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Climate Change and Livelihood Vulnerability of the Local Population on Sagar Island, India

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Abstract: This paper attempts to assess the vulnerability to climate change of human communities in selected *mouzas* of Sagar Island, South 24 Parganas District of India. A primary household survey has been conducted to collect data on socio-demographic profile, livelihood strategy, health, food, water, social network, natural disaster and climate variation indicators, were selected for Livelihood Vulnerability Index (LVI) and Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change (LVI-IPCC) analyses to measure and compare the vulnerability of *mouzas* (administrative unit) currently suffering from frequent flooding, coastal erosion and embankment breaching on an annual basis. Secondary data collected from the Indian Meteorological Department, the Water Resources Information System of India and the Global Sea Level Observing System have been used to identify dynamics of climate change by employing statistical and Geographic Information System (GIS) techniques. A GPS survey has been conducted to identify locations of embankment breaching, and satellite images obtained from the National Aeronautics and Space Administration and U.S. Geological Survey (NASA USGS) Government website have been applied to shoreline and land use change detection, using a supervised maximum likelihood classification. The results indicate that the study area has experienced increasing temperature, changing precipitation patterns, rise in sea level, higher storm surges, shoreline change, constant land loss, embankment breaching and changing land use, which have had impact on vulnerability, particularly of poorer people. The LVI (0.48 to 0.68) and LVI-IPCC (0.04 to 0.14) scores suggest that the populations of Dhablat, Bankimnagar, Sumatinagar, Muri Ganga and Sibpur *mouzas* are highly vulnerable (LVI scores of 0.60 to 0.68 and LVI-IPCC scores of 0.11 to 0.14) to climate change both because the communities are more exposed to it, and because poor access to food, health facilities and water makes them extremely sensitive to it and lowers their adaptive capacity. The findings of this study could be crucial to framing further development and adaptation strategies relating to climate change, and to safeguarding the estuarine ecosystem and the vulnerable population.

Keywords: climate change; livelihood vulnerability index (LVI); adaptation strategies; estuarine ecosystem; vulnerable population

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1 Introduction

Climate change has emerged as a leading global issue over the past few decades with a rise in both extreme rapid-onset events and slow-onset climate phenomena (Alston, 2014; Hondula et al., 2015). It has manifested itself in terms of rising sea and air temperatures, increasing frequency and intensity of storm surges and tidal surges, more intense cyclones, and increased flooding and heavy precipitation events (Resurrección4, 2013; Inter-governmental Panel on Climate Change (IPCC), 2014; Mukherjee and Siddique, 2018). Climate change can jeopardize many geophysical, biological and social systems (Zhang et al., 2008) and lead to problems such as scarcity of water (Milly et al., 2005), decreasing agricultural production (Tubiello, 2005), loss of biodi-

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versity (Thuiller et al., 2005), health hazards (Reiter et al., 2004), poverty, and inequality (Denton et al., 2014). Landmark research on climate change has correlated such phenomena with a greater disruption of food, water, health and livelihood security (FAO, 2007) of the individuals, households and communities concerned (Dankelman, 2010; Pelling, 2011). Livelihood vulnerability to climate change is a product of both biophysical and social factors (Cutter et al., 2000). Biophysical vulnerability emerges from the exposure of communities to climatic changes, while social vulnerability is the product of those factors that make communities more susceptible to such phenomena (Shah et al., 2013). The IPCC already warned in 2014 that the low-lying coastal areas of the world will continue to experience sea level rise, increasing winter temperatures, intensification of cyclones, coastal flooding, salt water intrusion into surface and sub-surface water, and loss of land and mangroves (IPCC, 2014). An example of such ravages of climate change can be found in the Sundarbans where the fragility of the ecosystem, underdevelopment and an over-dependence of people on climate-sensitive subsistence have made the population more vulnerable (Ghosh, 2012).

Situated at a meeting point of the Ganga and the Bay of Bengal, Sagar Island has experienced climate change phenomena such as sea level rise, violent cyclones, unpredictable tidal surges, higher soil salinity and severe coastal erosion (Ghosh, 2012). Sagar Island is part of the Sundarban coastal region which is an archipelago of 102 islands, of which 54 are inhabited. Khasimara, Lohachara, Bedford Island and Bishalakkhipur *mouzas* (administrative unit), on Sagar Island, have been deluviated by coastal erosion. The erosion has made Sagar *mouza* uninhabited. Ghoramara *mouza* will soon be completely inundated due to rising sea levels accompanied with a higher rate of erosion (Bandyopadhyay, 1997; Gopinath and Seralathan, 2005; Gopinath, 2010). The World Bank Report and the Oceanography Department of Jadavpur University noted that while the global average rate of sea level rise is 3 mm/yr, it varies in the range 3–8 mm/yr for the Sundarbans (Hazra et al., 2002; The World Bank, 2014). The current rate of sea level rise could lead to a 20% accrued risk of flooding above 1.52 m (5 ft) at Sagar by 2070 (Climate Central, 2018). The mangrove forests act as a natural buffer against cyclones and the annual monsoons, but now they are under threat of rising sea levels and increasing siltation. According to the Indian Space Research Organization, the Indian Sundarbans has already lost close to 4% of its forest cover and 9990 ha of its landmass in the past decade (World Wide Fund for Nature, 2017). Mud embankments built around the low-lying areas are frequently breached due to tidal ingression and wave action during storm surges or cyclones. As a result, saline water intrusion takes place, leaving the agricultural fields unproductive and the potable water saline. A vast majority of the population in Sagar relies on agriculture and fishing activities for their livelihood. Extreme weather events threaten both these occupations, forcing people to become environmental refugees by migrating to urban centres in search of jobs. Considering all these factors, assessment of vulnerability to climate change on the island becomes essential for community development planning and disaster preparedness.

Globally, research concerning the human dimensions of environmental change (Gbetibouo and Ringler, 2009; Abson et al., 2012) and environmental policy formulation (Stelzenmüller et al., 2010) applies vulnerability assessment methods, to identify vulnerable areas and populations and to frame and implement policies for possible mitigation and disaster risk reduction (Ericksen et al., 2011; Abson et al., 2012; Mandal et al., 2018). Such methods are used in the United States Agency for International Development (USAID) Famine Early Warning System (USAID, 2007), the World Food Programme's Vulnerability Analysis and Mapping tool for targeting food aid (World Food Programme, 2007) and in a range of geographical analyses related to biodiversity conservation, poverty mitigation, livelihood security, health status, globalization and other phenomena worldwide (Hahn et al., 2009). Several studies have already explained vulnerability in the context of climate change and they have outlined its chief components as exposure, sensitivity and adaptive capacity (Watts and Bohle, 1993; Cutter, 1996; Adger, 1999, 2006; Cutter et al., 2003; Füssel, 2007). Exposure is the extent to which a system is in contact with a change in climate; sensitivity is the degree to which the community is affected by the exposure; and adaptive capacity is the system's ability to withstand or recover from the change in climate (Ebi et al., 2006; Pandey et al., 2014). There are various empirical frameworks designed for assessing vulnerability to climate change (Turner et al., 2003; Ford and Smit, 2004). Among the diverse approaches to systematically examining and integrating interactions between climate change and vulnerability assessment, the Livelihood Vulnerability Index (LVI), developed by Hahn et al. (2009) following the IPCC climate change vulnerability framework, is one of the most effective methods, used by several researchers worldwide (Pandey and Jha, 2012; Etwire et al., 2013; Shah et al., 2013; Toufique and Islam, 2014; Panthi et al., 2016; Alam, 2017). It provides a precise indication of a household's ability to maintain sustainable means of living (Chambers and Conway, 1992). A sustainable livelihood is one which can enhance a household's ability to adapt to environmental changes and to recover from the shocks caused by such changes (Arvai et al., 2006). This approach examines primary data in order to avoid the shortcomings associated with secondary data, and reduces the dependency on coarse-resolution climate models. It also provides an opportunity to make household information available for community development and planning (Patz et al., 2005; Sullivan, 2006). However, there should be place-specific and context-specific assessment of vulnerability, as many local factors influencing vulnerability vary in space and time (Cutter et al., 2003; Füssel, 2010; Fraser et al., 2011; Wood et al., 2014; Alam, 2016). Though the indices used for vulnerability analysis generalize the complex phenomena of climate change and its potential impact, the benefit of such an assessment is that the vulnerability indicators can be used as an instrument for evaluating what policy development is required for adaption to and mitigation of climatic risks (Eriksen and Kelly, 2007; Gbetibouo et al., 2010; Preston et al., 2011).

Recent research work on Sagar Island has already outlined natural environmental hazards and their management (Bandyopadhyay, 1997), rapid coastal erosion (Gopinath and Seralathan, 2005; Purkait, 2009; Gopinath, 2010), shoreline change (Kundu et al., 2014; Mondal et al., 2017), climate change vulnerability of agrarian systems (Mandal et al., 2017), and precipitation pattern estimation for sustainable agrarian economies (Mandal and Choudhury, 2015). Realizing the need to better understand the impact of climate change on livelihood vulnerability in Sagar Island, the present study attempts to identify the indicators of climate change in terms of changes of temperature and precipitation conditions, changes of sea level, amplification of hazards, storm surges, and coastal erosion, and their cumulative effect on the livelihood vulnerability of the local marginal people. The study applies the LVI and the LVI-IPCC (Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change), followed by the IPCC framework on vulnerability analysis, for a risk assessment of selected *mouzas* on Sagar Island under the Indian Sundarbans. It evaluates vulnerability over space and time by giving due importance to its contributing processes, prioritizing strategies for reducing vulnerability and evaluating the efficiency of these strategies in variable ecological and social conditions (Dow, 1992; Adger et al., 2009; Shah et al., 2013) with the help of perception surveys in selected *mouzas*. Following Hahn et al. (2009) the LVI uses multiple indicators to assess the exposure of the community to natural disasters and climate variation. Current health status, food and water resource characteristics are analysed, to evaluate the sensitivity. Then socio-economic characteristics are examined to determine the adaptive capacity to climate changes. The analysis is carried out in two stages. In the first stage, the LVI composite index is calculated, and in the second stage, sub-components of vulnerability factors are used to examine the IPCC's three contributing elements of vulnerability previously mentioned. The LVI has been designed in such a way that information on the degree of vulnerability of a community to climate change can easily be used by developmental organizations and policy makers to frame appropriate adaptation strategies. It will also help governmental and non-governmental organizations to identify which areas need particular intervention for further development.

2 Materials and Methods

2.1 Study area

Sagar Island is situated in the Kakdwip Sub-Division of South 24 Parganas District of India, at a meeting point of the Ganga and the Bay of Bengal, 100 km south of Kolkata. It is bounded by Kakdwip Block to the north and northeast, Namkhana Block to the southeast, Purba Medinipur District to the west and the Bay of Bengal to the south. The island is part of a tidally active delta that is formed of alluvium brought down by the Ganga and Brahmaputra Rivers and their numerous tributaries. The Gabtala River flows to the west of Sagar Island and the Baratala, or Muri Ganga, River flows to the east. Land reclamation in Sagar started in 1811, from Sundarban mangrove wetlands. Currently the island covers an area of 282.11 km^2 and is inhabited by 212 037 people (Census of India, 2011). Its latitudinal and longitudinal extents are from 21°36′N to 21°56′N and from 88°02′E to 88°11′E, respectively (Fig. 1). The average temperature was 27.57℃ in 2017. May is the hottest month and January is the coldest. The total precipitation amount during 2017 was 154.25 mm with maximum precipitation occurring from June to September due to the south-west monsoon. The average evapotranspiration rate ranges from 15 to 90 mm/mon. The elevation varies from 0 to 15 m above mean sea level, although most of the area is below 5 m in elevation. Sagar Island has been considered as a global climate change hotspot. Erosion and accretion takes place continuously, because of tidal ingression, river fluxes, waves, long-shore currents, sea-level changes, cyclones and storms, which modify the shape of the island. Greater exposure to climate-driven hazards and a high dependency of rural people on a rain- fed agrarian economy means the island forms a significant part of the global climate change debate and discussion (Mandal and Chowdhury, 2015; Mandal et al., 2017).

2.2 Database and methodology

Seven out of the 42 inhabited *mouzas* of Sagar Island were selected to comprise the area under review, on the basis of the severity of erosion that was identified from a literature review, District Disaster Reports, field investigation and in consultation with experts. A primary survey was conducted to identify the livelihood vulnerability of marginal rural people to climate change and related issues. A random sampling technique was

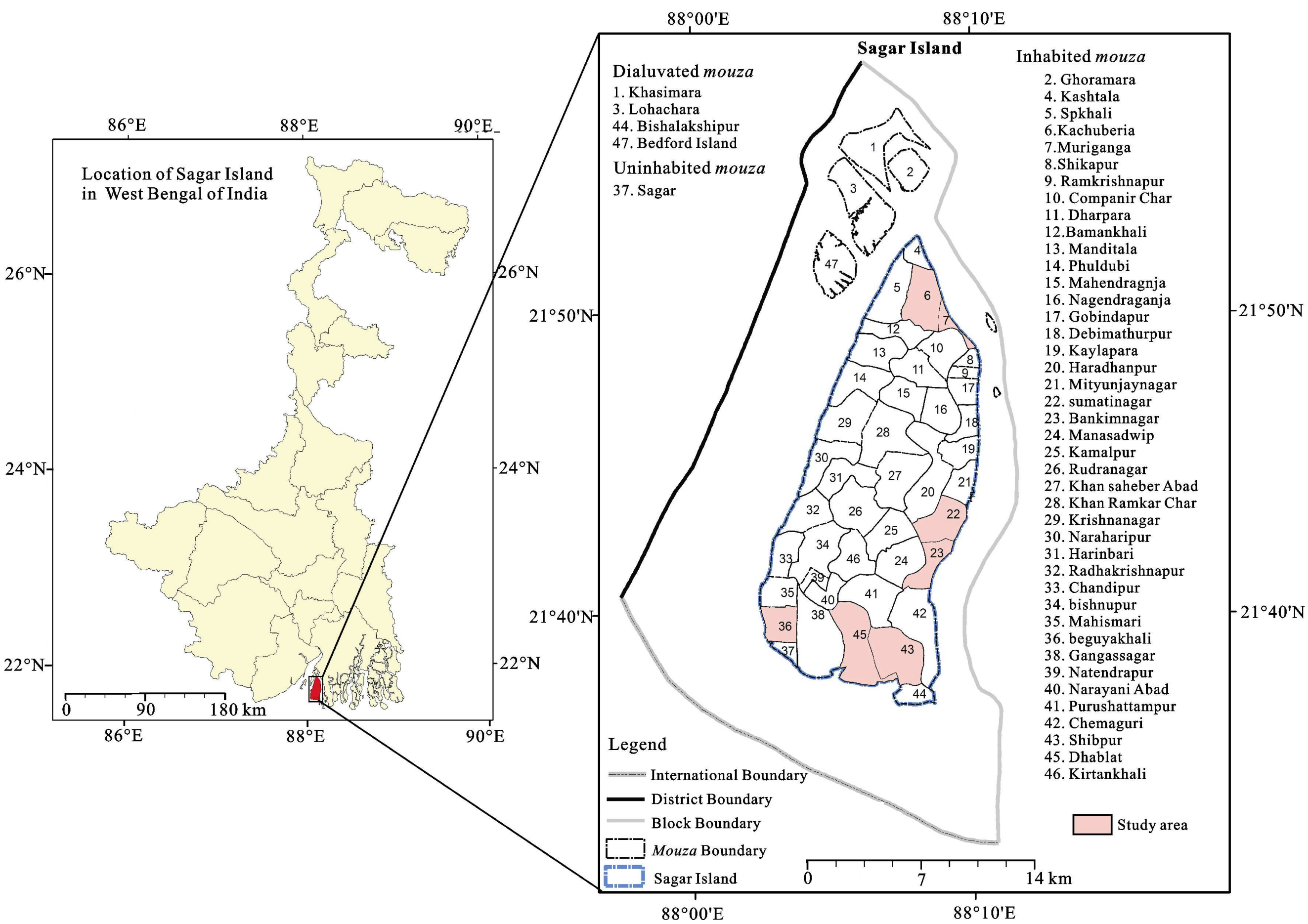

Fig. 1 The location of Sagar Island and the study area

applied to collect household data, with no bias-correction required because of the homogeneity of the population. Ten percent of households were surveyed in Beguakhali, Dhablat, Sibpur, Sumatinagar, Bankimnagar, Muri Ganga and Kachubaria *mouzas*, following the sample selection formula provided by the National StatisticalService (2018). Structured questionnaires were prepared according to the requirements of the study. The survey was conducted from December 2017 to May 2018. These seven *mouzas* have been chosen for the socio-economic vulnerability analysis because they have recently reported coastal erosion, embankment breaching and flood events every year.

Precipitation and temperature data for a period of 117 yr (1901–2017) and storm surge data during the period 1901–2002 were obtained from the Indian Meteorological Department (1901–2017) and the India Water Portal (1901–2002) (http://indiawaterportal.org), respectively, to identify climatic variation. Sea level rise data were obtained from the Global Sea Level Observing System for the period 1948–2013. Data relating to intensification of storm surges were obtained from the Water Resources Information System of India for 1901–2002, and cyclones from the Regional Meteorological Centre for the period 1891–2016. Landsat 2 Multispectral Scanner (MSS) (1977), Landsat 5 Thematic Mapper (TM) (1989, 1997, 2007) and Landsat 8 Operational Land Imager (OLI) (2017) images were extracted (Earth Explorer, USGS, 2018) to identify changes in shoreline and land loss of each of the villages through computational methods. A GPS survey was conducted to determine the current breaching locations. Land use/land cover maps were generated for change detection and analysis for 1996 (Landsat 5 TM) and 2017 (Landsat 8 OLI). A supervised maximum likelihood method was used for land use classification. The overall accuracy of the classifications for 1996 and 2017 is 90% and 91.66% respectively and the Kappa coefficients are 88% and 90% respectively. ArcGIS 10.2.1 and Erdas Imagine 9.2 software were used to prepare maps.

The Livelihood Vulnerability Index (LVI) proposed by Hahn et al. (2009), following the IPCC vulnerability framework, was adopted in the study and extended to measure and compare the livelihood vulnerability of the selected villages. The LVI major components are socio-demographic profile, livelihood strategies, health, food, water, social networks, natural disaster and climatic variation. Each major component has several sub-components and each sub-component contributes equally to the overall index (Table 1). The results are evaluated on a scale of 0 to 1, where 0 denotes least vulnerable and 1 denotes most vulnerable. A balanced weighted approach was followed for the LVI calculation (Hahn et al., 2009; Pandey and Jha, 2012). The values were standardized as:

$$s_d = (s_d - s_{\mathrm{Min}}) / (s_{\mathrm{Max}} - s_{\mathrm{Min}}), \tag{1}$$

where s_{d} is the original sub-component for an area d and s_{Min} and s_{Max} represent the minimum and maximum values for each sub-component respectively. After being standardized, the sub-components were averaged following:

$$M_d = \sum_{i=1}^{n} s_{di} / n \tag{2}$$

where M_d is one of the eight major components for an area d, s_{di} denotes the sub-components, indexed by i, which make up each major component, and n indicates number of sub-components for that major components. Once the values of each of the eight major components were calculated, they were then averaged to obtain the LVI using:

$$LVI_d = \sum_{i=1}^{8} Wm_i \times M_{di} / \sum_{i=1}^{8} Wm_i \tag{3}$$

where LVI_{d} is the LVI score of the area d and Wm_i is the weight, given by the number of sub-components that make up major component i.

The LVI-IPCC approach has also been applied in this study, following Hahn et al. (2009); this takes into account the IPCC vulnerability definition. The LVI-IPCC differentiates from the LVI as the major components are combined following the three elements of IPCC vulnerability mentioned in Section 1. Exposure of the target population is measured by their perception of natural disasters and climatic variation. Sensitivity is measured by assessing the present status of food, water and health security. Adaptive capacity is quantified by assessing the socio-demographic profile, livelihood strategies and social safety. The LVI-IPCC score varies from –1 to 1, where –1 is least vulnerable and 1 is most vulnerable. It was calculated using the following formula:

$$CF_d = \sum_{i-1}^{n} Wm_i \times M_{di} / \sum_{i-1}^{n} Wm_i \tag{4}$$

Table 1 Major components and sub-components of Livelihood Vulnerability Index (LVI)

Component	Explanation of the sub-component	Expected relationship
1. Socio Demographic Profile		
Dependency ratio	Ratio of population under 15 or over 65 years of age to population over 15 and under 65 years of age	Higher dependency ratio increases chances of vulnerability
Percentage of female-headed HHs	Percent of female members to total HH members	Higher proportion of female HH members increases vulnerability
Percentage of HHs where head of family did not attend school	Percentage of HHs where head had zero years of schooling	Higher non-attendance of school increases vulnerability
Percentage of HHs where head is the only earning member	Percentage of HHs where head is the only earning member	Higher percentage increases vulnerability
Average number of family members in a HH	Average number of family members in a HH	Higher number increases vulnerability because greater proportion of income will be used to feed members
Percentage of HHs with a non-climate-resilient home	Percentage of HHs with *kaccha* (mud) house type	Higher percentage increases vulnerability
2. Livelihood Strategy		
Percentage of HHs where family members migrate for work	Percentage of HHs where family members migrate for work	Higher percentage increases vulnerability since people have no work opportunity in their own place
Percentage of HHs dependent on natural resources	Percentage of HHs dependent on natural resources	Higher percentage increases vulnerability
Percentage of HHs where agriculture is the main source of income	Percentage of HHs where agriculture is the main source of income	Higher percentage increases vulnerability since agriculture is worst affected by climate change
Percentage of earning members in a HH	Percentage of members who earn in a HH	Lower percentage increases vulnerability
3. Health		
Percentage of HHs who find it difficult to reach health facilities	Percentage of HHs who find it difficult to reach health facilities because of greater distance of HH from health centre	Higher percentage increases vulnerability
Percentage of HHs whose family members died without treatment during natural hazards or other climatic events	Percentage of HHs whose family members died without treatment during natural hazards or other climatic events	Higher percentage increases vulnerability
Percentage of HHs without a sanitary latrine	Percent of HHs without a sanitary latrine	Higher percentage increases vulnerability
Percentage of HHs where members suffer from illness	Percentage of HHs reporting diseases	Higher percentage increases vulnerability
Percentage of HHs not visiting doctors during illness	Percentage of HHs not visiting doctors during illness due to lack of awareness	Higher percentage increases vulnerability
4. Food		
Percentage of HHs that do not get food from the family farm	Percentage of HHs that do not get food from the family farm	Higher percentage increases vulnerability
Percentage of HHs reporting decreasing regeneration of green leafy vegetables	Percentage of HHs reporting decreasing regeneration of green leafy vegetables	Higher percentage increases vulnerability
Percentage of HHs losing agricultural land	Percentages of HHs losing agricultural land	Higher percentage increases vulnerability
Percentage of HHs reporting decreasing agricultural production	Percentage of HHs reporting decreasing agricultural production	Higher percentage increases vulnerability
Percentage of HHs reporting increasing food insecurity during natural disasters or other climatic events	Percentage of HHs reporting increasing food insecurity during natural disasters or other climatic events	Higher percentage increases vulnerability
Percentage of HHs reporting decreasing fish production	Percentage of HHs reporting decreasing fish production because of saline water intrusion in the sweet water bodies	Higher percentage increases vulnerability
5. Water		
Percentage of HHs whose members walk more than 2 km to reach a water source	Total distance required to reach a safe drinking source	Higher percentage increases vulnerability
Percentage of HHs using unsafe water for drinking, cooking, bathing and washing	Percentage of HH use unsafe water for drinking, cooking, bathing and washing (river, pond, hole, contaminated water)	Higher percentage increases vulnerability
Percentage of HHs reporting water conflict	Percentage of HHs reporting conflict due to using the same water sources	Higher percentage increases vulnerability

Continued Table

Component	Explanation of the sub-component	Expected relationship
6. Social Safety		
Percentage of HHs who do not receive assistance from a social network	Percentage of HHs who do not receive assistance from a social network	Higher percentage increases vulnerability
Percentage of HHs who do not receive assistance from the Government	Percentage of HHs who do not receive assistance from the Government	Higher percentage increases vulnerability
Percentage of HHs who do not receive assistance from NGOs	Percentage of HHs who do not receive assistance from NGOs	Higher percentage increases vulnerability
Percentage of HHs who do not use mobile phones for communication	Percentage of HHs who do not use mobile phones for communication	Higher percentage increases vulnerability
Percentage of unaware HHs	Percentage of HHs who reported no awareness generation from local authority	Higher percentage increases vulnerability
7. Natural Disasters		
Percentage of HHs reporting increased frequency and intensity of storm surges and tidal surges	Percentage of HHs reporting increased frequency and intensity of storm surges and tidal surges in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs with an injury or death as a result of natural disasters	Percentage of HHs with an injury or death as a result of natural disasters occurring in the last 10 years	Higher percentage increases vulnerability
Percentage of HHs with an injury or death to their livestock as a result of natural disasters	Percentage of HHs with an injury or death to their livestock as a result of natural disasters occurring in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs with losses of physical assets	Loss of assets such as homestead, agricultural equipment, machinery in the last 10 years	Higher percentage increases vulnerability
Percentage of HHs that do not receive warning before a natural disaster	Percentage of HHs that do not receive a warning before a natural disaster	Higher percentage increases vulnerability
8. Climatic Variation		
Percentage of HHs reporting a change in summer temperature	Percentage of HHs reporting an increase in summer temperature in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs reporting a change in winter temperature	Percentage of HHs reporting a decrease in the span of winter in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs reporting variation monsoon precipitation	Percentage of HHs reporting variation in monsoon precipitation in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs reporting a change in winter precipitation	Percentage of HHs reporting an increase in winter precipitation in the last 10 yr	Higher percentage increases vulnerability
Percentage of HHs reporting a change in the frequency of floods	Percentage of HHs reporting an increase in the frequency of floods in the last 10 yr	Higher percentage increases vulnerability

Notes**:** HH, Household; NGO, Non-Governmental Organization.

where CF_d is an IPCC-defined contributing factor (exposure, sensitivity, or adaptive capacity) for *mouza d*, M_{di} are the major components for area d indexed by *i*, Wm_i is the weight of each major component, and *n* is the number of major components in each contributing factor. Once exposure, sensitivity, and adaptive capacity were calculated, the three contributing factors were combined using the following equation:

$$LVI\text{-}IPCC_d = (e_d - a_d) \times s_d \qquad (5)$$

where $LVI\text{-}IPCC_d$ is the LVI for *mouza d* expressed using the IPCC vulnerability framework, e_d is the calculated exposure score for area *d* (weighted average of natural disaster and climate variation major components), a_d is the calculated adaptive capacity score for area *d* (weighted average of the socio-demographic profile, livelihood strategy, and social networks major components), and s_d is the calculated sensitivity score for area *d* (weighted average of the health, food, and water major components).

3 Results and Discussion

3.1 Indicators of climate change

3.1.1 Change of temperature, precipitation

Globally, variations in temperature and precipitation patterns have been interconnected with climate change phenomena (Mondal et al., 2015; Rahman and Lateh, 2017). In this study, an analysis of temperature and precipitation data over 117 yr was conducted to identify how the patterns have changed. The results show that the average temperature and precipitation in the study area increased by 0.034℃ and 3.71 mm, respectively, from 1901 to 2017 (Figs. 2a, 2b). It has also been observed that most of these rises in temperature and precipitation took place during the period 2001–2017. In this study, variations in minimum and maximum temperatures in four seasons (Kundu et al., 2016): winter (December to February), pre- monsoon (March to May), monsoon (June to September) and post-monsoon (October to November), are shown. The result clearly indicates that maximum temperature has risen abruptly during the

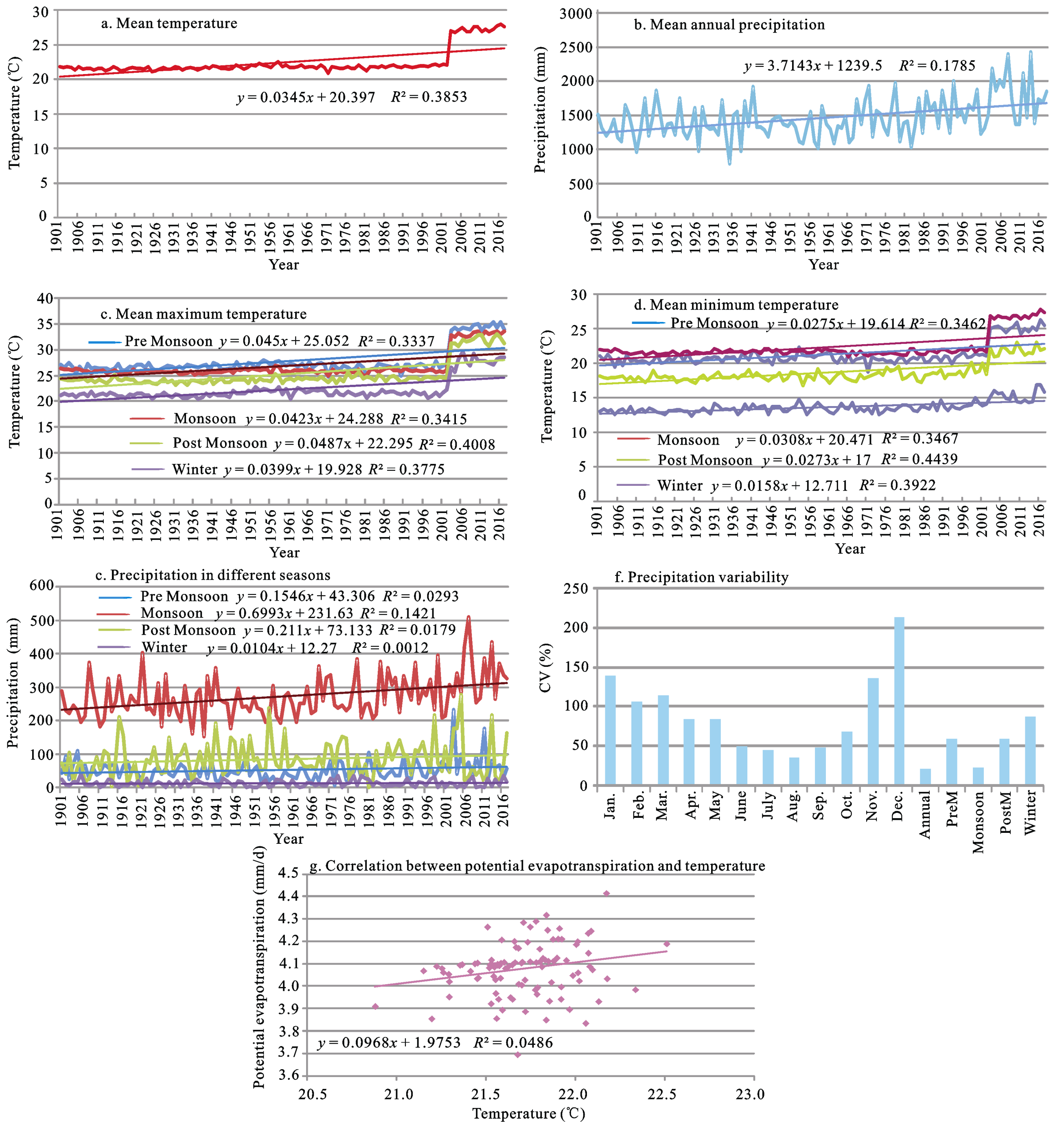

Fig. 2 Mean temperature (a), mean annual precipitation (b), mean maximum temperature (c), mean minimum temperature (d), precipitation in different seasons (e), precipitation variability (f) and correlation between potential evapotranspiration and temperature (g) of Sagar Island from 1901 to 2017. CV, coefficient of variation in precipitation; PreM, pre monsoon; PostM, post monsoon

pre-monsoon and post-monsoon seasons, while the greatest rise in minimum temperature is found in the pre-monsoon, monsoon and post-monsoon seasons (Figs. 2c, 2d). The greatest increase in precipitation was in the monsoon season, followed by the post-monsoon and pre-monsoon periods. Such pronounced changes of minimum and maximum temperature and precipitation in the study area in four seasons signify a large climatic variation. The coefficient of variation of precipitation over a period of 117 yr shows that the highest variation in precipitation is found in the winter, pre-monsoon and post-monsoon periods. The variation seems to be highest especially in the month of December (Figs. 2e, 2f). As well as temperature and precipitation, evapotranspiration is a significant climatic variable. It is directly related to temperature and influences the precipitation pattern, and its role is extremely important for understanding the trend of climatic changes (Kundu et al., 2016). A positive correlation between potential evapotranspiration and temperature signifies that with increasing temperature there is a greater amount of loss of water from the surface (Fig. 2g), which is an important factor in the growth of plants and crops (Palutikof et al., 1994).

3.1.2 Sea level rise and higher tidal surges

Sea level rise is one of the most critical consequences of climate change as it harms the coastal ecosystem, economy, infrastructure and, most importantly, coastal livelihoods, with more frequent flooding during storms and high tidal surges (Nicholls and Cazenave, 2010; Hallegatte et al., 2013). The IPCC predicted an increase in global mean sea level of 0.28–0.98 m by 2100 compared to the average estimated level between 1986 and 2005 (Church et al., 2013; Kemp et al., 2015). Sea level rise data for Sagar Island are only available for the period 1937–1988. Therefore, the present study considers the rate of sea level rise at Diamond Harbour Station (near Sagar), where the sea level has been rising at a rate of 5.74 mm/yr from 1948 to 2013 (Fig. 3). There is also evidence of higher storm surges (8.13–10.01 mm) in Sagar Island over a return period of 100 years (1901–2002), in comparison with areas nearby in South 24 Parganas District (Fig. 4). The storm surge heights are extremely low at islands which are uninhabited and covered by mangrove forest (Forest cover of Gosaba, Basanti Kutali Block).

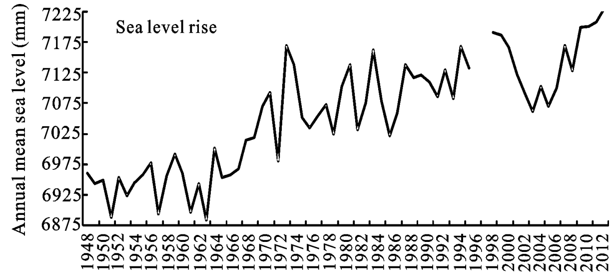

Fig. 3 Sea level rise at Diamond Harbour Station (near Sagar) from 1948 to 2013. Data are from Global Sea Level Observing System, 1948–2013, data in 1997 and 1998 are not available

3.1.3 Probability of intensification of depressions into cyclonic storms

Coastal communities around the world, especially in less-developed countries, are particularly threatened by violent storm surges and tropical cyclones, which lead to the loss of lives and assets of millions of people (Resio and Irish, 2015). For example, cyclone *Aila* (25 May, 2009), which struck coastal Bengal, affected over 5.1 million people in West Bengal and over 500 000 houses have been either fully or partially damaged (International Federation of the Red Cross and Red Crescent Societies (IFRCRCS, 2009). According to Indian Meteorological Department records, there were 809 depressions, 293 cyclonic storms and 232 severe cyclonic storms in the Bay of Bengal and its coastal land area during the period 1891–2016. Among these 9.64% of the depressions, 9.21% of the cyclonic storms and 6.03% of the severe cyclonic storms took place in the last decade, that is, during 2006–2016. The depressions and cyclonic storms occurring in the Bay of Bengal can play a vital role in Sagar Island, so they are considered for the current study. The probability of intensification of a depression into a cyclonic storm is 39.4%, and into a severe cyclonic storm is 17.4%. The probability is highest in the month of April followed by March, May and November in the case of depression to cyclone and in the month of May followed by April and November in the case of depression to severe cyclonic storm. More than 50% of the cyclonic disturbances that form in the months of March, April, May, November and December intensify into storms (Fig. 5). The wind speed during depressions varies in the range 41–61 km/h and during cyclones it increases to above 61 km/h. The wave heights during high tide and low tide in Sagar Island are

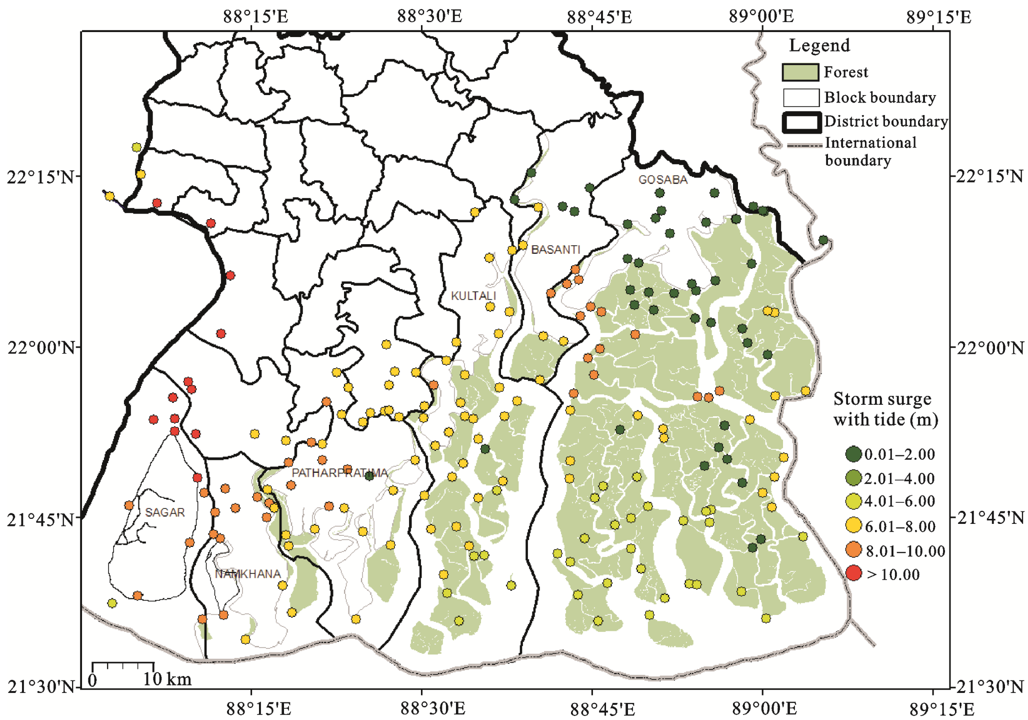

Fig. 4 Storm surges and tidal surges in a return period of 100 years in Sagar Island and South 24 Parganas District. Data are from Water Resources Information System, India, 1901–2002

generally 4.0 m and 1.8 m, respectively but occasionally reach 5.9 m and 0.1 m, respectively. During cyclones, the wave height even exceeds 9 m which leads to wider coastal erosion.

All this evidence of increasing temperature, variation of precipitation, increasing frequency of cyclones over the northern part of the Bay of Bengal, and higher storm surges, signifies an intensification of climatic forces, with coastal land loss, changes of land use patterns, decreases of crop land, and increases of saline marshy areas being the major impacts.

3.2 Impact analysis: shoreline change, coastal land loss and resultant land use change

Higher storm surges, rising frequency and intensity of cyclones and greater tidal ingression all intensify coastal erosion. Sagar Island has experienced considerable shoreline change from 1977 to 2017. The rate of accretion is 5.84% while the rate of erosion is 11.71% (Fig. 6a). The *mouzas* located in the southern part of the island experienced greater erosion compared to the villages in the eastern and northern parts. The southern part of Sagar has been heavily eroded and the erosion is extreme in Mansamandir Boatkhali, located in Dhablat and Sibpur *mouza*. Mud embankment construction work has taken place in Beguakhali, but the greater portion of Dhablat and Sibpur is still unprotected. The stretch of embankment breaching in the southern, eastern and northern parts is 6.74 km, 1.96 km and 1.94 km respectively (Fig. 6b). The primary survey showed that people of Dhablat are leaving their locality and moving to the interior of Sibpur. If erosion continues at its current rate then Dhablat village will soon disappear.

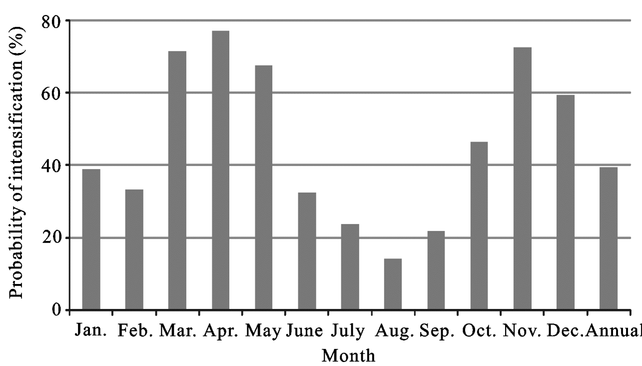

Fig. 5 Monthly probability of intensity of depressions and cyclonic storms (1891–2016). Data are from Regional Meteorological Centre, 1891–2016

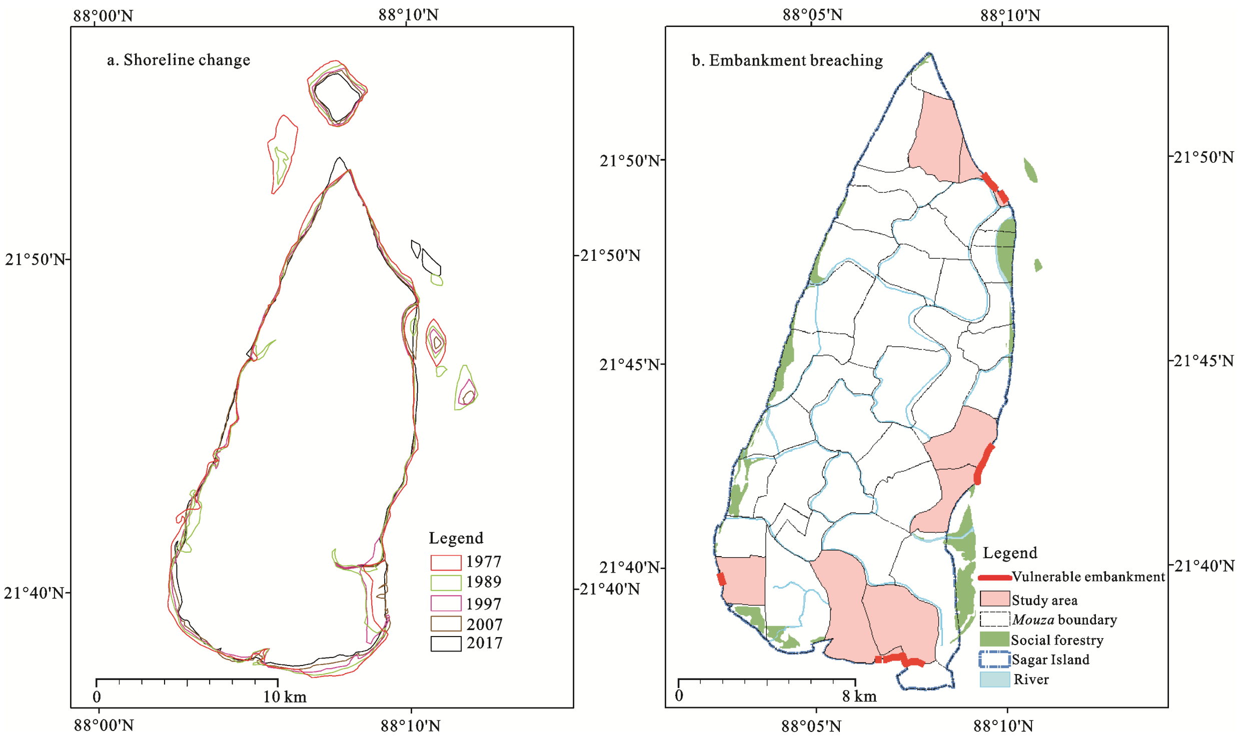

Fig. 6 Shoreline change (1977–2017) (a) and embankment breaching (b) of Sagar Island

The impact of a continuous erosion and accretion process on human activity and resource utilization patterns is mostly felt along the coastal zones of island systems (Hazra et al., 2017). There has been a change in the land use pattern, associated with the coastal land loss in the study area. Applying the supervised classification method to Sagar Island, it is observed that all the *mouzas* have experienced a decrease in total area. Sibpur (10.45%), Beguakhali (9.57%) and Dhablat (6.64%) lost the greatest percentage of land area from 1996 to 2017. There was also a decrease in the areas of arable land (12.10%), vegetation (0.81%) and mangrove (3.7%), and an increase in the areas of coastal water (1.58%), wetland (4.96%) and settlement (4.83%), in terms of the total land area of all *mouzas* (Fig. 7). Decreasing agricultural land and increasing land under coastal water and wetland signifies that agriculture is hugely affected, and such changes in land use are sure to have an impact on the livelihood of the population.

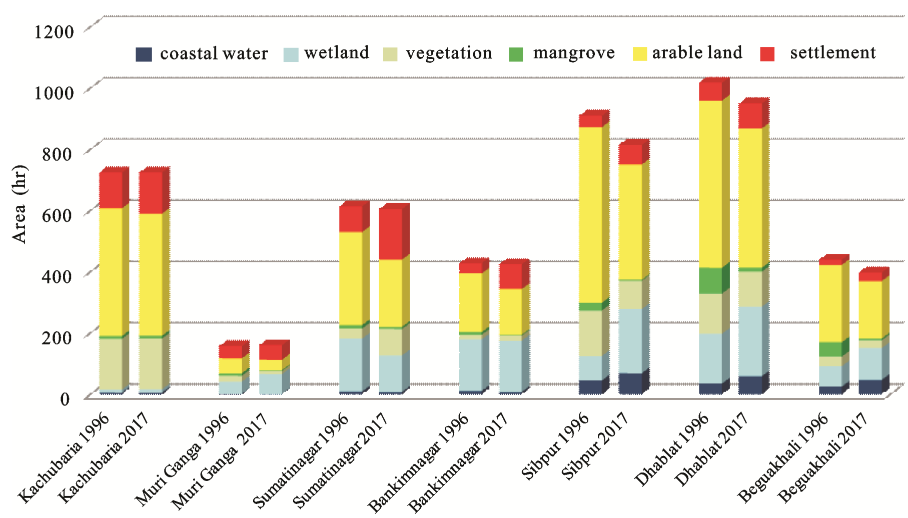

Fig. 7 Land use change of the seven *mouzas* identified through supervised classification on Sagar Island

3.3 LVI analysis

Table 2 shows the values of the main components and sub-components chosen for the LVI analysis, and also the composite value of LVI, for each of the *mouzas*. A higher index value score, signifies a higher vulnerability, and vice versa. The highest vulnerability is observed in Dhablat (0.678), followed by Sibpur (0.651), Bankimnagar (0.634), Sumatinagar (0.634) and Muri Ganga (0.603), while the lowest is observed in Kachubaria (0.475), followed by Beguakhali (0.579).

Table 2 Indexed values for Livelihood Vulnerability Index (LVI) of the seven *mouzas* on Sagar Island

Component	Beguakhali	Dhablat	Bankimnagar	Muri Ganga	Sumatinagar	Kachubaria	Sibpur
1. Socio-Demographic Profile	**0.472**	**0.483**	**0.417**	**0.402**	**0.445**	**0.461**	**0.434**
Dependency ratio	0.397	0.377	0.392	0.297	0.498	0.310	0.386
Percentage of female-headed HHs	0.027	0.154	0.020	0.075	0.075	0.172	0.078
Percentage of HH where head of family did not attend school	0.333	0.192	0.113	0.275	0.150	0.448	0.196
Percentage of HHs where head is the only earning member	0.638	0.769	0.681	0.625	0.800	0.655	0.627
Average number of family members in a HH	0.502	0.446	0.456	0.490	0.425	0.392	0.496
Percentage of HHs with a non-climate-resilient home	0.940	0.961	0.840	0.650	0.725	0.793	0.823
2. Livelihood Strategy	**0.570**	**0.562**	**0.517**	**0.383**	**0.552**	**0.409**	**0.657**
Percentage of HHs where family members migrate for work	0.638	0.567	0.504	0.725	0.775	0.586	0.725
Percentage of HHs dependent on natural resources	0.916	0.981	0.636	0.375	0.825	0.448	0.960
Percentage of HHs where agriculture is the main source of income	0.416	0.423	0.590	0.125	0.275	0.276	0.608
Percentage of earning members in a family	0.313	0.280	0.339	0.307	0.336	0.329	0.338
3. Health	**0.456**	**0.515**	**0.458**	**0.460**	**0.430**	**0.165**	**0.490**
Percentage of HHs who find it difficult to reach health facilities	0.922	0.962	0.954	0.825	0.950	0.793	0.925
Percentage of HHs whose family members died without treatment during natural hazards or other climatic events	0.027	0.230	0.181	0.125	0.125	0.310	0.196
Percentage of HHs without a sanitary latrine	0.694	0.807	0.477	0.425	0.400	0.196	0.686
Percentage of HHs where members suffer from illness	0.555	0.500	0.590	0.625	0.550	0.724	0.568
Percentage of HHs not visiting doctors during illness	0.083	0.0769	0.090	0.300	0.125	0.482	0.0784
4. Food	**0.722**	**0.785**	**0.711**	**0.722**	**0.698**	**0.086**	**0.877**
Percentage of HHs that do not get food from the family farm	0.500	0.577	0.500	0.900	0.825	0.793	0.451
Percentage of HHs reporting decreasing regeneration of green leafy vegetables	0.583	0.692	0.636	0.625	0.700	0.740	0.706
Percentage of HHs losing agricultural land	0.750	0.965	0.750	0.750	0.500	0.793	0.840
Percentage of HHs reporting decreasing agricultural production	0.694	0.615	0.727	0.475	0.475	0.620	0.549
Percentage of HHs reporting increasing food insecurity during natural disasters or other climatic events	0.805	0.923	0.886	0.825	0.948	0.586	0.902
Percentage of HHs reporting decreasing fish production	1.000	0.942	0.772	0.757	0.743	0.827	0.941
5. Water	**0.527**	**0.666**	**0.552**	**0.666**	**0.596**	**0.538**	**0.450**
Percentage of HHs who walk more than 2 km to reach a water source	0.472	0.692	0.704	0.725	0.517	0.517	0.745

Continued Table

Component	Beguakhali	Dhablat	Bankimnagar	Muri Ganga	Sumatinagar	Kachubaria	Sibpur
Percentage of HHs using unsafe water for drinking, cooking, bathing and washing	0.638	0.885	0.204	0.65	0.825	0.650	0.078
Percentage of HHs reporting water conflict	0.472	0.423	0.750	0.625	0.448	0.448	0.529
6. Social Safety	**0.376**	**0.523**	**0.558**	**0.555**	**0.525**	**0.578**	**0.471**
Percentage of HHs who do not receive assistance from a social network	0.027	0.038	0.272	0.500	0.075	0.413	0.176
Percentage of HHs who do not receive assistance from the Government	0.916	0.923	0.954	0.725	0.825	0.931	0.784
Percentage of HHs who do not receive assistance from NGOs	0.940	0.961	0.954	0.975	0.875	0.965	0.945
Percentage of HHs who do not use mobile phones for communication	0	0.002	0.136	0.050	0.025	0.206	0.058
Percentage of unaware HHs	0	0.692	0.477	0.525	0.825	0.379	0.392
7. Natural disasters	**0.421**	**0.596**	**0.583**	**0.335**	**0.535**	**0.723**	**0.458**
Percentage of HHs reporting increased frequency and intensity of storm surges and tidal surges	0.972	0.895	0.886	0.425	0.950	0.793	0.647
Percentage of HHs with an injury or death as a result of natural disasters	0	0.230	0.295	0.085	0.300	0.586	0.176
Percentage of HHs with an injury or death to their livestock as a result of natural disasters	0.194	0.461	0.431	0.142	0.450	0.482	0.450
Percentage of HHs with losses of physical assets	0.940	0.915	0.825	0.925	0.775	0.965	0.941
Percentage of HHs that do not receive warning before a natural disaster	0	0.482	0.481	0.100	0.200	0.793	0.078
8. Climatic Variation	**0.709**	**0.877**	**0.865**	**0.940**	**0.906**	**0.641**	**0.897**
Percentage of HHs reporting a change in summer temperature	0.832	0.961	0.954	0.975	0.900	0.800	0.960
Percentage of HHs reporting a change in winter temperature	0.658	0.654	0.681	0.925	0.900	0.650	0.607
Percentage of HHs reporting variation in monsoon precipitation	0.856	0.808	0.854	0.950	0.875	0.660	0.961
Percentage of HHs reporting a change in winter precipitation	0.844	0.981	0.915	0.925	0.915	0.715	0.980
Percentage of HHs reporting a change in the frequency of floods	0.358	0.981	0.925	0.925	0.941	0.380	0.980
score	**0.579**	**0.678**	**0.634**	**0.603**	**0.634**	**0.475**	**0.651**

Notes: HH, Household; NGO, Non-Governmental Organization.

3.4 LVI-IPCC analysis

LVI-IPCC analysis attempts to understand the degree of exposure and sensitivity of a community to climatic changes and whether its adaptive capacity is sufficient to cope with the situation (Fig. 8a). Table 3 shows that the adaptive capacity of all the *mouzas* varies from 0.460 to 0.510 so that they are all fairly similar, but it is the degree of exposure and sensitivity which makes these *mouzas* more or less vulnerable. The LVI-IPCC analysis shows that Dhablat (0.145) is highly vulnerable, followed by Bankimnagar (0.137), Sumatinagar (0.128), Muri Ganga (0.117) and Sibpur (0.111). The lowest vulnerability is observed in Kachubaria (0.041), followed by Beguakhali (0.057).

The LVI score matches with the LVI-IPCC score in that, apart from Kachubaria and Beguakhali, all the other *mouzas* score highly for both the indices (Fig. 8b). All the highly vulnerable *mouzas* have experienced higher rates of coastal erosion, embankment breaching and flooding, and this differentiates the levels of vulnerability among the *mouzas*. New embankment construction work has almost been completed in Beguakhali and Kachubaria, and this lowers both their LVI and LVI-IPCC scores.

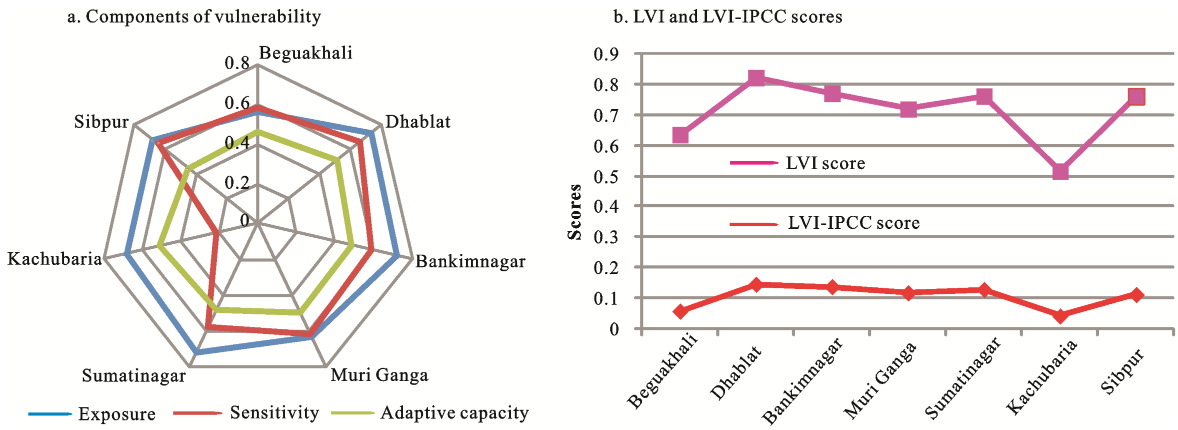

Fig. 8 Components of vulnerability (a), Livelihood Vulnerability Index (LVI) and Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change (LVI-IPCC) scores (b) of the seven *mouzas* on Sagar Island

Table 3 Livelihood Vulnerability Index-Intergovernmental Panel on Climate Change (LVI-IPCC) contributing factors for the seven *mouzas* on Sagar Island

	Beguakhali	Dhablat	Bankimnagar	Muri Ganga	Sumatinagar	Kachubaria	Sibpur
Exposure	0.565	0.736	0.724	0.637	0.720	0.682	0.678
Sensitivity	0.585	0.663	0.587	0.616	0.580	0.211	0.648
Adaptive capacity	0.466	0.517	0.490	0.447	0.500	0.486	0.506
LVI-IPCC	**0.057**	**0.145**	**0.137**	**0.117**	**0.128**	**0.041**	**0.111**

3.5 Component and sub-component-specific analysis

The first component is socio-demographic profile, where Dhablat *mouza* scored the highest and Muri Ganga *mouza*, the lowest index value. In Sumatinagar *mouza*, the dependency ratio (0.498) and single earning member HH (household) (0.800) indices are found to be highest amongst all the *mouzas*. Where the head is the only earning member of a HH, the resilience to any hazardous situation decreases and the dependency ratio increases. The percentage of female-headed HHs is highest in Kachubaria (17.2%), where also 44.8% of the heads of HH never attended school. These female heads of HH have to shoulder the huge pressure of HH activities and, in addition, they have to earn more for survival. A lack of education of a head of HH means they have less knowledge about how to cope with any disaster. More than 65% of the HHs are mud houses, with the highest percentage found in Dhablat (96.1%) and the average number of family members mostly varies from four to five. Their houses are generally made of mud with thatched roofs. Such houses are not climate-resilient in nature and during hazards become vulnerable to full or partial damage, increasing the vulnerability of the HH further.

The second component is livelihood strategy and its highest index value is found in Sibpur (0.657), and lowest in Muri Ganga (0.383). In Bankimnagar (59.0%) and Sibpur (60.8%) more HHs are solely dependent on agriculture. Coastal erosion leads to land loss and saline water intrusion which has a detrimental impact on agriculture (Fig. 7). Thus dependency on agriculture increases HH vulnerability. The percentage of earning members is lowest in Dhablat (28.0%), which signifies that HHs have fewer opportunities for earning income. This increases their risk factor during a disaster. Most of the HHs of all the *mouzas* are dependent on natural resources, which makes them all highly vulnerable because natural hazards and climatic events pose greater threats to local natural resources. The outward migration rate is highest in Sumatinagar (77.5%), Muri Ganga (72.5%) and Sibpur (72.5%), where HH members migrate to various places due to a scarcity of work opportunities in their locality. People in rural areas are compelled to migrate elsewhere—to places such as Andaman Nicobar Island, Tamilnadu, Chennai, Hyderabad, Punjab, Maharastra, Puruliya, Burdwan, Asansol, Kolkata, Delhi and Bangalore and, most frequently, Kerala and Gujarat—after becoming landless or jobless as a result of climate change. They earn INR 250–400 per day, but the jobs are seasonal in nature, so after just 3 to 4 months they return to their previous location with its associated level of vulnerability. The migration destination does not represent a long-term option because migration is based on an agent network.

Health is the third component, for which Dhablat *mouza* (0.515) has the highest and Kachubaria (0.165) the lowest vulnerability score. Inadequate development of transport and communication infrastructure inhibits people from visiting healthcare facilities. Rudranagar is the main health centre, and it is distant from Dhablat, Sibpur, Beguakhali and Kachubaria (approximately 12 km). A greater distance to the main health centre means people are more likely to visit unqualified doctors for medical treatment, which is insufficient and of poor quality. Many people surveyed in this study area also unaware of the need to visit the health centres (< 7% visit) during illness and a higher percentage of HHs do not have a proper sanitary latrine (> 40% except Kachubaria). The situation becomes worse during hazardous events, even leading to the death of family members.

The fourth component is food, with Dhablat (0.785) ranked highest and Kachubaria (0.086) lowest in index value. Salt water intrusion lowers the fertility of soil and directly affects post-flood agricultural production. 59.36% of HHs reported loss of cropland and reduced agricultural production owing to saline water intrusion. Before the Aila cyclone of 2009, agricultural yields were much higher than at present. High temperature and saline conditions affect certain species' phenotypic plasticity, often leading to decreased regeneration (Sengar and Sengar, 2015; Mukherjee and Siddique, 2018); this has been the case for the study area in the present study. Decreased regeneration of certain green leafy vegetables (*Marsilea minuta, Amaranthus spinosus*, *polia, pute, maris*) over a period of years has been reported by 66.88% of the total HHs. People from rural areas, who used to consume these leafy vegetables, mentioned that nowadays some of them are much less widely available and some are not available at all because of the high salinity of the soil. The number of HHs dependent on the yield of their own farm seems to be low (35.96%), so that the population is only partially supported directly by their farmland. A higher percentage of people procure a range of food items directly from the market. All these factors make the local people food insecure during hazardous events. People from the study area reported that since the intrusion of saline water into their ponds, there has been a huge reduction in fish yields from the fresh water system. Local people tried to drain the saline water from the ponds and allow fresh water to replace it to help fishing activity, while others adapted to cultivating prawns. However, there is a general opinion that good catches have become less common in the post-Aila period: both the quality and volume of the catches have significantly decreased.

For water, the fifth component, Dhablat (0.666) and Sibpur (0.450) recorded the highest and lowest index values respectively. Saline water intrusion has lowered the quality of potable water sources in the study area. 62.46% of HHs stated that their members have to walk for kilometres to reach water sources, where water is only available for a specific time period and the queue is quite long, which sometimes causes conflict among individuals (52.79% of HHs). Obtaining water for drinking and cooking for the household from the same source creates an extra burden for the female members. Saline pond water is used in most cases for washing clothes and bathing, which leads to skin diseases. Women are especially susceptible to such diseases (56.14% of HHs) because they often use saline water for various household activities, and they do most of the prawn seed collection, which requires a high level of body contact with saline water sources for a long time period. Research on shrimp fry (*meen*) farmers of the Sundarban Mangrove Forest found that direct and prolonged contact with salt water sources during farming activity exposes women more than men to skin infections and other waterborne diseases (Chowdhury et al., 2008; Das et al., 2016).

The sixth component is social safety. Here, the highest and lowest index values are found in Kachubaria (0.578) and Beguakhali (0.376), respectively. Most of the HHs receive social assistance from their neighbours and relatives in all of the *mouzas* surveyed. People living in elevated parts of inland areas allow others to take shelter during hazards and financial help is also given during periods of extreme food insecurity. More than 70% of the HHs in all of the *mouzas* informed us of their dissatisfaction with the role played by Government and Non-Government Organizations during post-hazard periods. Flood defences are not erected in a timely manner and the materials used for their construction are of poor quality, which causes frequent breaching. Villagers employ their own physical labour and use their own money to erect mud embankments or provide extra protection by using bamboo netting. Many HHs noted that even though they suffered severe damages during Aila, they are yet to receive partial (INR 2500) or full (Rs. 10 000) compensation. Flooding is a common phenomenon in any tidal zone, so training programmes need to be organized by schools or local clubs to help people to adapt to and cope with it. But such awareness is largely absent in the study area. Sumatinagar *mouza* records the lowest awareness score (82.5% of HHs), although more than 90% of HHs have access to a mobile phone, which keeps them informed about approaching hazards.

The seventh and eighth components, natural disasters and climatic variation, help to understand the population's perception of natural hazards and climate change. It is noted that the majority of the HHs of all *mouzas* perceive that there is an increasing effect of storm surges and natural hazards (79.54%), increasing summer temperatures (91.17%), decreasing span of the winter season (72.50%), enhanced monsoon precipitation extremes (85.20%) (affecting the agricultural community) and more precipitation during the post-monsoon and winter seasons (89.64%) (precipitation in November 2017 affected *Aman* rice production). Flooding occurs on an annual basis in the study area, either because of higher precipitation or embankment breaching, and Dhablat (0.981), Sibpur (0.980) and Sumatinagar (0.941) *mouzas* are the worst affected. Villagers living in the marginal areas of Dhablat, Sumatinagar and Bankimnagar reported that salt water enters into their land at every high tide, so they are constantly living with flooding. Flooding occurs in every village, especially during monsoon months. A high percentage of HHs are not climate-resilient. Houses located in the marginal areas are partially or completely damaged every year. Many people reported that in their lifetime of 50–70 yr, they have reconstructed their home at least three or four times. Many people who cannot afford to rebuild their severely damaged houses use tarpaulin to survive during the flooding period. They literally live on the embankment during this time, for weeks or even 3–4 mon depending on the degree of impact of the flood. When the water starts to recede, they return down from the embankment and start rebuilding their shelter with mud, bamboo sticks and other local natural resources. People also reported that embankments are not erected properly and not in good time to defend against flooding. Both the Aila embankment and boulder embankments were constructed with non-sustainable materials, resulting in frequent breaching. Villagers must protect and repair the embankments themselves using bamboo sticks and mud in most cases.

Finally, it can be stated that strengthening the socio-demographic profile, social network and diversification of livelihood activities may improve the adaptive capacity of the community. Further development of infrastructure in terms of providing proper health care, drinking water facilities and better transport and communication facilities is required to cope with vulnerability related to climate change.

4 Conclusions

Efforts have been made in this study to explore some of the indicators of climate change and their effects, and to compare LVI and LVI-IPCC scores among seven villages, in order to probe into the impact of climate change on coastal communities on Sagar Island. The study reveals that climate change has led to a rise in both maximum (0.043℃/yr) and minimum (0.025℃/yr) temperature (pre-monsoon and post-monsoon seasons), precipitation variation (monsoon and winter seasons), sea level rise (5.74 mm/yr) and intensification of natural hazards (higher storm surges of 8–10 m, cyclones, floods), which together lead to ecological and socio-economic impacts. The empirical study finds that the *mouzas* that experience severe coastal erosion, embankment breaching, flooding and poor management during post-disaster periods (i.e., poor embankment reconstruction and less help from the government and NGOs) scored high vulnerability index values for both LVI (0.60–0.68) and LVI-IPCC (0.11–0.14). Highly vulnerable *mouzas*, such as Dhablat, Sumatinagar, Bankimnagar, Sibpur and Muri Ganga, have a poor socio-demographic profile (43.60% of HHs), a poor livelihood status (53.47% of HHs), less social security (52.66% of HHs), potable water scarcity (58.67% of HHs), immense food insecurity during hazard and disaster periods (75.92% of HHs), a lower health status (47.09% of HHs), and greater exposure to climatic variation (89.73% of HHs) and natural environmental hazards (50.18% of HHs). Coastal erosion and consequent breaching of flood defences cause saline water intrusion in the study area that has turned the crop land and fresh water bodies sterile. Production of rice, vegetables and fish for local consumption has been greatly declining for years, forcing young male household members to leave for distant cities in other states in search of unskilled labour jobs.

The main result of this study is a quantification of the vulnerability of the lives and livelihoods of the population of Sagar Island. It has identified which sectors require special attention in developing resilience to cope with the negative impacts of climate change. The findings could help the Government or local authorities to improve and sustain site-specific coping and adaptation strategies for poor households living in coastal areas.

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