Journal of Environmental Management 240 (2019) 238–248

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Severe salinity contamination in drinking water and associated human health hazards increase migration risk in the southwestern coastal part of Bangladesh

M.A. Rakib[a,b,*], Jun Sasaki[c], Hirotaka Matsuda[d], Mayumi Fukunaga[c]

[a] Graduate Program in Sustainability Science - Global Leadership Initiative, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan

[b] Department of Disaster Management, Begum Rokeya University, Rangpur, 5400, Bangladesh

[c] Department of Socio-Cultural Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan

[d] Department of Agricultural Innovation for Sustainability, Faculty of Agriculture, Tokyo University of Agriculture, 1737 Funako, Atsugi-shi, Kanagawa, 243-0034, Japan

ARTICLE INFO

Keywords:
Socioeconomic vulnerability
Groundwater salinization
Potable water shortage
Health diseases
Human migration

ABSTRACT

Bangladesh is a deltaic country and is highly vulnerable to climate change and sea level rise. This study explores population migration risk in relation to communal crisis due to socioeconomic vulnerability, drinking water scarcity, and health threats caused by salinity hazards. For this, we conducted a household questionnaire survey as well as, focus group discussions, key informant interviews, and field observations. To identify the drinking water salinity and migration risk, our theoretical process hypothesizes a new composite indexing approach. Salinity hazards and potable water crises have increased the spread of human diseases and treatment costs, while socioeconomic crisis and poverty are inseparable risks of coastal communities because of frequent cyclone hits. Recently, salinity hazards have added a new dimension to health insecurities and household financial instability. Results showed a high migration risk in the unions of Gabura, Munshigonj, Atulia, Burigoaliny, and Padmapukur (from highest risk to lowest), as these areas exhibit worsening situations with respect to drinking water scarcity, salinity hazards, and health hazards, and their adaptive capacities are significantly low. Furthermore, socioeconomic vulnerabilities to cyclone hits, salinity hazards, and severe drinking water scarcity may soon contribute to increased population migration in response to climate change, sea level rise, and the associated impacts of these trends. To tackle the future mass population migration problem, urgent action is required to improve socioeconomic conditions, and provide alternative sources of potable water and health care facilities. Hard and soft measures must be ensured to reconstruct vulnerable areas impacted by riverbank erosion, flooding, and waterlogging. Additionally, action should be taken to enhance local awareness of coastal disasters, their associated hazardous consequences, and possible mitigation and adaptation measures.

1. Introduction

Climate change and its advancing threats are a matter of great concern throughout the world at present. The negative consequences of environmental change and human migration, such as climate change and large-scale natural disasters, have gained attention (Gray and Mueller, 2012). Because of sudden-onset climate-related hazards, more than 24 million people were displaced in 2016 (UNDP, 2017). Global environmental change may trigger the migration of anywhere between 50 million and approximately 700 million people by 2050 (Warner, 2010). Climate change and its associated hazards might be the principal reason for future migration. A rise in greenhouse gas emissions increasingly enhances the seriousness of these impacts. The rate of the global mean sea level rise was approximately 1.7 mm/year between 1901 and 2010 and increased to approximately 3.2 mm/year between 1993 and 2010 (Church et al., 2013). Nearly 600 million people who currently live in low-lying coastal zones worldwide (Jevrejeva et al., 2018) could potentially be affected by an increase in salinity. Substantial risks due to sea level rise are projected, particularly in Asian mega-deltas and small island communities (IPCC, 2007). In addition,

* Corresponding author. Graduate Program in Sustainability Science - Global Leadership Initiative, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan.
E-mail addresses: rakibmamun_ju@yahoo.com, md.rakib@s.k.u-tokyo.ac.jp (M.A. Rakib).

https://doi.org/10.1016/j.jenvman.2019.03.101
Received 24 November 2018; Received in revised form 24 February 2019; Accepted 20 March 2019

increased salinization associated with sea level rise is a water resource constraint for groundwater supplies (IPCC, 2007). Fresh water availability is projected to decrease in South, Central, East, and South-East Asia, particularly in large river basins by the 2050s (IPCC, 2007).

In Bangladesh, salinity intrusion is expected to increase because of a shortage of fresh water discharge from upstream and is projected to worsen with climate change and sea level rise (Nicholls et al., 2007). It has already increased by approximately 26% over the last 35 years (Naeen, 2018). It is expected that the total amount of land exposed to high cyclonic inundation levels will increase by over half due to direct impacts of climate change and sea level rise (World Bank Report, 2016). Projections of waterlogging owing to climate change and sea level rise indicate a worsening situation for the growing population in the coastal belt of Bangladesh (Dasgupta et al., 2014). Gradual changes in climate variables and environmental degradation can cause water quality deterioration in coastal areas. In addition, shrimp cultivation can increase salinity in inland water sources and groundwater because of the long-term retention of saltwater in shrimp cultivation ponds (Ali, 2006). Approximately 35 million people of the coastal belt of Bangladesh are considered vulnerable because of the salinization of fresh water (Talukder et al., 2016).

Coastal populations are highly exposed to saline-contaminated water through drinking, cooking, and bathing (Rakib et al., 2019). It increases potential health impacts, including skin diseases, miscarriage, hypertension, diarrhea, and acute respiratory infections (Caritas Development Institute, 2000; Ministry of Environment and Forests, 2006). Severe drinking water crises lead to high blood pressure, heart disease, and kidney disease among coastal communities (Raju, 2017). These types of diseases are more commonly found in the coastal community, which is mostly exposed to water salinity and a serious drinking water crisis, as compared with other parts of the country. The long-term coastal impacts are gradually shrinking livelihoods and the economy while a large number of people face health crises that primarily originate from unwanted changes in the environment and social components. Natural hazards may play a vital role in disrupting social interaction and encouraging human mobility (Warner, 2010). Natural hazards and adverse long-term consequences differ from place to place (Bathrellos et al., 2017; Rakib et al., 2017). In the coastal area of Bangladesh, approximately 12 million people live below the poverty line (World Bank Report, 2016). Scarcity of drinking water and river salinity will increase health risks (World Bank Report, 2016) that can lead to large-scale migration across the border or within the country (Abedin et al., 2014). Environmental factors are increasingly recognized as possible drivers of internal and cross-border human migration (Laczko and Aghazarm, 2009). People tend to displace and migrate as a part of a spectrum of possible responses to environmental change (Warner and Laczko, 2008). Many newspapers and magazines have reported on recent coastal issues such as sea level rise, existing salinity hazards, a severe potable water crisis, and diseases (Naeen, 2018; Cornwall, 2018; Rashid, 2018). However, there has not been enough research that clarifies the impacts of these issues. Regarding climate change and sea level rise, salinity is apparently one of the more serious threats along the coastal region of Bangladesh. Increase in salinity deteriorates fresh surface and sub-surface water resources. High salinity degrades the fresh water ecosystem and hampers the local livelihood strategies and household incomes. Many coastal people do not have access to fresh water for drinking and household purposes such as bathing, cooking, and washing. Additionally, severe salinity threats in drinking water and related health problems could jeopardize social components in the southwestern part of Bangladesh.

Until now, there has been no significant research on salinity-related diseases and additional health care costs, how salinity triggers an increased population migration risk, with consideration given to existing disaster-affected coastal household economies. This research introduces a new methodological approach to estimating migration risk through the theorization of recent salinity hazards and existing coastal threats in Bangladesh. A migration risk estimation indexing technique has been proposed to evaluate the migration risk of populations in coastal communities, by considering sensitivity, exposures, drinking water scarcity, health crises, and additional health costs, along with adaptive capacity, which can act as a significant coping component in any adverse condition. Not only have coastal hazards like cyclonic storm surges and inundation forced local people to migrate, but associated hazards like salinity intrusion and drinking water scarcity have emerged as new significant threats to public health in the last few years. Along with disaster-affected household economies, human health crises might be the cause of increased human migration in the future due to climate change and sea level rise impacts. Several indices related to social factors, household economy, environmental aspects, drinking water access, and public health impacts have been used to estimate migration risk. Thus, salinity, water, and social-based indicators may have the potential to assess social problems and the possible consequences among communities facing recent severe drinking water scarcities. The aim of this research is to estimate the migration risk in the coastal communities of Bangladesh. Three research questions were formulated to assess migration risk: 1) What is the present socioeconomic status of the coastal communities? 2) How does drinking water salinity and scarcity increase water-related health threats? 3) How do health care costs, socioeconomic vulnerabilities, and health hazards influence the coastal population migration risk? In addition, a question was raised about the possible measures: What would be the best possible measures to tackle future migration problems? The research findings can contribute significantly to the understanding of societal and development issues present in communities facing adverse climatic conditions, with considerations given to diverse limiting factors.

2. Research methods

2.1. Study area

This study was carried out in the Shyamnagar sub-district (22.3306°N 89.1028°E) in the Satkhira district of Bangladesh as shown in Fig. 1. This sub-district is divided into twelve unions.[1] For our research, we selected the five unions of Atulia, Burigoaliny, Gabura, Munshigonj, and Padmapukur. Those unions are located in the south-western part of the country, adjacent to a mangrove forest and the Bay of Bengal. Gabura in particular is isolated from the mainland and is highly vulnerable to cyclonic storm surges and flooding hazards. Most of the unions are adjacent to tidal rivers while Munshigonj is located at the edge of the mainland and is relatively more vulnerable to cyclonic storm surges and waterlogging compared to the remaining three unions. In terms of geographical locations, these areas are extremely vulnerable to climate change, coastal disasters, and sea level rise (Ministry of Environment and Forests, 2016). The average elevation of the exposed coastal area is about 1.5 m above sea level (MASL) (Chowdhury, 2009). Several natural disasters have severely damaged the coastal population, leading to large death tolls and property losses. Under global climate change, people are now going to face severe salinity hazards due to saltwater intrusion and cyclonic storm surges. High salinity hazards lead to the destruction of livelihood sectors and drinking water sources. A purposive sampling technique was applied to evaluate the coastal environmental crisis and its consequences on the coastal community.

[1] Union is the smallest administrative and local government units in Bangladesh, which is consist of nine wards. Each of the village is designated as a ward (Khan, 2018).

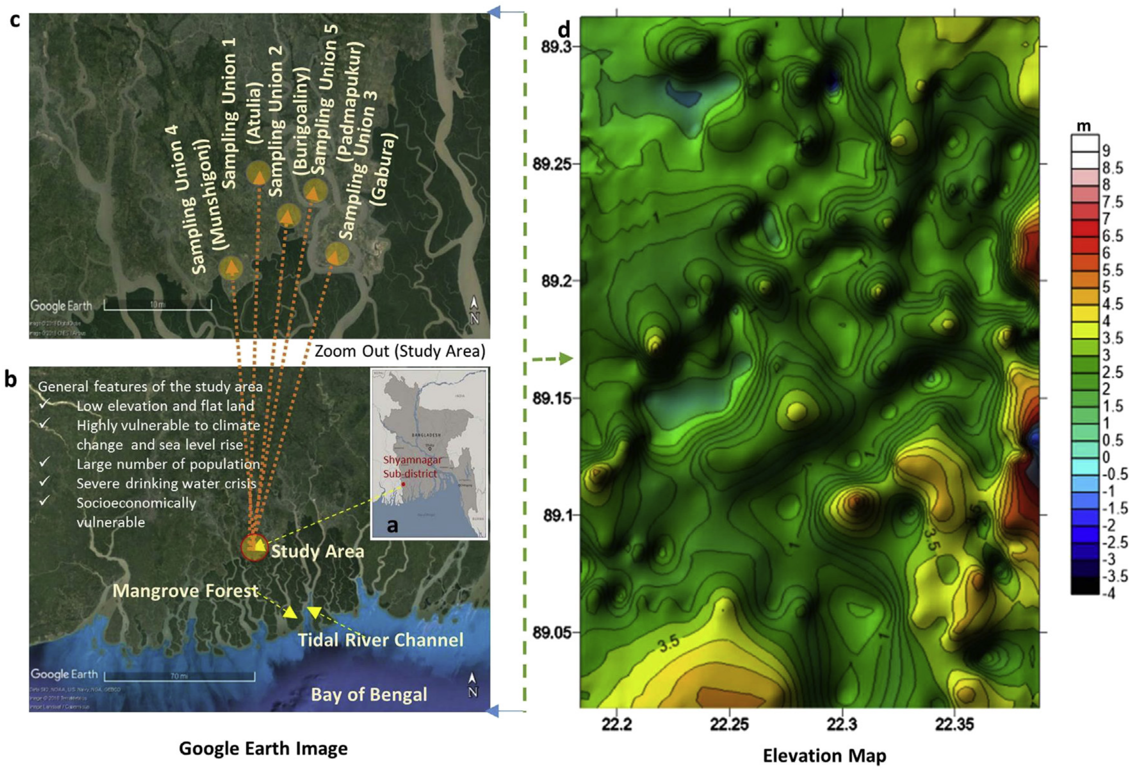


Fig. 1. Location map of the study area.

2.2. Data collection

Both qualitative and quantitative techniques were applied, including a household questionnaire survey, focus group discussions, key informant interviews, and field observation. A semi-structured household questionnaire survey was administered in the five selected unions. Before designing a questionnaire sheet, discussions were held with the local peoples and field observations were conducted. Each of the questions followed a chronological linkage to understand the influence of different variables related to coastal hazards and social vulnerabilities. The questionnaire sheet was divided into ten sections: 1) demographic data, 2) social factors, 3) economic data, 4) household physical assets, 5) natural disaster vulnerability, 6) salinity context and potable water status, 7) inconsistent water access, 8) water-related health diseases, 9) health care facilities, and 10) health expenditure. Each of the sections contained significant and interrelated information to explore the population migration risk in terms of socioeconomic issues, coastal disasters, salinity hazards, drinking water scarcity, and diseases at the community level. A total of 300 household questionnaires were collected in August 2017 and September 2017. Approximately one hour was allocated to complete each questionnaire. In addition, a majority of household respondents were middle-aged, ranging from 41 to above 55 years.

Focus group discussions were performed in various communities. Particularly, seven focus group discussion sessions were arranged in each of the five unions. People from all walks of life were invited to share their views on overall regional coastal hazards, socioeconomic vulnerabilities, potable water crises, salinity intrusion, present potable water status, diseases, health care facilities, and household health care costs. Most of them shared their experiences and views related to their daily life, personal observations, and insights. After the discussion, we identified the significant discussion points and thematic findings. On the other hand, key informant interviews were carried out among local political leaders, local government authorities, non-government organization officials, teachers, professors, and doctors regarding coastal disaster issues, salinity hazards, drinking water crises, health impacts, trends, and prospective measures. Local government authorities are involved in disaster risk reduction, and local political leaders are engaged in local decision-making processes to reduce risk during coastal disasters. School teachers can play a vital role in rearranging or reshaping the society as the potential stakeholders in the community. Members of non-government organizations are engaged in local community development activities. Doctors play an important role in exploring public health issues related to high-saline water consumption and regional potable water shortages. As a supporting technique, field observation approved significant in justifying social perceptions with proper evidence. Much information was recorded in a written format in notebooks using this technique. Local photos and videos were collected using a camera, including footage of environmentally critical areas, water shortage scenarios, and topographical features. In addition, the statistical software, including SPSS (IBM 21) and GraphPad Prism 7 (Windows version), was used for coding and analysis.

2.3. Estimation of human migration risk

2.3.1. Hypothesized theory

For decades, disasters associated with socioeconomic vulnerabilities have been considered common in the coastal belt of Bangladesh. According to our hypothesized theory (Fig. 2) salinity hazards and drinking water shortages lead to human health diseases that are primarily caused by salinity contamination. As an additional household cost, health expenditures exert pressure on disaster-affected household economies and could not be completely covered by external health care support (e.g., government and non-government organizations). As a combined consequence, socioeconomic vulnerabilities, health hazards, and additional health care costs increase coastal population migration risks that can lead to mass migration from the vulnerable coastal region to interior regions of the country or to neighboring countries. Coastal population migration risk is a major concern that is closely related to natural disasters and its associated hazards, the impacts of which can

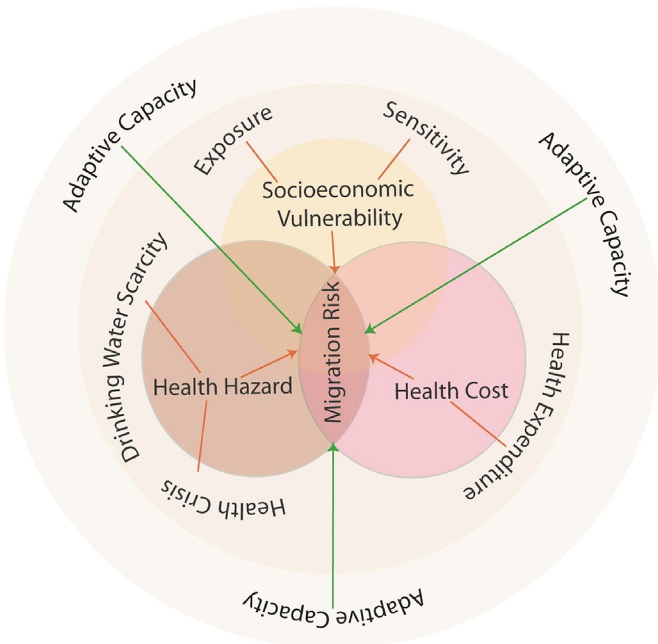


Fig. 2. Conceptualized theoretical framework for coastal population migration risk. (Source: Author).

cause of socioeconomic vulnerabilities, severe drinking water scarcity, health crises, additional health care costs, and realized adaptive capacities.

2.3.2. Composite index approach

A composite index approach was employed to estimate migration risk at the household level in relation to coastal hazards, socioeconomic crisis, potable water shortage, severe salinity problems, and health problems. The index method was reliable, plausible, and weighty to compare the estimated scores of different components with scale. It is extensively used to assess livelihood assets (Chen et al., 2013), livelihood (Hahn et al., 2009), and socioeconomic vulnerabilities (Ahsan and Warner, 2014) where data are not available and to determine the present condition in varying contexts. Due to lack of baseline data, the equal-weighted index proposed by Sullivan was used (2002).

Working indicators were developed through intensive literature review. Additional indicators were selected on the basis of field observations and discussions with local people (indicators table included in the supplementary material). Most of the indicators were related to coastal environmental factors, household economy, salinity problems, drinking water shortage, and emerging health-related shocks. As selected indicators were measured on different scales, it was required to normalize each as an index value. Eq. (1) was used to measure the index value for union *i*, which was first introduced by the United Nations Development Programme (UNDP, 2007) to calculate the life expectancy index:

$$\mathrm{index_{ij}} = \frac{X_{ij} - X_{j,\,min}}{X_{j,\,max} - X_{j,\,min}} \tag{1}$$

where $\mathrm{index_{ij}}$ represents the index score of *i*th ($i = 1,2,3,4,5$) union and *j*th ($j = 1,2,3 \ldots \ldots 49$) indicator. X_{ij} is the original value of *i*th union and *j*th indicator, and $X_{j,\,min}$ and $X_{j,max}$ are the minimum (lowest) and the maximum (highest) value of *j*th indicator, respectively. The normalized score ranged from 0 to 1. After the normalization of each indicator, it was averaged using Eq. (2) to obtain the scores of each sub-component.

$$SC_i = \frac{\sum_{j=1}^{m} \mathrm{index_{ij}}}{m} \tag{2}$$

where SC_i indicates the sub-component score of union *i* and *m* represents the total number of indicators of each sub-component. Each of the sub-components of the respective union is classified as demographic, social, economic, physical, natural disaster vulnerability, salinity context and potable water status, inconsistent water access, water-related health diseases, health care facilities, or household health care cost.

After the estimation of SC_i value, we calculated socioeconomic vulnerability with due consideration to Intergovernmental Panel on Climate Change (IPCC) dimensions such as sensitivity and exposure. Here, we did not include adaptive capacity because of its inverse relationship and because heterogeneous characters of adaptive capacity variables can influence the expected values of socioeconomic vulnerabilities. Moreover, to fulfill the research purpose, separate health hazards and health costs were calculated with due consideration to severe drinking water scarcity, health crisis, and household health care cost to evaluate the migration risk in the coastal community. The following equation (Eq. (3)) adopted by Hahn et al. (2009) was used to calculate household vulnerabilities:

$$MC_{ik} = \frac{\sum_{q=1}^{n} W_{sc_{iq}} SC_{iq}}{\sum_{q=1}^{n} W_{sc_{iq}}} \tag{3}$$

where MC_{ik} denotes the vulnerabilities index of each major component ($k = 1, 2, 3, 4, 5, 6$) of union *i*, and W_{sc_q} denotes the weight of each sub-component which is estimated using the sum of the total number of indicators for each sub-component to ensure that all indicators contributes equally to the overall score of MC_{ik} (Sullivan, 2002). SC_i represents the sub-component values of union *i*, and n indicates the number of sub-components. Using Eq. (3), weighted scores of major components like adaptive capacity (MC_1), sensitivity (MC_2), exposures (MC_3), drinking water scarcity (MC_4), health crisis (MC_5), and health cost (MC_6) were estimated.

After obtaining the major component values for each union, we proceeded to calculate socioeconomic vulnerability (SeV_i), health hazards (HeH_i), and migration risk (MiR_i). Migration risk was estimated by Eq. (4), which is

$$MiR_i = \frac{1}{3}\left(\frac{1}{2}MC_2 + \frac{1}{2}MC_3 + \frac{1}{2}MC_4 + \frac{1}{2}MC_5 + MC_6\right) \tag{4}$$

Socioeconomic vulnerability was calculated using the average of exposure and sensitivity, and values were estimated using weighted average techniques. Similarly, health hazard was calculated by taking the average of the values of drinking water scarcity and health crisis that were also estimated using weighted average scoring techniques. In this research, health cost (MC_6) is considered a significant component that pertains to regional interests regarding long-term salinity hazards. This variable is significantly associated with migration risk because it is considered an emerging and important constraint to the development of household economies of the coastal community. As a new dimension of exposure, acute (e.g., diarrhea and skin) and chronic (e.g., high blood pressure, cardiovascular, and kidney) diseases increase health expenditures. Particularly, drinking water salinity and its impacts on health are the substantial cause of high health expenditures. It also has the potential to influence overall migration risk along with health hazards that are discussed in detail in the results and discussion section. Health cost indicators were processed using weighted scores to calculate the migration risk, combining both socioeconomic vulnerability and health hazard scores for each of the studied unions (Eq. (4)). To define migration risk status in this study, MiR_i scores were calculated, ranging from 0 (least risk) to 1.0 (most risk).

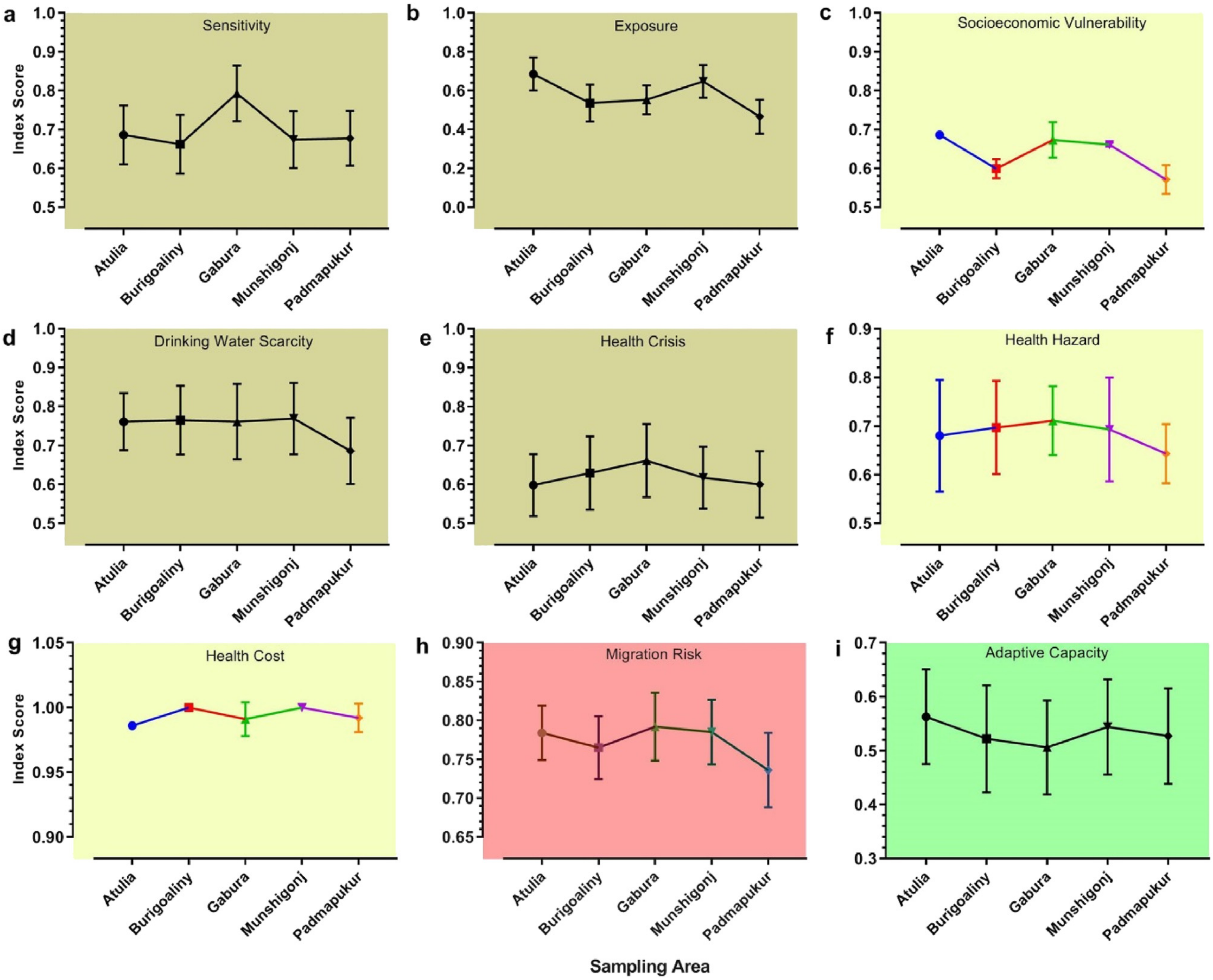


Fig. 3. Weighted scores of different components, along with vulnerabilities. (Source: Author).

3. Results

3.1. Vulnerable coastal household economy

As shown in Fig. 3, c, Atulia is identified as the most socioeconomically vulnerable (score 0.686) union, while Padmapukur (score 0.571) is recognized as the least socioeconomically vulnerable of all the unions, including Gabura (score 0.673), Munshigonj (score 0.661), and Burigoaliny (score 0.599). On the basis of the survey results, the average household property loss was recorded as US$1459.75 for Padmapukur, US$1392.86 for Munshigonj, US$1269.05 for Burigoaliny, US$1185.00 for Gabura, and US$890.05 for Atulia in the last ten years, as shown in Table 1. The largest numbers of relief-dependent (during and post disaster) people were found in Padmapukur (49.23%) and Gabura (28.57%) unions. In addition, a few individuals were dependent on fishing in the river and worked with relief organizations. Likewise, many households were dependent on daily work in the five studied unions specifically, 82.86% for Atulia, 73.85% for Padmapukur, 67.86% for Gabura, 49.06% for Burigoaliny, and 28.57% for Munshigonj. The highest percentages of peoples living below the poverty line were found in Gabura union (35.71%). Moreover, approximately 90% of households in the entire study area had no sanitary latrine, while nearly 100% of households in the Gabura union had no electricity.

On the basis of sensitivity factors, Gabura union is found to be highly sensitive (score 0.793) owing to a disaster-exposed economy (Fig. 3, a), followed by Atulia (score 0.686), Padmapukur (score 0.677), Munshigonj (score 0.674), and Burigoaliny (score 0.662). According to survey results, 100% of households in all the studied unions were severely affected by disaster. The average number of cyclone hits per year was recorded as 1.36 for Atulia, 1.70 for Burigoaliny, 1.64 for Gabura, 1.88 for Munshigonj, and 2.46 for Padmapukur. Approximately 100% of people throughout the five unions reported that the consequences of regional high salinity hazards are strongly associated with cyclonic storm surges. On the other hand, an insufficient number of cyclone shelters, long distances required to reach a cyclone shelter, high salinity hazards, and insufficient knowledge about the national warning system increase the coastal disaster exposure level. Depending on these factors, the highest scores for exposure were found in Atulia union (score 0.686), followed by Munshigonj (score 0.648), Gabura (score 0.553), Burigoaliny (score 0.536), and Padmapukur (score 0.466) union (Fig. 3, b).

3.2. Salinity hazards and health threats

Gabura union (score 0.711) is identified as a highly risky union regarding public health issues compared to the Burigoaliny (score 0.697), Munshigonj (score 0.693), Atulia (score 0.680), and Padmapukur (score 0.643) unions (Fig. 3, f). Local people reported that salinity gradients and the degree of contamination in groundwater

Table 1
Some of the significant values of social and environmental factors in sample. (Source: field survey).

Variables	Atulia Union	Burigoaliny Union	Gabura Union	Munshigonj Union	Padmapukur Union
Locations	Adjacent to mainland	Adjacent to mainland	Isolated from mainland	Adjacent to mainland	Adjacent to mainland
Illiteracy rate (%)	37.41	29.57	39.32	26.34	23.57
Average number of cyclone per year (Counts)	1.36	1.70	1.64	1.88	2.46
Loss and damage (for disaster) in the last ten years (US$)	890.05	1269.05	1185.00	1392.86	1459.75
Below poverty line (%)	22.86	16.98	35.71	12.50	18.46
Migrated family members (%)	18.57	20.76	23.21	39.29	30.77
No pure groundwater (%)	88.57	90.57	100.00	100.00	49.23
Conflict (for water scarcity) (%)	77.14	86.79	92.86	85.71	75.39
Salt (as a major problem in groundwater) (%)	88.57	100.00	98.21	94.64	93.85
Salinity increases in the last ten years (%)	98.57	100.00	98.21	100.00	95.39
Pond water use for drinking purpose (%)	54.29	41.51	28.57	78.57	20.00
Drink pond water (without any treatment or boiling) (%)	81.56	26.09	75.00	11.36	30.77
Rainwater harvesting (%)	94.29	90.57	100.00	96.43	90.77
Rainwater use for drinking purpose (%)	50.00	37.74	48.21	33.93	32.31
Average rainwater using time (months)	3.46	3.98	2.89	3.09	2.58
Average time loss for drinking water collection per day (h)	3.42	2.69	3.25	4.25	4.14
No household efficient water treatment facilities (%)	100.00	98.11	100.00	100.00	100.00
Not having good road networking system (%)	65.71	62.26	69.64	53.57	60.00
Blood pressure (%)	48.57	43.40	44.64	48.21	50.77
Cardiovascular diseases (%)	21.43	22.64	32.14	33.93	24.62
Kidney diseases (%)	4.29	13.21	10.71	10.71	3.07
Skin diseases (%)	72.86	86.79	87.50	71.43	87.69
Frequent diarrhea (%)	77.14	79.25	91.07	82.14	86.15
Other diseases (%)	37.14	33.96	33.93	39.29	27.70
Health cost highly increased (chronic and acute) (%)	98.57	100.00	99.1	100.00	99.23
Do not get proper health care support (%)	92.14	94.34	100.00	87.50	87.69

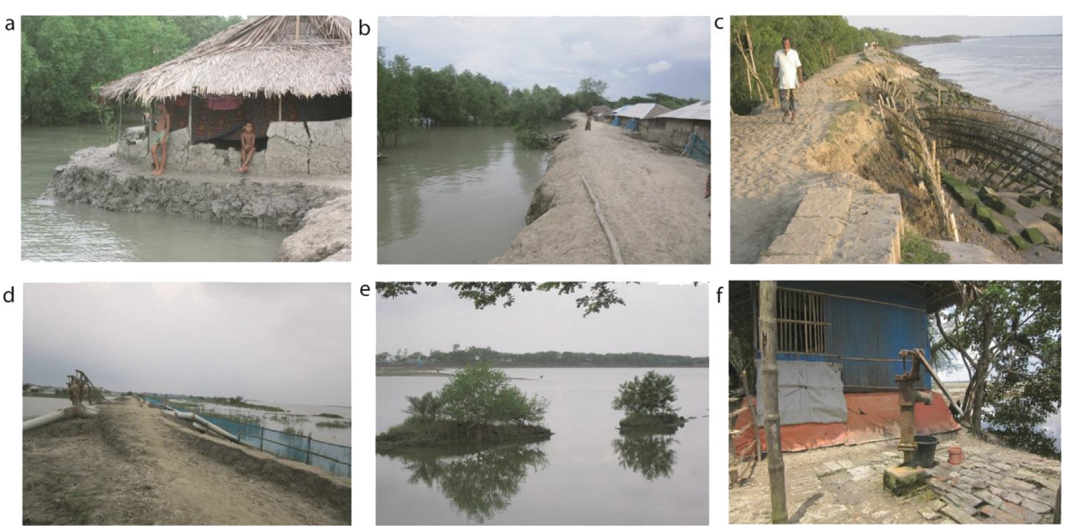


Fig. 4. Coastal impacts in Bangladesh: a, b. high-tide impacts, c. riverbank erosion, d. saline water withdrawal from the tidal river for shrimp farming, e. water-logging area, and f. tube-well drinking water source with high salt content. (Source: Author).

increased several-fold over previous decades. Many community respondents reported that they noticed abnormally high tides in the river, which were not seen before, and that sometimes the river surface rises (Fig. 4a and b) and intermittently floods some of the dry-land areas. Numerous fishermen reported that the average height of the tidal river water surface has risen compared to average heights ten to fifteen years ago. Additionally, approximately 100% of respondents noticed a significant change in salinity of the groundwater aquifer over the last ten years and reported that during the summer season the salt content is at its highest level. Almost 95% of households surveyed mentioned that the presence of high salt content in the groundwater aquifer is considered a main threat for fresh groundwater availability in the coastal belt of Bangladesh (Table 1). The high salinity problem leads to severe drinking water crisis, due to which residents are affected by several diseases. One of the local respondents stated that "drinking water scarcity is one of the biggest problems in these areas, with the main problem being the presence of salt in tube-well water. We cannot drink water properly, and if we drink more water, we do not feel comfortable."

3.2.1. *Drinking water scarcity and local adaptation strategies*

A significant drinking water scarcity score was observed in Munshigonj (score 0.769), Burigoaliny (score 0.765), Gabura (score 0.761), and Atulia (score 0.761) unions, whereas Padmapukur had a score of 0.686, as shown in Fig. 3, d. These scores are indicative of regional salinity hazards, potable water scarcity, and an inconsistent drinking water supply in the coastal community. As seen in Table 1, approximately 100% of the households in Gabura and Munshigonj union had no access to pure groundwater while nearly 88.57%, 90.57%, and 49.23% of households in Atulia, Burigoaliny, and Padmapukur, respectively, reported the presence of groundwater contaminants in their areas. On average, we found that 95% of households try to harvest rainwater (short-term or long-term) for drinking purposes. The average number of months per year in which rainwater was available for drinking purposes was recorded as 3.46 months for Atulia, 3.98 months for Burigoaliny, 2.89 months for Gabura, 3.09 months for Munshigonj, and 2.58 months for Padmapukur union, as shown in Table 1. During the rest of the year, they had to drink local pond water or salinity-contaminated tube-well water.

Approximately 100% of the households have a household member who travels a particular distance to meet their daily drinking water demand. During the survey, the average potable water collection time in hours per day (h) was estimated for the five studied unions in the study area. The results were 3.42 h for Atulia, 2.69 h for Burigoaliny, 3.25 h for Gabura, 4.25 h for Munshigonj, and 4.14 h for Padmapukur (Table 1). Moreover, approximately 45% of the households regularly use pond water for drinking purposes and most of them drink it directly without taking any disinfection measures. A small number of households were found to drink pond water after boiling it. Not all households reported on whether they treated pond water with chemicals. Pond water may contain pathogens and several types of contaminants (both inorganic and organic) that can cause human diseases through short- and long-term poisoning.

Our study showed that 78.57% of households in Atulia, 60.38% of households in Burigoaliny, 85.71% of households in Gabura, 37.86% of households in Munshigonj, and 73.85% of households in Padmapukur union have no capacity to buy fresh bottled water during emergency health conditions such as severe diarrhea. Very few people were found to use water from desalination plants during emergency periods to fulfill their needs. Local people reported that they could not regularly drink enough water to meet their body's demands owing to serious drinking water shortages and lack of access to drinking water. Consequently, an average of 83% of local people reported facing unwanted conflict (e.g., a quarrel or physical altercation) with neighbors during severe water scarcity periods.

3.2.2. Health crisis

Because of the long-term consequences of the regional water crisis, health crisis scores were estimated as 0.661 for Gabura, 0.629 for Burigoaliny, 0.617 for Munshigonj, 0.600 for Padmapukur, and 0.598 for Atulia, as shown in Fig. 3, e. Many households with members suffering from high blood pressure and cardiovascular diseases were identified. Estimated percentages of high blood pressure and cardiovascular disease, respectively, were 48.57% and 21.43% for Atulia, 43.40% and 22.64% for Burigoaliny, 44.64% and 32.14% for Gabura, 48.21% and 33.93% for Munshigonj, and 50.77% and 24.62% for Padmapukur (Table 1). More than 10% of households in Gabura, Burigoaliny, and Munshigonj reported a high prevalence of kidney diseases. Nearly 90% of households in Gabura reported the incidence of skin diseases (Fig. 5, a-d) and diarrhea. Approximately 80% of households in the remaining unions reported skin diseases and diarrhea. In addition, almost 30% of households across all unions reported other conditions such as respiratory diseases, asthma, dysentery, typhoid fever, etc.

Approximately 100% of people opined that the regional prevalence of acute and chronic diseases has increased. Simultaneously, the average household health expenditure has also significantly increased (Fig. 3, g), but the financial capacity of the local people is too weak to cover the actual treatment cost. Thus, more than 95% of residents do not get proper treatment because of high treatment costs and lack of government and non-government medical support at the community level, receiving some medical support only during the immediate aftermath of devastating disasters. Our study found that 95% of peoples are not satisfied with the present status of external healthcare facilities. One of the local respondents stated, “I am suffering from severe skin diseases, heart diseases, and dysentery for the last 7 years. Two of my sons are severely affected by heart diseases and tumor, but I do not have enough money to get treatment for me or my sons. We are passing through a very difficult time now.”

3.3. Migration risk

Local people feel the necessity for additional money to meet many of their household demands at the end of month, whereas the average health treatment cost has increased by 28.14% in Atulia, 24.21% in Munshigonj, 23.21% in Gabura, 22.54% in Padmapukur, and 21.76% in Burigoaliny. Considering this situation, migration risk levels were estimated for Gabura (score 0.792), Munshigonj (score 0.785), Atulia (score 0.784), Burigoaliny (score 0.765), and Padmapukur (score 0.736) (Fig. 3, h). Local opinion reveals that, in most cases, low-income people try to ignore their health diseases or treatments owing to food insecurity and financial crisis, which leads to a thought process of “*first food, then treatment*.” Simultaneously, socioeconomic vulnerability and household health expenditures have significantly increased because of salinity hazards in the coastal belt of Bangladesh. According to discussions with local people, if something like Aila happens again, individuals who have enough money or property within a society would migrate to other areas of the country or across the border, depending on their options.

3.4. Adaptive capacity

Finally, a relatively high adaptive capacity score was found in Atulia (score 0.563), followed by Munshigonj (score 0.544), Padmapukur (score 0.527), and Burigoaliny (score 0.522) (Fig. 3, i). The lowest adaptive capacity was found in Gabura (score 0.506). Approximately 40% of the total population in Gabura is illiterate; illiteracy rates in the remaining unions were observed as 37.41% in Atulia, 29.57% in Burigoaliny, 26.34% in Munshigonj, and 23.57% in Padmapukur. The highest dependency ratio was estimated in Gabura (0.500), followed by Atulia (0.475), and Padmapukur (0.392). According to survey results, the highest and lowest numbers of migrated households were found in the Munshigonj (39.29%) and Atulia (18.57%), respectively. Almost all the five unions depended on support from government and non-government organizations, which was calculated as Atulia (57.14%), Burigoaliny (54.72%), Gabura (37.50%), Munshigonj (66.07%), and Padmapukur (47.69%). Household expenses were a major factor in the need for credit support. In addition, road networks were not well-developed in Gabura (Table 1), nor was the connectivity of Gabura to mainland areas.

4. Discussion

Sensitivity and the degree of disaster exposure are considered the principal limiting factors in weakening the household economy. However, the average loss of household property was significantly high compared to family income over the last ten years. Kulatunga et al. (2014) stated that tropical cyclone causes damage and, economy loss, and disturbs social settings. Coping mechanisms in coastal communities varied during post-disaster periods in relation to household adaptive capacity, resource availability, and external support. Most individuals coped with their disaster losses and damages by depending on natural resources, fishing in the river, taking a loan, relief, working with relief, and by withholding food intake until a certain time of the day. A number of people were identified who live below the poverty line. The principal causes of poverty were cyclonic hits, damages, property loss, salinity intrusion, and decreased work opportunities.

Thus, sensitivity is a spectrum of social components that illustrate existing economic statuses and facilities, as well as how efficiently the community is in recovering from disaster impacts. Local peoples believe

Fig. 5. Adaptation techniques to remedy potable water scarcities and health crises among coastal communities: a-d. skin disease patients, e. rainwater harvesting tank connected to rooftops, f, g. rainwater harvesting techniques at a house, h. women collecting pond water, i. household head traveling outside of the community to collect potable water, j. abandoned pond sand filter (PSF) that was used to filter pond water, k. abandoned pond water treatment plant that was used to treat water through chemicals, and l. local water filter using sand particles to treat water. (Source: Author).

that coastal disaster and its associated hazards decreased their local livelihood opportunities. Many local people try to find work outside of the community as day laborer, such as a rickshaw puller, brick field worker, or garment worker. For at least a few months in a year, many of them remain unemployed. On the other hand, exposure relates to how those areas are exposed or affected by environmental consequences and/or climate disasters. Essentially, exposure level depends on disaster frequencies, magnitudes, intensities, and adaptive capacities. Owing to climate change impacts, the magnitudes and frequency of hydro-climatic impacts, such as cyclonic storm surges and floods, have increased (Penning-Rowsell et al., 2013). In response to cyclonic storm surges, damage, and property loss, many coastal households have migrated to other parts of the country or to other countries. In addition, fresh water and soil-based livelihood sectors are nearly devastated and seem to be limited to the coastal belt of Bangladesh. Individuals are not getting enough support to lead their coastal lifestyles and are now facing more dire situations for longer periods of time.

Both high salinity drinking water and health crises increase human health hazards. Local people harvest rainwater using plastic tanks, cement tanks, mud pots, buckets, and kitchen utensils. Primarily, water tanks are connected to rooftops with a pipe (Fig. 5, e). During rainy periods, water accumulates along with debris and unhygienic substances (Fig. 5, f). Polyethylene sheets were used by the people as a tool to harvest rainwater, and this technique causes, water to remain exposed to open air and sometimes contain external materials or contaminants like particulate matter and debris (Fig. 5, g). Based on local opinions, the average dependency ratio of rainwater use for drinking purposes has increased by several-fold owing to severe salinity hazards in subsurface and surface water. Khan et al. (2011) reported that sea level rise is the possible cause of salinity in natural drinking water sources and that salinity may contribute to rise in the future. Most people cannot rely on rainwater for drinking because of a lack of rainwater harvesting facilities and rainfall uncertainty. Thus, the harvesting, preservation, and proper management of rainwater is directly associated with individual behaviors, regional rainfall patterns, financial wellbeing, and rainwater harvesting facilities (Rakib et al., 2019). A majority of the local people cannot afford to purchase a rainwater-harvesting tank for long-term water conservation.

In many cases, rural women are engaged in rainwater harvesting and water storage-related household activities, but they spend much more time on potable water collection activities (Fig. 5, h). Often, the household head goes outside of the community to collect drinking water, as shown in Fig. 5, i, and travels more than four kilometers for this purpose. The travel frequency and total travel time vary depending on the potable water demand in a family, the location of the water source, and the road network system. In addition, local people try to collect drinking water from other sources. This water is generally collected from a source that is not a fresh water source, such as a local pond or a tube-well with less contaminated water.

Additionally, the average salinity of local pond water has increased with time. Local ponds do not contain fresh water, and the salinity of pond water is highest during the summer season. A pond may contain only slightly salinized water during some periods but exceed the permissible salinity level for the human body at others. Local people believe that since the Aila cyclone in 2009, most fresh water reservoirs, such as local ponds, have been contaminated with high salinity water owing to devastating cyclonic storm surges, long inundation periods, and flooding. Local peoples regularly use contaminated water for drinking, washing, bathing, and cooking purposes. Respondents stated that when used for cooking, the water accumulates salt in cooked food, and such meals are unappetizing and unhealthy. Eating high-salt food regularly may pose a severe health risk, although this can vary depending on the type of food cooked and the number of times a person eats food cooked in saline water in a day. Furthermore, local people do not have the capacity to buy bottled water for drinking purposes. In addition, transportation costs and travel time were also potential constraints that caused the respondents to drink less water per day.

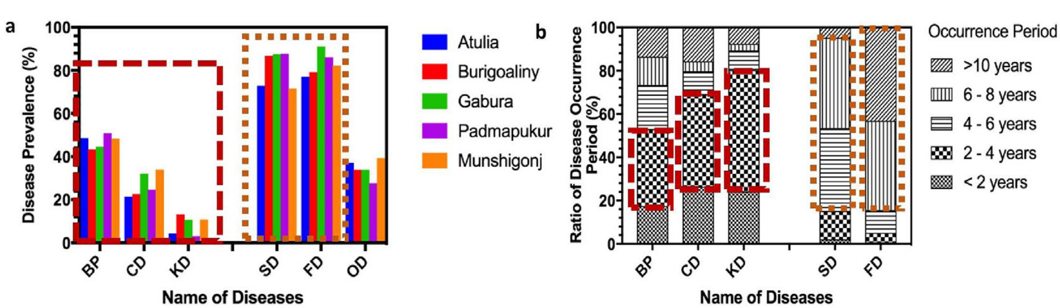
Vineis et al. (2011) reported that salinity-related health impacts are much higher in low-income countries, as people in these nations are more likely to use untreated or insufficiently-treated water. In the past, pond sand filter (PSF) systems were commonly used to filter pond water in various regions of the coastal belt (Fig. 5, j), but there were difficulties in terms of system maintenance, operational process, responsibilities, and financial support with this practice. This type of treatment facility is not effective in protecting against detrimental pathogens and chemical components. Another treatment plant shown in Fig. 5, k, was established to treat local pond water using a chemical process, but now it has been shut down. According to local people's opinion, most people are interested in communal water treatment facilities, but high maintenance and operational costs are difficult to bear because of worsening socioeconomic conditions. In effect, they do not have efficient water treatment facilities that can serve them in the long-term during adverse drinking water crisis situations. A few households use local water filters (such as a local sand filtering system) (Fig. 5, l), but they are not effective in removing salt, pathogens, and other harmful components (e.g., organic and inorganic contaminants). They only help to interlock and remove macro debris. In addition, there is no consistent water supply system for a multitude of people living with serious water scarcity problems. Therefore, social conflict is a common issue in terms of potable water scarcity and collection of water from sources, such as ponds or tube-wells.

In our study, health crisis was considered to encompass substantial diseases that primarily originate from the water salinity problem in the coastal communities of Bangladesh. Skin diseases and diarrhea were typically found to be acute problems and these diseases are significantly spreading in coastal communities due to the increasing level of water salinity. During the summer season, skin diseases and incidence of diarrhea become more severe because of high salinity conditions in surface and groundwater, lack of access to fresh water, and local people regularly working in high salinity conditions. A majority of respondents reported that chronic diseases, including blood pressure, cardiovascular diseases, and kidney diseases, have become more prevalent in the past two to four years, while acute diseases like skin diseases and diarrhea have been common ailments within the community for the past six to eight years (Fig. 6a and b). Blood pressure is considered as a cause of hypertension and cardiovascular diseases (Talukder et al., 2016). Thus, human health diseases (both acute and chronic) have increased after the devastating disaster Aila (2009) compared to previous eras. On the other hand, most of the local people surveyed work regularly in high-salinity environments (e.g., in shrimp farms), but suffer greatly from severe skin disease and diarrhea during the summer season in particular. According to local doctors, water salinity and potable water scarcity are considered the principal causes of various human health diseases. Therefore, local people regularly try to obtain a loan from neighbors to tackle an emergency situation. This is not a good strategy to continue a long-term treatment. In addition, the long-term use of salinity-contaminated water for drinking purposes can cause massive public health problems in coastal communities while frequent coastal disasters, waterlogging, and climate change impacts increase the river and groundwater salinity in coastal lowland areas. The degree of salinity hazards and social health crises may soon become more severe.

As presented in Fig. 3, a, in Gabura union, the household economy and physical aspects are found to be highly sensitive because of chronic poverty, lack of energy access, inadequate sanitation facilities, disaster loss and damage, high food consumption costs, a lack of intensive farming activities, and high disease prevalence. Exposure to natural disasters in Gabura union is lower than that of other unions because of their effective individual and social responses during disasters, such as evacuation periods, alertness to disasters, signal, and so on. Despite its relatively low disaster exposure, it showed the highest socioeconomic vulnerability because of high sensitivity scores on factors of disaster-affected economy and physical assets of the household. On the other hand, owing to potable water scarcity and human health diseases, it revealed a high health hazard status when exploring significant index values. Health diseases in various communities in all the five unions have led to increased health expenditures; meanwhile, the socioeconomic condition of these unions is considered more vulnerable and their existing adaptive capacity is significantly low. Now, health expenditure is one of the most influential factors that can increase population migration considering coastal environmental hazards, drinking water contamination, and health diseases.

Even though the migration risk of Padmapukur union was also significantly high, it was relatively low compared to Munshigonj, Atulia, and Burigoaliny because it has less socioeconomic vulnerabilities, less drinking water scarcity, lower levels of health crisis, and less health hazards. Local peoples believe that human health diseases and health expenditures significantly increased after the devastating cyclonic storms Aila (2009) and Sidr (2007). After Aila, some parts of the coastal area were inundated with high salinity water for two to three years. During those periods, a majority of residents were greatly exposed to the high salinity environment (Fig. 7). Numerous respondents within Padmapukur union said they try to drink less salinized water because they have a few potable water desalinization facilities inside or outside of their community. In some places, a few deep tube-well water sources also contain a low salt content. In addition, they try to collect less contaminated water from remote areas.

A majority of coastal communities depend on coast-based livelihoods and credit support. Because of a decrease in the diversity of livelihood patterns, household incomes have been interrupted. Along with socioeconomic vulnerability, local peoples encounter massive regional salinity hazards in surface and sub-surface water, along with potable water scarcity, widespread disease, and lack of health care



BP (Blood Pressure), CD (Cardiovascular Disease), KD (Kidney Disease),
SD (Skin Disease), FD (Frequent Diarrhea), OD (Other Diseases)

Fig. 6. Salinity causes disease prevalence among the coastal communities. a, chronic and acute diseases patients ratio among the five unions. b, diseases prevalence period (average ratio) with the respective diseases. (Source: Author)

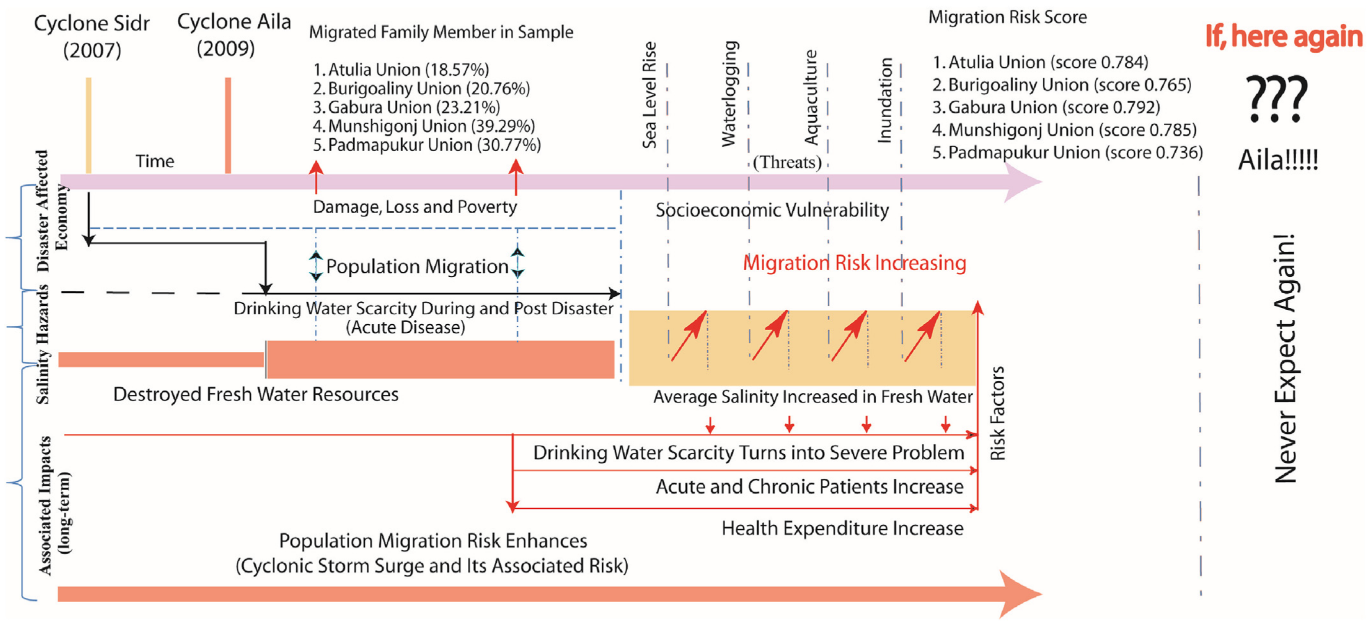


Fig. 7. A summary of study findings in regard to the household questionnaire survey results, local people's perceptions, and field observations. Many peoples migrated after cyclone Sidr (2007) and Aila (2009). After Aila, a majority of people in the southwestern coastal belt were severely affected, and socioeconomic structures were devastated because of infrastructure damage, property loss, poverty, and death. Severe drinking water shortages and acute health crises emerged because of the inundation of the large area while sub-surface and surface water were contaminated by seawater intrusion in the coastal area. Within a short time, the area was overwhelmed. As a result, approximately 98% of fresh water reservoirs and ecosystem were destroyed due to the inclusion of seawater. For the time being, the average salinity of water in the tidal rivers and other surface water has been increased. Due to the long presence of salinity hazards, local people have shifted from agricultural farming to aquaculture. The impacts of sea level rise, waterlogging, aquaculture, and flooding hazards are augmenting the average salinity in the coastal aquifer. Over the last few decades, local peoples have been highly exposed to drinking water salinity and a severe water crisis that has created a coastal public health crisis. Within the disaster-affected economy, local peoples are facing difficulties meeting the demand of potable water collection and health expenditures. The integrated impacts of coastal hazards have increased the mass population migration risk in the southwestern coastal community of Bangladesh. (Source: Author).

support. A continuation of this may lead to social crises that contribute to increased migration of coastal communities within the country or across the border. Climate change and sea level rise may act as principal enhancers of social insecurities and the possible migration of coastal communities. Environmental events influence displacement or cause migration (Collins, 2013). Similarly, adaptive capacity scores of the studied unions were significantly lower than their migration risk values, which suggest an imbalanced development in the coastal community.

5. Conclusions and policy implications

This study estimated population migration risk due to the recent coastal salinity hazard that is creating potable water scarcities and health implications in Bangladesh. Across each of the studied unions, there were no significant differences in geographical location, environmental exposure, or social and economic activities. The southwestern part was found to be more vulnerable to cyclonic storm surges and sea level rise caused by climate change. However, coastal communities have recently been experiencing worsening salinity conditions. Socioeconomically, all the studied unions were highly exposed to coastal disaster and were economically sensitive. On the other hand, as a silent killer, high and long-term salinity exposure has deteriorated the coastal lifestyle and changed the way in which the communities access and use fresh water. As an isolated union, Gabura was identified as having the highest possibility of heightening population migration based on aspects of a worse socioeconomic status, severe health hazards, and increased treatment costs. Gabura was followed by the Munshigonj, Atulia, Burigualini, and Padmapukur unions, respectively. An insignificant difference was found between migration risk scores because of the selected locations and degrees of environmental exposure and social-economic activities. In contrast, the adaptive capacity of each studied union was much lower than the migration risk scores, which singularly demonstrated the vulnerability of various coastal communities. Soon, sea level rise and related hazards like salinity, drinking water crises, and health hazards may increase population migration from the coastal belt of Bangladesh.

To tackle coastal hazards and relevant risks, as an urgent action, a policy should be formulated that integrates matters related to coastal problems, impact of natural disasters, and possible solutions aimed at creating a better future for coastal environments and communities. Integrated policy measures can be helpful in securing coastal communities facing coastal disasters; severe salinity hazards and drinking water scarcity are also serious issues to be handled. In this case, there is an immediate need to identify social perceptions regarding the high salinity water crisis, how its impact could be reduced, and what are the best social actions or co-activities between government and non-government organizations regarding the salinity problem, potable water shortages, and strategies for meeting drinking water demands. Simultaneously, the government should identify weak zones of riverbank erosion as well as areas vulnerable to flooding and waterlogging during and after cyclonic storm surges, and then try to reconstruct dams or embankments to ensure future sustainability. Additionally, the government should stop human intervention along the riverbank, which occurs for the purpose of shrimp cultivation. Furthermore, local people try to harvest rainwater, but it is not sufficient to meet their potable water demands. Therefore, a communal rainwater harvesting yard should be facilitated that can supply drinking water to meet each household's potable water demands. Alternatively, low-cost sustainable technology can be provided to meet household potable water demands, or a common desalinization plant can be installed to ensure a sustainable water supply in conjunction with sustainable consumption techniques practiced at the household level. A master aquifer could be identified in some areas to help supply water to all peripheries of the coastal community. Furthermore, coastal residents are suffering from various types of diseases that are mostly caused by salinized water. Health check-ups should be conducted regularly to measure the impact of potable water access and salt intake, and to monitor how health diseases worsen. Moreover, this crisis exerts pressure on the basic needs of people because of additional costs of medical treatments. Our principal findings show that people are more vulnerable to migrate when faced with the challenges discussed in this study. To stop mass migration caused by coastal disaster, socioeconomic vulnerability and the consequences of hazards, such as high salinity environments, potable water crisis, and public health issues, must be considered. Additionally, these considerations should be followed up with development activities in areas facing adverse conditions to ensure sustainable social development in the coastal community.

Competing interests

The authors declare no competing interests.

Acknowledgements

The authors acknowledge the local communities who were assisted and cooperated during the field survey. The authors also acknowledge the Ministry of Education, Culture, Sports, Science and Technology (MEXT) for scholarship support during the authors' MS program with the Graduate Program of Sustainability Science-Global Leadership Initiative at the Graduate School of Frontier Sciences, the University of Tokyo, Japan. This work was partially funded by JSPS KAKENHI Grant No. JP25303016.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.03.101.

References

Abedin, M.A., Habiba, U., Shaw, R., 2014. Community perception and adaptation to safe drinking water scarcity: salinity, arsenic, and drought risks in coastal Bangladesh. Int. J. Disaster Risk Sci. 5 (2), 110–124. https://doi:10.1007/s13753-014-0021-6.

Ahsan, M., Warner, J., 2014. The socioeconomic vulnerability index: a pragmatic approach for assessing climate change led risks – a case study in the south-western coastal Bangladesh. Int. J. Disaster Risk Red. 8, 32–49. https://doi:10.1016/j.ijdrr.2013.12.009.

Ali, A.M.S., 2006. Rice to shrimp: land use/land cover changes and soil degradation in Southwestern Bangladesh. Land Use Pol. 23 (4), 421–435. https://doi:10.1016/j.landusepol.2005.02.001.

Bathrellos, G.D., Skilodimou, H.D., Chousianitis, K., Youssef, A.M., Pradhan, B., 2017. Suitability estimation for urban development using multi-hazard assessment map. Sci. Total Environ. 575, 119–134. https://doi.org/10.1016/j.scitotenv.2016.10.025.

Caritas Development Institute (CDI), 2000. Report on "Base Line Survey of Brackish Water Resources and Environmental Situation in Shyamnagar, Satkhira". Prepared to Supplement the: Sustainable Environment Management Program (SEMP) of Caritas.

Chen, H., Zhu, T., Krott, M., Calvo, J.F., Ganesh, S.P., Makoto, I., 2013. Measurement and evaluation of livelihood assets in sustainable forest commons governance. Land Use Pol. 30 (1), 908–914. https://doi:10.1016/j.landusepol.2012.06.009.

Chowdhury, K.R., 2009. September 6. Tidal River Plan Could Allay Climate Threat in Southwest. bdnews24.Com. http://bdnews24.com/bangladesh/2009/09/06/tidal-river-plan-could-allayclimate-threat-in-southwest, Accessed date: 12 October 2016.

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D., Unnikrishnan, A.S., 2013. Sea level change. In: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Collins, A.E., 2013. Applications of the disaster risk reduction approach to migration influenced by environmental change. Environ. Sci. Policy 27, 112–125. https://doi.org/10.1016/j.envsci.2012.10.005.

Cornwall, W., 2018. March 1. As sea levels rise, Bangladeshi islanders must decide between keeping the water out-or letting it in. Science. https://doi:10.1126/science.aat4495.

Dasgupta, S., Kamal, F.A., Khan, Z.H., et al., 2014. River Salinity and Climate Change: Evidence from Coastal Bangladesh. Policy Research Working Paper; no. WPS 6817. World Bank Group, Washington, DC. http://documents.worldbank.org/curated/en/522091468209055387/pdf/WPS6817.pdf, Accessed date: 26 March 2018.

Gray, C., Mueller, V., 2012. Natural disaster and population mobility in Bangladesh. Proc. Natl. Acad. Sci. 109 (16), 6000–6005. https://doi:10.1073/pnas.1115944109.

Hahn, M.B., Riederer, A.M., Foster, S.O., 2009. The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change. A case study in Mozambique. Glob. Environ. Chang. 19 (1), 74–88. https://doi:10.1016/j.gloenvcha.2008.11.002.

IPCC, 2007. In: Pachauri, R.K., Reisinger, A. (Eds.), Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4_syr_full_report.pdf, Accessed date: 10 September 2016.

Jevrejeva, S., Jackson, L.P., Grinsted, A., Lincke, D., Marzeion, B., 2018. Flood damage costs under the sea level rise with warming of 1.5 °C and 2 °C. Environ. Res. Lett. 13 (7), 074014. https://doi:10.1088/1748-9326/aacc76.

Khan, A.E., Ireson, A., Kovats, S., Mojumder, S.K., Khusru, A., Rahman, A., Vineis, P., 2011. Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change. Environ. Health Perspect. 119 (9), 1328–1332. https://doi:10.1289/ehp.1002804.

Khan, M.M., 2018. July 15. Wikipedia, the Free Encyclopedia. https://en.wikipedia.org/wiki/Union_councils_of_Bangladesh, Accessed date: 15 December 2018.

Kulatunga, U., Wedawatta, G., Amaratunga, D., Haigh, R., 2014. Evaluation of vulnerability factors for cyclones: the case of Patuakhali, Bangladesh. Int. J. Disaster Risk Reduct. 9, 204–211. https://doi:10.1016/j.ijdrr.2014.05.011.

Laczko, F., Aghazarm, C., 2009. Migration, Environment and Climate Change: Assessing the Evidence. International Organization for Migration. https://publications.iom.int/es/system/files/pdf/migration_and_environment.pdf, Accessed date: 18 December 2017.

Ministry of Environment and Forests B, 2006. April. Coastal Land Zoning in the Southwest: Report on "Impact of Sea Level Rise on Land Use Suitability and Adaptation Options".

Ministry of Environment and Forests, 2016. July. Report on "Assessment of Sea Level Rise on Bangladesh Coast through Trend Analysis". . http://gobeshona.net/wp-content/uploads/2016/08/SLR-Report_final_July-2016.pdf, Accessed date: 13 February 2018.

Naeen, Z., 2018. April 30. A harsh reality of Bangladesh: water security, salinity intrusion, and internal migration-OpEd. Eurasia Review. https://www.eurasiareview.com/30042018-a-harsh-reality-of-bangladesh-water-security-salinity-intrusion-and-internal-migration-oped/, Accessed date: 28 June 2018.

Nicholls, R.J., Wong, P.P., Burkett, V.R., et al., 2007. Coastal systems and low-lying areas. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Penning-Rowsell, E.C., Sultana, P., Thompson, P.M., 2013. The 'last resort'? Population movement in response to climate related hazards in Bangladesh. Environ. Sci. Policy 27, 44–59. https://doi.org/10.1016/j.envsci.2012.03.009.

Raju, M.N.A., 2017, December 31. Potable Water Crisis in Southwest Bangladesh. The Daily Star. https://www.thedailystar.net/opinion/environment/potable-water-crisis-southwest-bangladesh-1512511, Accessed date: 22 February 2018.

Rakib, M.A., Islam, S., Nikolaos, I., Bodrud-Doza, M., Bhuiyan, M.A.H., 2017. Flood vulnerability, local perception and gender role judgment using multivariate analysis:a problem-based "participatory action to Future Skill Management" to cope with flood impacts. Weather Clim. Extrem. 18, 29–43. https://doi:10.1016/j.wace.2017.10.002.

Rakib, M.A., Sasaki, J., Pal, S., Newaz, M.A., Bodrud-Doza, M., Bhuiyan, M.A.H., 2019. An investigation of coastal vulnerability and internal consistency of local perceptions under climate change risk in the southwest part of Bangladesh. J. Environ. Manag. 231, 419–428. https://doi:10.1016/j.jenvman.2018.10.054.

Rashid, H., 2018. June 3.the Crisis of Fresh Water. Retrieved from. The Daily Star. Retrieved from. https://www.thedailystar.net/opinion/perspective/the-crisis-fresh-water-1585291, Accessed date: 10 July 2018.

Sullivan, C., 2002. Calculating a water poverty index. World Dev. 30 (7), 1195–1210. https://doi:10.1016/s0305-750x(02)00035-9.

Talukder, M.R.R., Rutherford, S., Phung, D., Islam, M.Z., Chu, C., 2016. The effect of drinking water salinity on blood pressure in young adults of coastal Bangladesh. Environ. Pollut. 214, 248–254. https://doi:10.1016/j.envpol.2016.03.074.

UNDP, 2007. Human Development Reports 2007/8, Fighting Climate Change: Human Solidarity in a Divided World. . http://hdr.undp.org/sites/default/files/reports/268/hdr_20072008_en_complete.pdf, Accessed date: 10 October 2016.

UNDP, 2017. Climate Change, Migration and Displacement, the Need for a Risk-Informed and Coherent Approach. https://www.odi.org/sites/odi.org.uk/files/resource-documents/11874.pdf, Accessed date: 11 August 2018.

Vineis, P., Chan, Q., Khan, A., 2011. Climate change impacts on water salinity and health. J. Epidemiol. Glob. Health 1 (1), 5–10. https://doi:10.1016/j.jegh.2011.09.001.

Warner, K., 2010. Global environmental change and migration: governance challenges. Glob. Environ. Chang. 20 (3), 402–413. https://doi:10.1016/j.gloenvcha.2009.12.001.

Warner, K., Laczko, F., 2008. A global research agenda. Climate change and displacement. Forced Migr. Rev. 31, 59–60.

World Bank Report, 2016. June 24. Climate Change Poses Urgent Threat to Poor of Coastal Bangladesh. http://www.worldbank.org/en/news/feature/2016/06/24/climate-change-poses-urgent-threat-to-poor-of-coastal-bangladesh, Accessed date: 11 November 2016.