal, R., 2017. Historical perspectives of the global carbon cycle. In: Carbon Sequestration for Climate Change Mitigation and Adaptation. Springer, Cham, pp. 103–161.
Van Aalst, M.K., Cannon, T., Burton, I., 2008. Community level adaptation to climate change: the potential role of participatory community risk assessment. Global Environ. Change 18 (1), 165–179.
Venkatappa, M., Sasaki, N., Han, P., Abe, I., 2021. Impacts of droughts and floods on croplands and crop production in Southeast Asia–An application of Google Earth Engine. Sci. Total Environ. 795, 148829.
Werners, S.E., Wise, R.M., Butler, J.R., Totin, E., Vincent, K., 2021. Adaptation pathways: a review of approaches and a learning framework. Environ. Sci. Pol. 116, 266–275.
Wheeler, R., Lobley, M., 2021. Managing extreme weather and climate change in UK agriculture: impacts, attitudes and action among farmers and stakeholders. Clim. Risk Manag. 32, 100313.
Whitehead, P.G., Jin, L., Macadam, I., Janes, T., Sarkar, S., Rodda, H.J., Sinha, R., Nicholls, R.J., 2018. Modelling impacts of climate change and socio-economic change on the Ganga, Brahmaputra, Meghna, Hooghly and Mahanadi river systems in India and Bangladesh. Sci. Total Environ. 636, 1362–1372.
Zougmoré, R.B., Läderach, P., Campbell, B.M., 2021. Transforming food systems in Africa under climate change pressure: role of climate-smart agriculture. Sustainability 13 (8), 4305.