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Research article

Coping with crisis on the coast: The effect of community-developed coping-strategies on vulnerability in crisis-prone regions of the Ganges delta

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ABSTRACT

Coastal communities are prone to crises. Repeated exposure to crises constrains the ability of residents to access basic needs such as health, water and food, and may increase their vulnerability levels. In response, communities develop coping strategies such as depoldering (temporary breaching of embankments for TRM: tidal rivers management) and anti-aquaculture movements. However, existing research has not adequately explored the relationship between coping strategies and vulnerability. Theoretical literature is characterized by ambiguity on how various geocentric and anthropocentric factors affect vulnerability in the presence of community-developed coping strategies. Therefore, to advance theoretical knowledge in this field, this article first conceptualizes an integrated framework on the association between vulnerability and coping strategies by merging anthropocentric and geocentric approaches. It then uses mixed methods drawn from social science (surveys, semi-structured interviews), geography (spatial tools) and statistics (multiple regression) on data collected from the coastal belt of Bangladesh to demonstrate that coping strategies may have an effect on vulnerability in crisis-prone coastal regions. The significance of this study is that it demonstrates how the association between vulnerability and coping strategies is likely to be nuanced: depending on a) the type of vulnerability (food/water/health), and b) the coping strategy (TRM vs. anti-aquaculture movements). Different coping strategies are associated with different kinds of vulnerability and these relationships depend on local context (other anthropocentric and geocentric variables). Community movements against aquaculture could reduce food vulnerability, whereas TRM may reduce water vulnerability. Reduction in health vulnerability may instead be associated with urbanization and infrastructure development.

1. Introduction

Coastal regions are crisis-prone (Khandker, 2007; Islam et al., 2018). Consider the coastal belt of Bangladesh: in May 2020 Cyclone Amphan struck (Fig. 1), damaging 150 km of embankments, flooding around 149,000 ha of agricultural and aquacultural land, and destroying over 18,000 water points in 26 districts (OCHA, 2020). The disaster took place while the country was struggling to contain the spread of the Covid pandemic (Bryson, 2020). However, Bangladesh spends very little on public health: in 2012 the country spent only about 3.5% of its GDP on health, whereas the average spend for low-income countries is around 5% (WB, 2015). The crisis created by Covid-19 and Cyclone Amphan has severely affected the basic needs of coastal residents. A study amongst fishing communities revealed that 71% of households were unable to meet food requirements during the crisis, 45% felt that their local healthcare centers were not equipped to deal with the crisis, and water access had become difficult in communities where limited availability of tube wells meant that social distancing requirements were not observed (Sunny et al., 2020).

Exposure to such humanitarian crises have wide-ranging impacts on basic needs such as public health, food security and water poverty, especially amongst marginalized communities in coastal regions, and may increase their vulnerability levels (Butler and Adamowski, 2015; Islam et al., 2018). In order to decrease the vulnerability of such communities, especially from storm surges and flooding, polders (embankments constructed around low-lying land to control the hydrological

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regime) have been constructed across the coastal belt of Bangladesh since the 1960s (Alam et al., 2017; Ishtiaque et al., 2017). Polder-like structures have also been constructed in coastal regions across the world (Inniss and Simcock, 2016). On the short term, polders have increased agricultural productivity in Bangladesh and offered protection from extreme events (Choudhury et al., 2004; Adnan et al., 2019). Livelihood vulnerability of local populations may also have reduced (Nath et al., 2019). On the long term, however, waterlogging, drainage congestion, and sedimentation of waterways increased in some polders, particularly those located in the southwestern coastal region (Auerbach et al., 2015; Wilson et al., 2017). Concurrently, sea-level rise increased tidal surges and salinity intrusion (Auerbach et al., 2015; Alam et al., 2017), and agriculture gave way to aquaculture (Morshed et al., 2020). Such factors may have led to an increase of livelihood vulnerability in waterlogged polders as compared to non-waterlogged polders (Nath et al., 2019).

Communities in different polders developed different coping-strategies to tackle such problems (van Staveren et al., 2017; Paprocki and Cons, 2014). In some polders, communities periodically created temporary cuts in embankments so that sediment-rich brackish and fresh water flows into the polders, reducing drainage congestion and waterlogging while also increasing aquacultural and agricultural productivity, a depoldering practice known as Tidal River Management (TRM, Gain, et al., 2017; Mutahara, 2018). TRM is a community-developed coping strategy. It was community-led in Beel Dakatia and Beel Bhayna and was later implemented by a public agency in Beel Khuksia. Depoldering is common across the world (Warner et al., 2018). In contrast, some polders were taken over by shrimp cultivators who constructed numerous illegal inlets on the polder-embankments to allow uncontrolled flow of brackish water into agricultural lands. Aqua-cultural productivity increased significantly at huge costs to the traditional agriculture-led life of local communities (Paprocki and Cons, 2014).

However in some polders local communities have not permitted

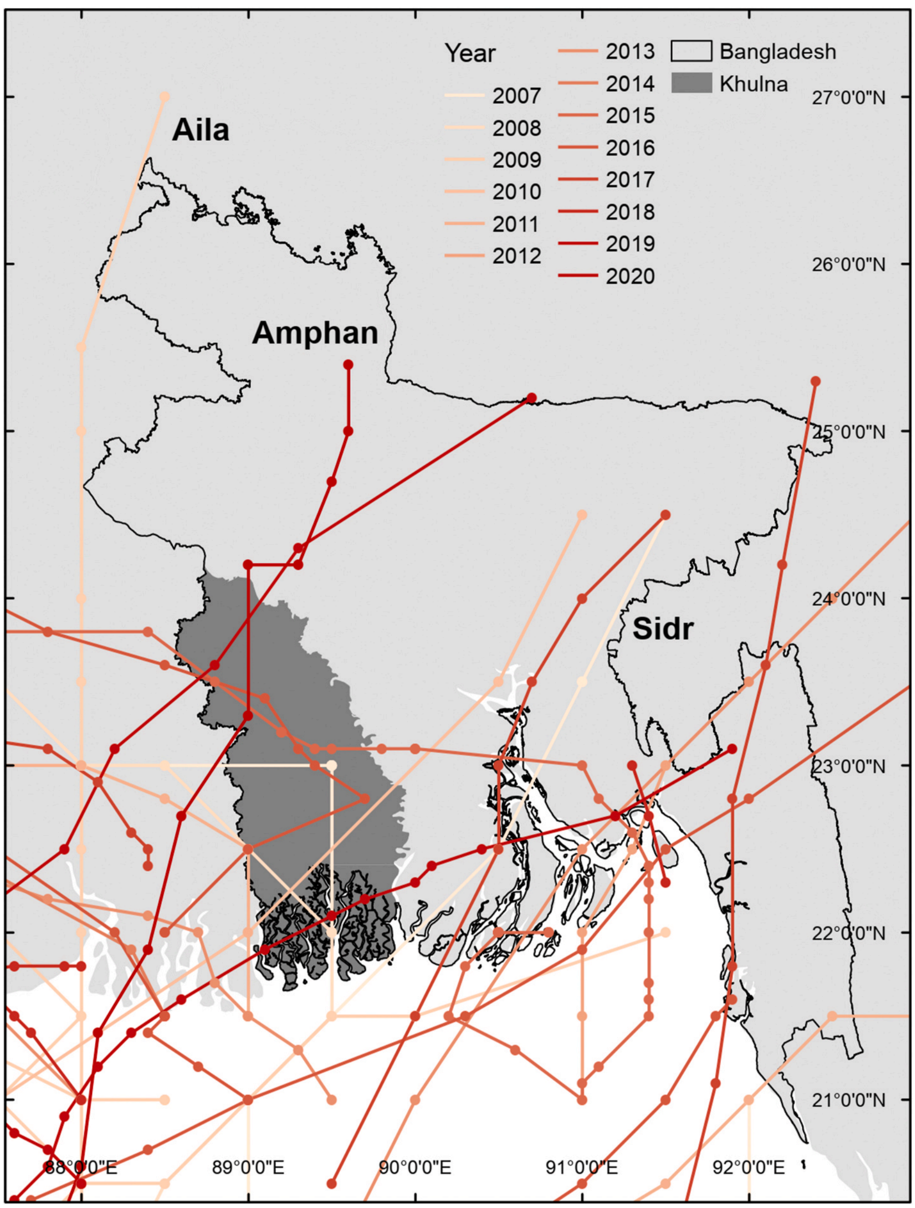

Fig. 1. Tracks of cyclonic depressions near and within Bangladesh since 2007 (IMD, 2020).

brackish-water aquaculture, have resisted the construction of illegal inlets, strengthened their drainage-gates, and only allow fresh water into their lands. These successful community-developed anti-aquaculture movements have allowed agriculture to flourish not only in Bangladesh but across the global coastline (Bavinck et al., 2017; Paprocki and Cons, 2014). Successful implementation of such coping strategies often depends on support from local households (Metcalf et al., 2015). However, there is limited understanding of how community-developed coping strategies affect household vulnerability in crisis-prone coastal regions (Miller et al., 2010). More research is needed on identifying those anthropocentric or geocentric variables which moderate relationships between coping strategies and vulnerability (Moser, 1998; Wood, 2003).

Crises have different effects on different households (Moser 1998). While all households suffer from the crisis, marginalized households bear the brunt of suffering (Butler and Adamowski, 2015). Anthropocentric variables such as household-level human capital (e.g. education, livelihood-choices) or social capital influences a household's ability to meet basic needs such as food, water and health, which come under pressure during crises (Rakib et al., 2019a,b). Household behavior may also be affected by geocentric variables such as natural capital (e.g. access to drinking water) which could have a differential effect on the food, water and health vulnerability of different households (Moser 1998; Wood 2003). In addition, physical capital (e.g. access to embankments) may also affect vulnerability since technological interceptions such as polderization or depolderization are often used for adapting to crisis in coastal regions. However instead of studying micro-level behavior, most comparative analyses of vulnerability using regression techniques have focused on national dynamics (Adger 2006; Marshall et al., 2014).

This research therefore seeks to answer the following question: How do community-developed coping strategies affect vulnerability in crisis-prone coastal regions? The objective of this research is to analyze whether household vulnerability in coastal regions is affected by coping strategies adopted by them to tackle crises: do different kinds of coping strategies affect vulnerability differently? For instance, does TRM have the same effect on food, water and health vulnerability or do different coping strategies affect different kinds of vulnerability differently and why? To answer these questions, we first conceptualize an integrated framework (Section 2) on the association between vulnerability and coping strategies by merging anthropocentric and geocentric approaches. We then use mixed methods (Section 3) drawn from social science (surveys, semi-structured interviews), geography (spatial tools) and statistics (multiple regression) to collect and analyze data on variables derived from our integrated vulnerability framework. Regression analysis tests the significance of the relationships between vulnerability and coping strategies by controlling for the effects of moderating variables. Results presented in Section 4 and discussed in Section 5 suggest that the association between vulnerability and coping strategies is nuanced and depends on the context. The implication of this finding is discussed in the conclusion section of this article.

2. Theoretical approach

Vulnerability can be defined as the extent to which a household is susceptible to, or is unable to cope with, the adverse impacts of external shocks and disturbances in the absence of capacity to adapt (Adger, 2006). It is a measure of whether a household can tackle various crises situations that household members encounter (see Adger 2006 for an account of how vulnerability research has evolved). Vulnerability research is rooted in multiple disciplines, resulting in a variety of perspectives (Eakin and Luers (2006). Two broad research traditions underlie these perspectives: a) an anthropocentric approach, and b) a geocentric approach (Adger, 2006; Füssel, 2007). The anthropocentric approach focuses on how society affects vulnerability by studying various socio-economic, demographic, political, institutional, cultural and technological factors. The geocentric approach, in contrast, studies how various geomorphological, ecological and environmental factors (including natural hazards) affect vulnerability. The anthropocentric approach analyzes the vulnerability of a household without accounting for its exposure to environmental variability, thereby ignoring the effect of biophysical factors such as the ability of households to draw on natural capital to cope with anthropocentric crises. In contrast, the geocentric approach seeks to understand the vulnerability of a household without taking into account human society, including households' ability to draw on socio-economic or political resources to cope with geocentric crises. The anthropocentric and biophysical approaches therefore complement each other, and scholars have developed unified frameworks by combining anthropocentric and geocentric approaches for the integrated analysis of factors which affect vulnerability (Füssel, 2007; Marshall et al., 2014). This article customizes an integrated framework of variables proposed by Metcalf et al. (2015) to analyze the relationship between vulnerability and community-developed coping--strategies (Fig. 2) by drawing on social-ecological systems theory (Metcalf et al., 2015) and the sustainable livelihood approach (Scoones, 2015).

According to this framework, household vulnerability depends on a wide range of variables characterizing human society (within social, political and technological systems) as well as the larger bio-physical system with which human society continuously interacts to satisfy basic needs (Marshall et al., 2014). Variables from these systems constantly interact with each other: e.g. a household may construct an embankment (technological system) to reduce vulnerability from flooding (bio-physical system); or, conflict (political system) amongst households over access to water (bio-physical system) may increase vulnerability (Nath et al., 2020). The local context determines whether a variable from the biophysical system or from human society acts as a barrier or enabler to vulnerability (Metcalf et al., 2015). Each system can be categorized into sub-groups of variables such as exposure to natural hazards, natural capital, physical capital, social capital, human capital and human agency. Using the language of capitals drawn from the sustainable livelihoods approach (Scoones, 2015; Nath et al., 2020) emphasizes that vulnerability is associated with resource dependency (Adger, 2006; Nath et al., 2020). Such resources can be drawn from the biophysical, social or technological systems. Human agency represents the agency of a community to adapt to the barriers created by natural hazards and other crises (Füssel, 2007), and it also affects vulnerability e.g. through community-developed coping strategies (Adger, 2006). The association between agency and vulnerability may be moderated by complex interactions amongst a range of anthropocentric and geocentric factors (Cutter et al., 2003; Brooks et al., 2005; Adger, 2006; Notenbaert et al., 2013; Marshall et al., 2014; Metcalf et al., 2015): a) expsoure to natural hazards; b) physical capital: distance from hydrological structures and infrsatructure (drainage gate, embankment, road); c) social capital; d) human capital: education, livelihood diversification, health status and access to healthcare (Rakib et al., 2019a,b); e) political variables such as conflict; f) natural capital: access to water, capacity to grow rice and capacity to save crops (Allison and Horemans, 2006). Such complex interactions can be both functional (Papadimitriou, 2012) and spatial (Papadimitriou, 2021).

3. Methods

3.1. Research hypothesis and operationalization of variables

The hypothesis this research seeks to test is that coping strategies affect vulnerability, and this relationship is moderated by household-level variables and local context. Independent and dependent variables and their methodologies are characterized in Table 1. The methodology for calculating the dependent variables has been derived from Hahn et al. (2009) and is outlined in Section 3.1.1 (Table 2). The theoretical rationale for the use of the independent variables has been derived from Cutter et al. (2003), Brooks et al. (2005), Adger (2006),

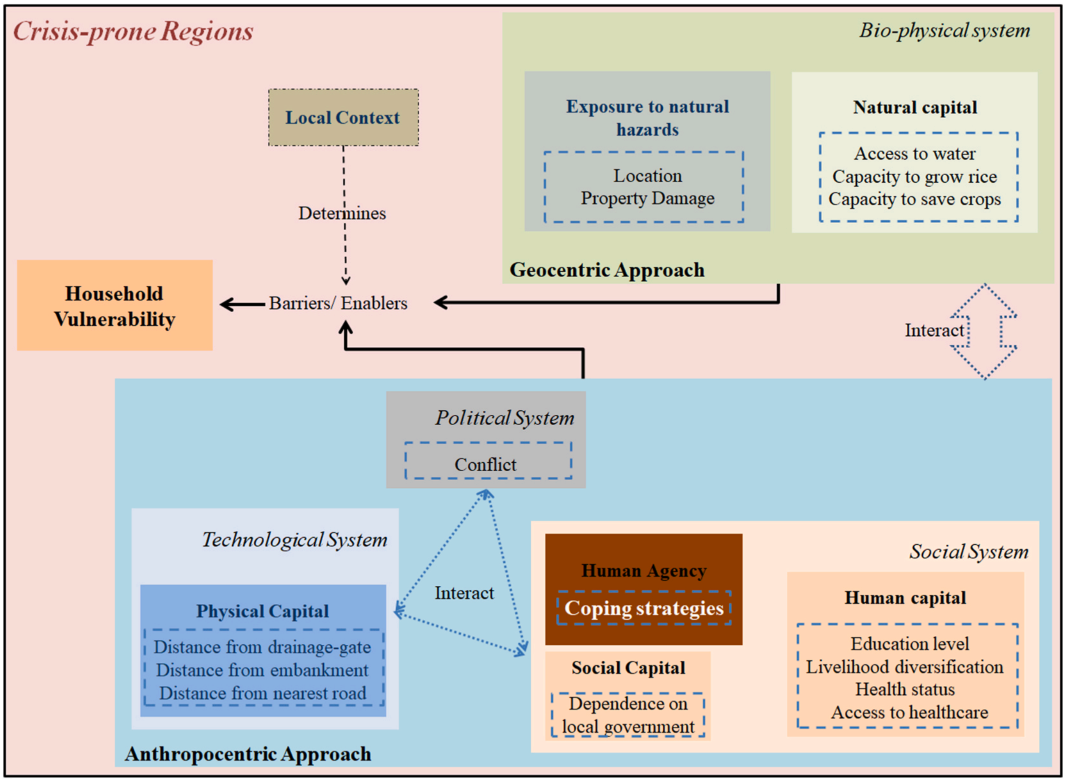

Fig. 2. Theoretical framework. Adopted from Metcalf et al. (2015). Includes only those variables (within dotted boxes) which are studied in this article (see Table 1).

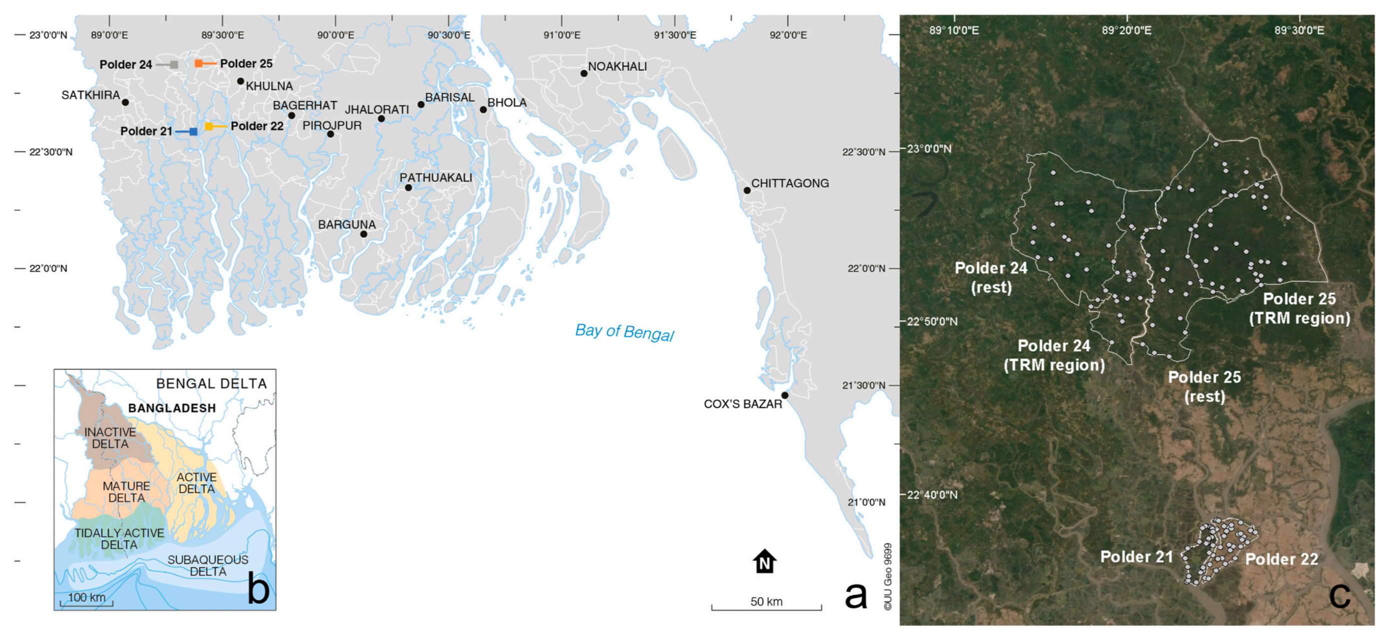

Fig. 3. Study site location: (a) coastal Bangladesh and polder study site locations, (b) the Bengal Delta regions, (c) polders and locations of household surveys (Google Maps, GED (2017), BWDB (2012)).

Füssel (2007), and (Notenbaert et al., 2013) as outlined in Section 2.

3.2. Study sites

The coastal belt of Bangladesh (Fig. 3a) has 139 polders (GED, 2017; BWDB 2012) spread across the deltaic region of three rivers: Ganges, Brahmaputra and Meghna. The Ganges delta is a mature delta and lies in the southwestern part of the coastal belt (Fig. 3b). Polders in this delta are characterized by different kinds of coping strategies: depoldering, anti-aquaculture movements, or neither. Polder-like structures and community-developed coping strategies such as depoldering and anti-aquaculture movements characterize coastal regions across the world. Therefore findings from this research may apply to other coastal regions. Nonethess, replication of similar studies across other crisis-prone regions is required for greater external validity.

This research considers two kinds of depoldering: a) TRM, and b) construction of illegal inlets. TRM has occurred in Polders 24 and 25 (Mutahara 2018), lying on either side of the Hari-Sibsa River (Fig. 3c). These polders can each be split into two regions: a) TRM region, and b) the rest of the polder, because the costs and benefits of TRM may not be distributed equally within a polder as TRM requires hydrological exchange with a waterbody situated next to an embankment, therefore within TRM polders households located near waterbodies involved in TRM may experience different physical environments compared to households in other parts of the polder. TRM took place in Polder 25 within Beel Dakatia 1990–1994 and in Polder 24 within Beel Bhayna, Beel Kedaria and Beel Khuksia in three different phases 1997–2012 (Seijger et al., 2019), meaning that Polder 24 has been exposed more extensively to TRM. Downstream of Polders 24 and 25 on the same river lie Polders 21 and 22, which do not conduct TRM. Communities in Polder 22 have not allowed brackish-water aquaculture in their lands. They have actively resisted the construction of illegal inlets, strengthened their drainage-gates and only allow fresh water into the polder (Paprocki and Cons 2014). In contrast, communities in Polder 21 have allowed aquaculture to take over (Nath et al., 2019), Such polders are characterized by numerous illegal inlets with uncontrolled flow of brackish water into the polder (Paprocki and Cons 2014).

Such differences in coping strategies along with the intensity of illegal cuts in polder embankments result in 6 sites within the 4 polders: a) TRM region in Polder 24; b) Rest of Polder 24; c) TRM region in Polder 25; d) Rest of Polder 25; e) Polder 21; and f) Polder 22 (Fig. 3c). Polder 22 is the only site which does not have any illegal cuts in the embankment, whereas the embankment of Polder 21 has many, with the intensity of illegal cuts at the other sites lying between that of Polders 21 and 22. Variations in the intensity of illegal cuts in embankments is associated with different livelihood vulnerability within polders (Nath et al., 2020), which could occur because such cuts are used by the aquaculture industry to increase intrusion of brackish water into polders (Paprocki and Cons 2014). The TRM regions of Polders 24 and 25 were also exposed daily (high tide) to brackish water during the TRM period, meaning that the 6 sites differ in exposure to salinity intrusion, and also in terms of strategies adopted by local communities to adapt to drainage congestion and waterlogging.

3.3. Measuring vulnerability

Food, water and health vulnerability for each household was determined using composite indices (Hahn et al., 2009) because they use information from multiple parameters and therefore capture ground realities more accurately (Alwang et al., 2001). Indicators used in this research were adapted from Hahn et al. (2009) and modified to fit the local context (Table 2). The methodology for aggregating these indicators into the three indices has also been adapted from Hahn et al. (2009). First, the indicators were standardized using the following formula:

$$IndicatorS_H = \frac{(S_H - S_{min})}{(S_{max} - S_{min})}$$

where S_H is the value of the indicator for household H, and S_{max} and S_{min} are the maximum and minimum values, respectively, for each indicator for all the households.

Next, the standardized indicators were aggregated into the corresponding indices using the following formula:

$$IndexI_H = \frac{\sum_{i=1}^{n} IndicatorS_{Hi}}{n}$$

where $IndexI_H$ is one of the three vulnerability indices {food (F), water (W) and health (H)} for household H; $IndicatorS_{Hi}$ represents the indicators, indexed by i, that make up each of the three vulnerability indices; n is the number of indicators in each vulnerability index.

Note: for each index, the higher the score the more vulnerable a household is.

3.4. Sample selection, data collection, processing and analysis

Primary data was collected December 2018 to March 2019. A survey instrument (questions listed in Table 2 and Supplementary Table 1) was used to collect data for the (non-geographical) independent and dependent variables. Semi-structured interviews were then used to develop a detailed understanding of how various factors may influence vulnerability in the region. Secondary research and site visits were used to characterize geographical and hydrological conditions such as illegal cuts in embankments, drainage gates, roads, and waterlogging, and to develop a nuanced understanding of local community dynamics. Surveys were administered at the household level and were geo-tagged. The households were sampled based on three parameters: a) geographical spread: coverage of all parts of the polders (Fig. 3c); b) purposive: coverage of a wide variety of livelihood groups ranging from services to landless laborers; and, c) convenience: respondent approachability and willingness to talk. Researchers traveled on motorbikes into the interiors as long as appropriate roads were available. Polder 21 could only be reached by boat. The last portion of travel was by foot. Some regions could not be accessed to ensure the personal safety of researchers, or because they were underwater or under cultivation.

Fig. 3c shows the locations of the 153 surveys: 31 in Polder 22, 25 in Polder 21, 20 in the Polder 24 TRM region, 16 in the rest of Polder 24, 31 in the Polder 25 TRM region, and, 30 in the rest of polder 25. Respondents were mainly male and spoke on behalf of the whole household. Female respondents were accessible only when no male respondent was available at home. 40 semi-structured interviews (20–60 min) were conducted with school teachers and principals (aged 30–55) in schools across the polders. These respondents were chosen because they are knowledgeable about local dynamics and have a better grasp of the ‘bigger picture’ as compared to less literate respondents. Female respondents were reluctant to be interviewed, especially in the presence of male colleagues. Surveys and semi-structured interviews were conducted till saturation was reached in terms of collecting a wide variety of responses. The highly urbanized areas on the northeastern and southeastern parts of Polder 25 were excluded from this research because pilots conducted in the area revealed that respondents in the urban regions had either not heard of TRM and polderization, or felt that TRM and polderization do not affect their lives. Socioeconomic, demographic and biophysical conditions also tend to be very different in urban and rural areas, and so including the urbanized parts of Polder 25 in the study would have biased the analysis.

All surveyed households were geo-tagged, and ArcGIS was used to associate each household location with relevant geographical variables. Variables were chosen for analysis due to their theoretical justifications, although some variables (such as altitude) were not included in the final statistical models because they did not demonstrate significant statistical relationships. Table 1 lists the statistically-significant variables under ‘Physical Capital’. The household position relative to the embankments determines both the coping strategy which the household is influenced by and the distance from the river, both of which could affect hydrological conditions and therefore household vulnerability. The distance of the household from the nearest drainage gate similarly may influence hydrological conditions. Finally, the distance of the household from the nearest road may be an indication of the desirability of the location and an indicator for other factors that affect vulnerability.

The polder embankments were delineated for the current research based on BWDB (2012), corrected using recent satellite imagery from Google Earth. The polder boundaries were adjusted where they were different at the time of the satellite imagery due to construction or abandonment of protected areas adjacent to the main river channel. In practice, for Polders 24 and 25 this methodology meant that only part of the embankments were corrected, as much of the northern boundary is administrative and not visible from satellite imagery. The corrections were predominantly executed to ensure that those households very close to polder boundaries were located in the appropriate polder and that the distance between these households and the embankments was accurate, which was not necessary in the northern parts of Polders 24 and 25. In addition to delineating the polder boundaries, the division between the TRM and non-TRM areas of Polders 24 and 25 were digitized. Key main-roads which act as hydrological barriers within each polder were used to divide Polders 24 and 25 into two parts each with differing hydrological management.

Food, water and health vulnerability was first calculated for each of the surveyed households and then these household-level scores were averaged for all households located in each of the 6 sites to give the food, water and health vulnerability per site (Fig. 4). Polder 21 has the highest values for all three vulnerabilities, and can therefore be conceptualized as a threshold of vulnerability for the region since the overall wellbeing of the region may be undermined if vulnerability levels of other polders reach this point (Adger, 2006). Accordingly, Polder 21 (Community coping strategies = 1) was treated as the base level[1] for the independent categorical variable 'community coping strategies' during regression analysis.

Regression analysis was then conducted by using household-level food, water and health vulnerability as dependent variables. This analysis was conducted at the household level (n = 153; see Table 3). Ordinary multiple regression using ordinary least squares OLS assumptions and robust standard errors was used for analysis of the following generalized regression model using Stata:

Vulnerability $_{\text{Food/Water/Health}} = \beta_1{}^*$ Community coping-strategies + $\beta_2{}^*$ Human Capital + $\beta_3{}^*$ Social Capital + $\beta_4{}^*$ Political Variables + $\beta_5{}^*$ Physical Capital + $\beta_6{}^*$ Natural Capital + $\beta_7{}^*$ Exposure to natural disaster-related Variables + constant.

Since different groups of independent variables affect the three dependent variables under different conditions, 9 sector-specific models produced significant results: 1 for food vulnerability, 6 for water vulnerability and 2 for health vulnerability. All models were tested for model specification error, multicolinearity, homoscedasticity of residuals and auto-correlation, and did not demonstrate such features.

4. Results

Aggregated vulnerabilities for each study site are shown in Fig. 4. Table 1 lists the summary statistics for each variable. Table 3 summarizes the findings of the regression analysis. Regression models are detailed in Table 2 to 11 of the Supplementary File.

The research question (how do community-developed coping strategies affect vulnerability in crisis-prone coastal regions?) was chosen because existing research has not adequately explored the relationship between coping strategies and vulnerability in crisis-prone coastal regions at sub-national levels. Theoretical literature is ambiguous on how various geocentric and anthropocentric factors affect vulnerability in the presence of community-developed coping strategies. According to the framework conceptualized in section 2, a wide range of anthropocentric (including coping strategies) and geocentric variables affect vulnerability. Based on this framework, this articles draws upon vulnerability theory and hypothesizes that there may be a causal association between coping strategies and vulnerability.

Regression analysis reveals that the hypothesis is not rejected. Most levels of the variable 'community coping strategies' have a significant effect on the three types of vulnerability. TRM and community-led movements against aquaculture may therefore have a significant effect on vulnerability after controlling for other factors. This finding is consistent with results from studies on coping and vulnerability in other country settings (Srinivasan et al., 2013; Bacon et al., 2017).

However, while earlier studies focused on only one type of vulnerability e.g. food or water, we tested the effect of the same set of coping strategies on three different kinds of vulnerability (food, water and health) and found that the influence of such strategies is likely to be nuanced: a) food vulnerability is most affected in Polder 22; b) water vulnerability is most affected in TRM region of Polder 24; c) health vulnerability is most affected in TRM region of Polder 25; and, d) there is no statistically significant relationship between health vulnerability and TRM region of Polder 24 (Fig. 5).

Therefore, the significance of this study is that it demonstrates how the association between vulnerability and coping strategies is not straightforward. The relationship between these two variables depends on a) the type of vulnerability (food/water/health) being considered, and b) the specifics of the coping strategy (TRM vs. anti-aquaculture movements). Different coping strategies are associated with different kinds of vulnerability and these relationships depend on other anthropocentric and geocentric variables.

Other geographical, socioeconomic and political factors also appear to have a significant effect on household vulnerability (Table 3). A shorter distance from drainage gate, embankment and nearest road appears to be associated with increased vulnerability (Water Index Models 1–6 and Health Index Model 2 in Table 3), potentially because these regions are more impacted by extreme weather events. Households located in such regions often belong to marginalized communities who have constructed their houses (sometimes illegally) on Khas land[2] (Paprocki and Cons, 2014; Das et al., 2012). In addition, such land is often characterized by conflict over land and water access (Health Index Models 1, 2 in Table 3). As these marginalized households often do not own land and so cannot construct tube wells, they depend on community-level facilities (Staddon et al., 2020) which are venues of additional conflict. Landlessness also forces such households to work as laborers in shrimp farms, brick factories, or other strenuous, low-paying jobs, as they are not able to grow their own food, so they may have limited options to diversify their livelihoods (Adger, 2006) and must procure food from markets which reduces the income available for healthcare and water (Paprocki and Cons, 2014). Income remaining after meeting basic needs such as food, water and health may not be enough to access quality education which results in low literacy rates amongst such households (Health Index Model 2 in Table 3). Therefore, marginalized households in the Ganges delta are often dependent on aid from local government (Adger, 2006); however, this dependence of marginalized communities on government aid enshrines systemic inequalities (Butler and Adamowski, 2015).

5. Discussion

5.1. Food vulnerability and coping strategies

The community-led movement against aquaculture in Polder 22 was a battle for food sovereignty – local communities wanted to ensure food security for their households. Having witnessed that the expansion of aquaculture was taking place at the expense of agricultural land in nearby polders, community leaders of Polder 22 may have felt that holding onto their traditional agricultural way of life would be more sustainable (Paprocki and Cons, 2014; Morshed et al., 2020). The movement may therefore have resulted in an increase in the average diversity of food production in Polder 22 and lower food vulnerability as

[1] When a variable is treated as categorical during regression, all other levels of the variables are compared against the base-level to determine how significantly different they are from the base level.

[2] Land with disputed ownership, land owned by migrants who have left the country or land possessed by public agencies etc. (Das et al., 2012).

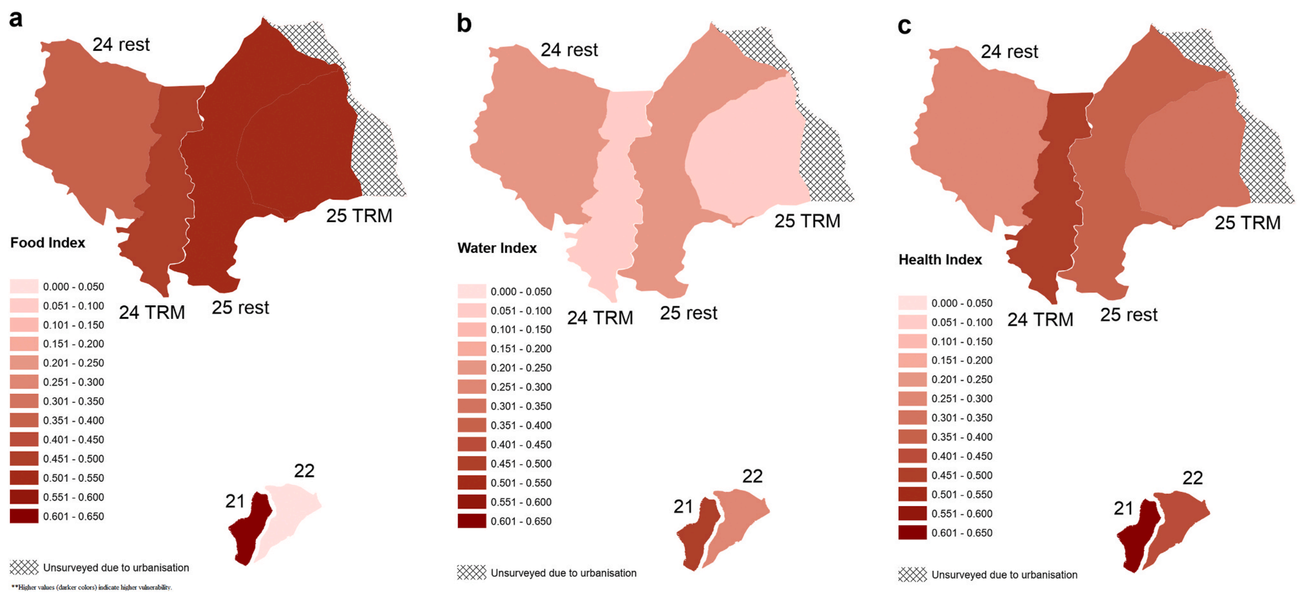

Fig. 4. Site-level vulnerability: (a) food vulnerability, (b) water vulnerability, (c) health vulnerability. **Higher values (darker colors) indicate higher vulnerability. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Theoretically derived variables analyzed in this research. See Supplementary Table 1 for definitions.

Type of Variable	*Variable Name*	Mean/Median	Standard Deviation/Interquartile Range
Dependent Variables			
Vulnerability	Food vulnerability	0.50	0.28
	Water vulnerability	0.24	0.24
	Health vulnerability	0.42	0.27
Independent Variables			
Human Agency	Community coping strategies	4.00	3.00
Human Capital	Education level	0.50	0.38
	Livelihood diversification index	0.47	0.32
	Health status	0.35	0.48
	Access to healthcare	0.20	0.19
Social capital	Dependence on local government	0.45	0.50
Political	Conflict	0.25	0.44
Physical Capital	Distance from drainage-gate	0.28	0.25
	Distance from embankment	0.26	0.27
	Distance from nearest road	0.11	0.17
Natural Capital	Access to water	0.05	0.10
	Grow rice	0.37	0.45
	Save crops	0.52	0.50
Exposure to natural hazards	Impact	0.51	0.26
	Property damage	0.48	0.50

compared to the other sites (Fig. 5, Food Index-Model 1 from Table 3). Production of new crops such as watermelon has increased in this polder, whereas the production of the same crops has declined in upstream regions e.g. Polder 24 TRM region. This may be because seepage of salinity from shrimp farms into nearby agricultural lands makes crop production less profitable, which reduces the market value of such agricultural land so large landowners can purchase these lands at lower prices resulting in further expansion of aquaculture (Rakib et al., 2019a, b).

5.2. Water vulnerability and coping strategies

The breaching of embankments associated with TRM began as a reaction against increased waterlogging and drainage congestion, so it is logical that TRM practices appear to have a significant effect on water vulnerability (Fig. 5, Water Index-Model 1 from Table 3). Salinity intrusion and therefore water vulnerability is potentially worse in Polders 21 and 22 as they lie downstream of Polders 24 and 25. However, the community-led movement against aquaculture in Polder 22 has ensured that local communities allow only fresh water into their lands: drainage-gates are well-maintained and cuts in the embankments are not allowed, which has enabled local communities to address water vulnerability better than in Polder 21.

Beel Dakatia, the TRM region in Polder 25, is close to Khulna City, the nearest divisional headquarters. Similarly, the TRM region of Polder 24 is well-connected to Khulna and Jassore, a district headquarters. In contrast, the connectivity of Polder 22 to Khulna, Jassore or Paikgacha (the nearest urban center) is patchy and Polder 21 can only be reached by boat. Beel Dakatia is therefore urbanizing rapidly in comparison to the other sites. Proximity to administrative offices, located at district and divisional headquarters, can result in better access to tube wells and piped water leading to decreased water vulnerability. However, proximity to urban centers has resulted in the conversion of water-bodies and agricultural land for urban uses (Xu et al., 2020), and in the process

Table 2
Indicators of food, water and health vulnerability indices (adapted from Hahn et al. (2009).

Name of Dependent Variable	Indicator	Determining the Indicator Values	Similar to indicator proposed by Hahn et al. (2009)?
Food Vulnerability Index	Dependence on household farm for food	Does the household get its food primarily from its personal farm? Ternary variable: personal farm = 0; partly personal farm and partly market = 0.5; market = 1.	Yes
	Struggle to find food	Average number of months in a year that the household struggles to obtain food. Continuous variable (0–12).	Yes
	Food production index	How diverse is the range of food produced by the household for sale? Calculated using the following formula: 1/(1+ types of food produced by the household for sale). Continuous variable (0–1).	Yes, but adapted to include a larger diversity of food items to reflect ground realities
	Saving crops	Does the household save crops for later consumption? Binary variable: Yes = 0; No = 1.	Yes
	Saving seeds	Does the household save seeds from crops for use in later years? Ternary variable: Yes, always = 0; Yes, sometimes = 0.5; No = 1.	Yes
Water Vulnerability Index	Water conflicts	Does the household lie in a region reporting water conflict? Binary variable: No = 0; Yes = 1.	Yes
	Source of water	Weighted average of the different sources of water used by the household, with different sources of water assigned different weights. Continuous variable (0–1).	No. Replacement indicator for 'Percent of households that utilize a natural water source' because purchased water and tube wells are important sources of water in the study sites. The choice of water source affects vulnerability.
	Average time to water source	Average time it takes the households to travel to their primary water source (minutes). Continuous variable.	Yes
	Consistent water supply	Does the household report that water is available at their primary water source every day? Binary variable: Available every day = 0; Not available every day = 1.	Yes
	Water stored	The inverse of (the average number of liters of water stored by each household + 1). Continuous variable.	Yes
Health Vulnerability Index	Average time to health facility	Average time it takes the household to reach the nearest health facility (minutes). Continuous variable.	Yes
	Chronic illness	Does the household report at least 1 family member with chronic illness? Chronic illness was defined subjectively by respondent. Binary variable: No = 0; Yes = 1.	Yes
	Missed work or school due to illness	Does the household report at least 1 family member who missed school or work due to illness in the last 2 weeks? Binary variable: No = 0; Yes = 1.	Yes
	Exposure to mosquito-borne and/or waterborne disease	Does the household report exposure to mosquito-borne and/or waterborne disease? Binary variable: No = 0; Yes = 1.	No. Replacement indicator for 'Average Malaria Exposure*Prevention Index ' because almost all households had access to prevention via mosquito nets.

households may have lost their connection to land and therefore may have started procuring food and seeds from local markets, leading to an increase in food vulnerability. In addition, TRM took place in Polder 25 much earlier than in Polder 24. The effectiveness of TRM tends to decrease over time, as waterlogging and drainage congestion increase. These factors could explain why the effect of TRM on food and water vulnerability in Polder 25 is lower than the effect in Polder 24 (Fig. 5, Food Index-Model 1 from Table 3, and Water Index-Model 1 from Table 3).

5.3. *Health vulnerability and coping strategies*

Urbanization could also explain why the relationship between low health vulnerability and the TRM region of Polder 25 is so strong (Fig. 5, Health Index-Model 1 from Table 3). Proximity to Khulna ensures better access to healthcare compared to other sites. The ongoing urbanization of Beel Dakatia may also have reduced exposure to mosquito- or waterborne diseases. In contrast, waterlogging in the TRM region of Polder 24 has increased in recent years which may have increased exposure to mosquito- or waterborne diseases, which could explain why the health vulnerability of communities in the TRM region of Polder 24 are not that different from those in Polder 21 (Rakib et al., 2019). In polders such as 24 or 25 where a part of the polder is characterized by a predominant community coping strategy, additional research must consider whether the use of a strategy (e.g. TRM) in one region affects the rest of the polder, or whether other factors (such as urbanization) interact with coping strategies to affect vulnerability differently in the rest of the polder.

6. Conclusion

Exposure to extreme weather events and other crises is the norm along the coastline of the Ganges Delta. Extreme weather events have repeatedly affected TRM operations. In 2009, TRM operations in Beel Khuksia (polder 24) were thrown into disarray when Cyclone Aila struck (Fig. 1). IMD, 2020, history repeated itself: in the midst of the Covid-19 pandemic, Cyclone Amphan devastated the southwestern coast of Bangladesh. TRM operations were again hampered, this time in Beel Pakhimara (polder 6–8).

Communities may have become accustomed to living under these conditions, and so may not consider crisis situations to carry additional risk (Alwang et al., 2001). Technological interventions such as polderization reduce vulnerability but also create or increase problems such as waterlogging, salinity intrusion and aquaculture expansion at the expense of agriculture. Local communities try to mitigate problems by engaging strategies such as Tidal River Management and resisting aquaculture. As this research demonstrates, such strategies may have been effective in reducing vulnerability but with mixed results: reduction of food vulnerability could be related to community movements against aquaculture, whereas reduction in water vulnerability may be related to TRM. On the other hand, reduction in health vulnerability may instead be related to urbanization and infrastructure development.

Such findings have relevance for non-governmental organizations, public agencies and multilateral institutions working with marginalized

Table 3
Summary of findings - regression analysis.

Dependent variables - >		Food Index	Water Index	Water Index	Water Index	Water Index	Water Index	Water Index	Health Index	Health Index
Independent variables		Model 1	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 1	Model 2
Type of variable	Variable name									
Human Agency	Community coping strategies *and its 6 levels* *# Base level value = 1: Polder 21*									
	2: TRM region in Polder 24	−0.1764 (0.016)	−0.3645 (0.000)						−0.1145 (0.141)	
	3: Rest of polder 24	−0.2929 (0.000)	−0.2141 (0.002)						−0.3370 (0.000)	
	4: TRM region in Polder 25	−0.1447 (0.043)	−0.3290 (0.000)						−0.2648 (0.000)	
	5: Rest of polder 25	−0.1357 (0.075)	−0.2014 (0.006)						−0.2780 (0.000)	
	6: Polder 22	−0.2833 (0.000)	−0.1578 (0.015)						−0.1763 (0.016)	
Physical Capital	Distance from drainage gate						−0.2193 (0.003)	−0.2042 (0.006)		−0.1603 (0.043)
	Distance from embankment			−0.1945 (0.002)	−0.1919 (0.002)	−0.2266 (0.000)				
	Distance from nearest road						−0.1648 (0.030)			
Dependent variables - >		Food Index	Water Index	Water Index	Water Index	Water Index	Water Index	Water Index	Health Index	Health Index
Independent Variables		Model 1	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 1	Model 2
Human Capital	Education level	0.1395 (0.007)								0.0524 (0.364)
	Livelihood diversification index	0.2227 (0.001)								
	Health status		0.0762 (0.048)	0.0851 (0.027)		0.0867 (0.033)	0.1100 (0.006)	0.0987 (0.018)		
	Access to healthcare			0.2964 (0.005)	0.2920 (0.006)					
Natural Capital	Access to water	0.2933 (0.011)							0.3987 (0.007)	
	Save crops									0.0964 (0.028)
Social capital	Dependence on local government				−0.0787 (0.033)	−0.0827 (0.028)		−0.0887 (0.017)		
Political	Conflict									0.1265 (0.014)
Exposure to natural hazards	Property damage	0.0782 (0.066)								
Dependent variables - >		Food Index	Water Index	Water Index	Water Index	Water Index	Water Index	Water Index	Health Index	Health Index
Independent variables		Model 1	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 1	Model 2
Interaction terms	Grow rice * Distance from embankment		−0.1796 (0.003)							
	Conflict * Impact								0.2089 (0.008)	
_constant		0.4394 (0.000)	0.4322 (0.000)	0.1961 (0.000)	0.2619 (0.000)	0.3010 (0.000)	0.2754 (0.000)	0.2970 (0.000)	0.5705 (0.000)	0.3586 (0.000)
n		153	153	153	153	153	153	153	153	153
r^2		0.2538	0.3487	0.1867	0.1842	0.1626	0.1272	0.1465	0.2071	0.1077
AIC		22.1142	−58.8030	−32.8124	−32.3350	−28.3475	−22.0046	−25.4239	15.5045	27.5668
BIC		52.4186	−34.5595	−20.6906	−20.2132	−16.2257	−9.8829	−13.3022	39.7480	42.7190

p-values in parentheses

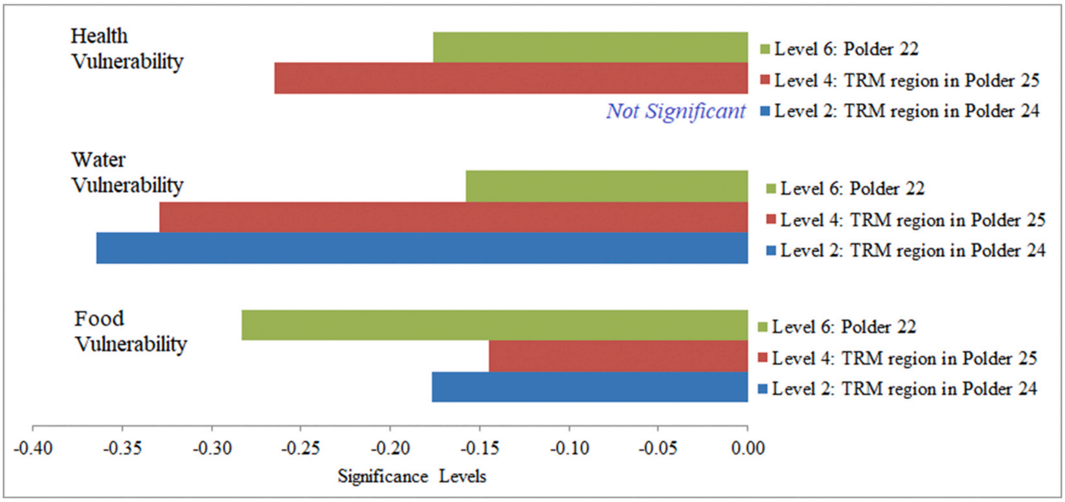

Fig. 5. Comparative analysis of the significance-levels of 'community coping-strategies'. See Models 1 of Food Index, Water Index and Health Index in Table 3.

communities in crisis-prone regions. This is because crisis situations enshrine systemic inequalities resulting in a vicious cycle of increasing vulnerability amongst those who are the most helpless (HLPE, 2020; Staddon et al., 2020), as access to basic needs such as food, water and health are severely constrained under such circumstances (Rakib et al., 2019a,b). Marginalized households, who are characterized by high food, water and health vulnerability even in non-crisis periods, often suffer most during crises regardless of community coping strategies (Butler and Adamowski, 2015; Adger, 2006).

The United Nations has declared the decade starting 2020 as the Decade of Action for Sustainable Development. One of the purposes of sustainable development is to meet the basic needs of marginalized communities in less developed countries such as Bangladesh where absolute poverty is concentrated (Streeten and Burki, 1978). However, such communities are often cut off from positions of power and are inadequately represented in local government. Vulnerability to basic needs such as food, water and health is therefore a governance challenge primarily because local government in such countries often caters to the interests of the local elite (Butler and Adamowski, 2015), with governance interventions designed to reduce the vulnerability of those who already have access to power (Adger, 2006). In contrast, marginalized communities depend on temporary doles from local administration to cope with their vulnerability, which only provides short term relief and does not increase capabilities to cope with crises.

Policy-makers and practitioners looking at improving the efficacy of locally-conceptualized, community-level, coping strategies such as Tidal River Management therefore need to strengthen the governance capabilities of Union Parishads, the lowest rung of local government in Bangladesh, so that they are equipped to satisfy the basic needs of marginalized communities during crises. This is because, irrespective of the long-term benefits of TRM, marginalized communities face extreme hardships during TRM implementation: agricultural lands and homesteads get inundated with brackish water, livelihoods are disrupted and out-migration increases (Mutahara, 2018). Vulnerability increases on the short term (Nath et al., 2019) and local communities start opposing the implementation of TRM (Mutahara, 2018).

To test of the robustness of our findings, future research needs to purposefully sample households in those areas which we could not access. For instance, to interview households in the center of Beel Dakatia considering the absence of adequate maps, researchers would need to find a local boatman familiar with the territory and seek the support of local policemen. In addition, greater representation should be sought from female-headed households. Identifying such households requires relationships of trust with gatekeepers from local NGOs.

Additional research should consider if extreme weather and other crises affect households differently in societies characterized by inequity and income disparity. This research found only limited support for the theory that property damage due to natural hazards bears a significant relationship with vulnerability, potentially because local households perceive extreme events as less risky than they actually are (Alwang et al., 2001). However, there appears to be some evidence which suggests that changes in stakeholder mental models are associated with changes in governance outcomes (Nath and Laerhoven, 2020). Questions therefore remain about whether changes in stakeholder perceptions of the effect of extreme events are also associated with change in household vulnerability.

Future research should also analyze the drivers of food and health vulnerability in polders with multiple community-level adaptation strategies, as this research has shown that TRM is not the dominant driver of differences in these vulnerabilities within the larger polders but factors such as land use (e.g. aquaculture and urbanization) may be important. Urban areas are characterized by greater diversity in livelihoods and increasing disconnect from land. Future research should therefore use a maximum variation sampling strategy for capturing livelihood variation in the rural-urban continuum to understand how land-use change influences the relationship between vulnerability and coping. The ease of conducting such research would increase if national policy-makers allocate more funds for collecting and disseminating more stratified, granular socio-economic data so that more systematic random sampling protocols can be employed for data collection. Such research can be improved by increased access to high-resolution spatial data. Much of the geographical data considered in this research, while having a strong theoretical basis for inclusion, was not available at high enough resolution to identify meaningful relationships at the household scale. It is therefore possible that significant relationships were not identified due to inadequate data resolution rather than the absence of such relationships in reality.

This research has tried to "better access the perspectives of the most vulnerable" who often move to coastal regions in search of livelihood opportunities (Miller et al., 2010). Polder-like structures, such as the ones along the coast of Bangladesh, have been constructed across the global coastline in countries as varied as Egypt, Venezuela, Denmark and the USA (Inniss and Simcock, 2016). Coastal polders around the world host marginalized communities and must cope with crises. Therefore, lessons drawn from this research may be used to analyze the interconnections between vulnerability and coping strategies adopted by marginalized communities across the world. However, the association between vulnerability and coping strategies is likely to be dependent on local context.

Author contributions

Conceptualization & methodology: Sanchayan Nath, Frances E. Dunn, Frank van Laerhoven and Peter Driessen, data collection, investigation & analysis: Sanchayan Nath and Frances E. Dunn, writing: Sanchayan Nath, Frances E. Dunn, Frank van Laerhoven, and Peter Driessen, project administration: Sanchayan Nath and Frank van Laerhoven, funding acquisition: Frank van Laerhoven.

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.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jenvman.2021.112072.

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