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Assessing risks from climate variability and change for disaster-prone zones in Bangladesh

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ABSTRACT

We have measured livelihoods vulnerability indices for four disaster prone zones in Bangladesh, namely saline, flood, flash flood and drought. A total of 2558 households were surveyed to collect data on socio-demographics, livelihoods, social networks, health, food and water security, natural disasters and climate variability. The data were aggregated using a composite index and vulnerabilities across the four disaster prone areas were compared. Our results show that the flash flood zone is the most vulnerable zone followed by the saline, drought and flood zones respectively. The flash flood zone is mainly a mono-rice crop area and local livelihood opportunities are uncertain and limited. Road infrastructure is poor as a large part of this zone remains under water in the wet season. Public health services are underprovided and the hospitals are understaffed, sanitary conditions are poor and the households suffer a longer period of food insecurity. The poor households living in the saline zone have to depend more on social networks and local authorities to withstand livelihood shocks brought about by natural disasters such as tidal surges, cyclones and increasing salinity. The drought and saline zones are highly vulnerable to water. Water in these zones is not only scarce but also unsafe for drinking. The saline zone also suffers from salinity in water used for irrigation which has already affected productivity of land. We suggest an increase in public spending on sanitation and drinking water, health and rural infrastructure particularly in the disaster prone areas where incidence of poverty is high.

1. Introduction

Climate vulnerabilities and associated impacts vary by spatial, temporal scale and socio-economic condition of communities. For instance, Bangladesh faces too much water in the monsoon causing floods and too little water in the dry season causing droughts. The coastal area of the country is prone to salinity intrusion and tropical cyclones; floodplains in the central areas are prone to flood; north western region of the country is prone to drought; and the north-eastern part of the country is prone to flash flood. Variation in climate vulnerabilities and associated impacts demand different, disaster specific, adaptation measures and actions. In order to do this, however, there is a need for a thorough understanding of the nature of vulnerabilities and its magnitude and determinants in different disaster zones in Bangladesh.

Disaster risk reduction agenda has gradually shifted from public reaction to prevention [5]. Natural disasters may be considered as rapid, instantaneous or profound impacts on natural environment upon the socio-economic system [3,4]. The risks involved in disasters are connected

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with vulnerabilities people face in their normal existence [9,36]. Vulnerability can be defined as "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impacts of hazards" [41, p. 16]. Disaster risk is developed because of hazards and the vulnerabilities of the social and the physical environments to hazards [32]. Thus disasters are also product of social, political and economic environments. Wisner [43] has shown that the effects of Hurricane Mitch in Honduras are caused also by misguided political decisions and vulnerability in rural South Africa is largely determined by apartheid's spatial planning, rural poverty and mismanagement of land resources.

Vulnerability assessment helps understand the complex set of factors that contribute to adaptive capacity of the households and describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. Hahn et al. [20] estimated the livelihood vulnerability index (LVIs) as well as LVI–IPCC indices for two districts in Mozambique but suggested that the scale of vulnerability can be extended to include other dimensions such as communities or regions. The LVI is comprised of a composite index comprising seven major components while LVI/IPCC aggregates these components to IPCC's three contributing factors to vulnerability: exposure, sensitivity, and adaptive capacity. Eakin and Bojorquez-Tapia [15] have also emphasisedthe need to compare vulnerabilities across larger regional processes. Both have found that the indicators considered to measure vulnerability index do not vary much within a smaller region. More heterogeneous regions in the context of larger size and climate variability may provide larger divergence in the indicators of vulnerability.

We have harnessed the flexibility and advantages of the indices proposed by Hahn et al. [20] to measure livelihoods vulnerability in four disaster prone zones in Bangladesh, namely saline, flood, flash flood and drought by using primary survey data. We have presented the results from using the two alternative approaches; the LVI and LVI/IPCC. We have not preferred one approach to the other but following Hahn et al. [20] only presented them as alternatives. Each approach provides detailed depiction of factors driving livelihood vulnerability of the households in a particular region [20, p. 86]. This has never been done in Bangladesh and existing studies on vulnerability assessment suffer from at least two major drawbacks. First, the studies have taken the qualitative route [36] and lack systematic identification and measurement of the determinants of livelihood vulnerabilities. Second, there is a disproportionately larger focus on coastal vulnerability at the expense of vulnerabilities in other parts of the country [40,2]. We do not know which region can be most affected by climate change in terms of livelihood vulnerabilities as expressed through factors such as health, water, food and so on. As a result Bangladesh is yet to develop region-specific coping and adaptive strategies, although information on some aspects such as health or water is already available.

The next section describes how LVIs are constructed and that is followed by a brief description of the disaster zones (Section 3). The household survey is described in Section 4 and the results are discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. Livelihoods vulnerability indices

Livelihood vulnerability indices are constructed from factors that are thought to affect vulnerability across regions. There is no single theory that helps to identify these factors. The sustainable livelihoods approach initially developed by Chambers and Conway [11] often offers the starting point. This approach assumes that a household is endowed with natural, social, financial, physical, and human capitals. These are employed to withstand shocks and stresses to generate a favourable livelihood outcome. The use of this approach is rather limited as it fails to integrate "climate exposures and accounts for household adaptation practices… needed… to comprehensively evaluate livelihood risks resulting from climate change" [20, p. 75]. The method proposed by Hahn et al. [20] uses "multiple indicators to assess exposure to natural disasters and climate variability, social and economic characteristics of households that affect their adaptive capacity and current health food, and water resource characteristics that determine their sensitivity to climate change impacts" [20, p. 75].

Hahn et al. [20] proposed a simple livelihood vulnerability index (LVI), as well as an IPCC–LVI approach, to capture and rank vulnerability associated with climate change factors. The LVI approach expresses LVI as a composite index based on seven major components which, in turn, are determined by several sub-components. IPCC–LVI, on the other hand, integrates these major components to IPCC's three contributing factors to vulnerability – exposure, sensitivity, and adaptive capacity.

Hahn et al. [20] used two approaches to calculate LVI, the composite index approach and the IPCC framework approach.

2.1. The composite index approach

LVI is composed of seven major components and each major component is further composed of several sub-components (Table 1). Hahn et al. [20] considered 7 major components: socio-demographic profile (SDP), livelihood strategies (LS), social networks (SN), health (H), food (F), water (W), natural disasters and climate variability (NDCV).

Hahn et al. [20] used a balanced weighted average approach where each sub component contributes equally to the overall index even though each major component is comprised of a different number of sub-components. Since each sub-component is measured on a different scale, they are standardised using the following equation:

$$\text{Index}_x = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{1}$$

X is the original sub-component, X_{min} and X_{max} are the minimum and maximum values, respectively, for each sub-component. For example, X may represent the average number of natural disasters in the past 5 years in a given zone. For variables that measure frequencies, the minimum value is set at 0 and the maximum at 100. Some sub-components, such as "average agricultural livelihood diversity index", are inversed because an increase in the indicator variables such as the number of agricultural livelihood activities undertaken by a household is assumed to decrease vulnerability.

Table 1
Major components and sub-components comprising the livelihood vulnerability index (LVI).

Major components	Sub components	Explanation of sub-components	Survey question	Relationship/explanation
1. Social and Demo-graphic Profile, SDP	1.1. Dependency ratio	Ratio of the population under 15 and over 65 years of age to the population over 15 and below 65	Information collected from household roster on age of each member	Higher dependency ratio increases vulnerability
	1.2. Percent of female headed households	Percentage of households where the head of the household is female	Household roster identified the sex of the head of households	Female headed households are more vulnerable
	1.3. Percent of households where head of household has not attended school	Percentage of households where the head of household reports that they have not attended in any formal school	Household roster collected information on the education status of the head of the households. The category "never attended school/cannot read or sign" was considered here	The extent of more illiterate household heads increases vulnerability
	1.4. Average age of female head of the households	Average age of females who are head of households	Information collected from household roster on age of the female head of the households	Female headed households are represented by women who are widowed, separated or divorced. Elder female household heads normally live with their sons or daughters whereas younger ones have to look after children and work or have to depend on others
2. Livelihood strategies, LS	2.1. Percent of households dependent solely on agricultural activities	Agricultural livelihoods include farming, fishing, livestock rearing etc.	The survey made a detail list of livelihoods that are classified into agricultural and non-agricultural livelihoods	A household depending only on agricultural livelihoods is more vulnerable than households that diversified to non-agricultural livelihoods
	2.2. Average agricultural livelihood diversification index	The inverse of (the number of agricultural livelihood activities +1) reported by a household, e.g., a household that cultivates rice, has poultry and livestock will have an Agricultural Livelihood Diversification Index=1/(3+1)=0.25	The following agricultural livelihoods were considered: farming, poultry, livestock, fish culture in ponds, harvest from forests, and salt-pan mining	Higher the number of agricultural livelihoods pursued by a household lower will be the vulnerability
	2.3. Percent of household having no migrant member	Self-explanatory	Household roster identified migrants. Both internal (within Bangladesh) and external (outside, international) migrant was identified	Remittances play an important role in reducing vulnerability. Households having no migrant member do not get any remittances
	2.4. Ratio of agricultural income to total income	Household survey questionnaire classified income into income from farming, wages and salary, non-farm enterprises, property Income and remittances. Income from wages was added to farming income to define agricultural income	Survey included questions for measuring total income and its components	Agriculture is likely to be more affected by climate change as compared to non-agricultural income. Proportionately higher agricultural income increases vulnerability
3. Health, H	3.1. Average time to health facility	Average time it takes households to get to the nearest health facility	How long does it take you to go to the nearest health facility?	More time it takes to reach the available health facility, more vulnerable is the household
	3.2. Percent of households with family member who are chronically ill	Percentage of households that report at least a family member with chronic illness	Is anybody in your household chronically ill?	Chronic illness takes away resources from the households that could have been used to reduce vulnerability
	3.3. Percent of household where a family member missed work or school in past two weeks due to illness	Percentage of households that report at least 1 family member who had to miss school or work due to illness in the last 15 days	Has anyone in your family been so sick in the past 2 weeks that they had to miss work or school?	Affects vulnerability through loss of present and future income
	3.4. Percent of households with no sanitary toilet facilities	All types of latrines other than sanitary latrine and ring slabs are considered not sanitary	What is the type of latrine you use? Type of latrine 1. sanitary latrine with septic tank, 2. ring slab (water sealed), 3. ring slab (water not sealed), 4. ordinary pucca, 5. *kancha* (i.e. septic tank), 6. bush/open space	Higher the proportion of households without access to sanitary latrines, higher the vulnerability

Table 1 (*continued*)

Major components	Sub components	Explanation of sub-components	Survey question	Relationship/explanation
4. Water, W	4.1. Percentage of households reporting water conflicts	Percentage of households that report conflicts over water in their community	In the past year was there any conflict in your village over water?	Higher conflicts over water increases vulnerability
	4.2. Percentage of households that utilises a natural source of water	Percentage of households that report a pond, river, rain water, well, as their primary source of water. These sources of water are considered unsafe	What kind of water is consumed? The following sources are mentioned: 1. tube well, 2. *haor*/river/canal, 3. pond, 4. rainwater, 5. well, 6. tap. Consumption of water from pond, river, rain water, well are considered less safe	Increasing percentage of households using unsafe natural source of water increased vulnerability
	4.3. Average time taken to reach the source of drinking water	Average time it takes the households to travel to their primary drinking water source	How long does it take to get to your drinking water source?	More time to collect water for drinking purposes, higher is the vulnerability
	4.4 Percentage of households that do not have a consistent supply of water	Percentage of households that report that water is not available at their primary water source every day	Is this water available every day?	Inconsistent availability of water increases vulnerability
5. Social networks, SN	5.1. Average borrow: lend money ratio	Ratio of households borrowing money in the past month to household lending money in the past month. For example, if a household borrowed money but did not lend money, the ratio=2:1 or 2 and if they lent money but did not borrow any, the ratio=1:2 or 0.5	Did you borrow any money from relatives or friends in the past month? Did you lend any money to relatives or friends in the past month?	We assume that a household that receives money or in-kind assistance often but offers little assistance to others is more insecure and vulnerable compared to those with excess money and time to help others
	5.2. Average receive: give ratio (range 0–7)	Ratio of (the number of types of help received by a household in the past month+1) to (the number of types of help given by a household to someone else in the past month+1)	In the past month, did relative/ friends help your family? In the past month, did your family help relative/friends? Help items include medical care, child care, helping the household to sell goods/produced	We assume that a household that receives more help is more vulnerable
	5.3. Percentage of households that have gone to their local government authorities or well-off households for assistance in the past 12 months	Percentage of households that reported that they have asked their local government or well-off households for assistance in the past 12 months	In the past year, have you or any of your family member received any help from the local administration, UP, or leader?	Households seeking more assistance from the local government institutions are more vulnerable
6. Food, F	6.1. Average crop diversity index	The inverse of (the number of crops grown by a household +1). For example, a household that grows rice, wheat, lentil, and vegetables will have a crop diversity index=1/(4+1)=0.2	The survey questionnaire listed all the crops grown by the household over the previous year	Higher number of crops grown by a household reduces vulnerability
	6.2. Percentage of households that do not get food from family farm	Higher the percentage of households who do not depend on family farm for food, higher is the vulnerability	Household survey questionnaire collected information on the amount of output consumed by the producing household	If a household does not self-produce food, they are likely to be more vulnerable
	6.3. Average number of months households struggle to get food	Self-explanatory	The households identify the months they struggle to get food	Higher the number of months households struggle to get food, higher is vulnerability
	6.4. Percentage of households that do not save rice seeds	Self-explanatory	Do you save seed for production in the following season?	Households that do not save rice seeds are more vulnerable because they have to depend on unreliable source of seed
7. Natural Disaster and Climate Variability, NDCV	7.1. Average number of natural disasters in the last 5 years	Total number of flood, flash floods, cyclones, storms, tides, dam fails, salinity, droughts, river bank erosions, water logging reported by households in the last 3 months	In the last 3 months, how many times has this area been affected by flood/ flash floods/ cyclones/ storms/ tides/ dam fails/ salinity/ droughts/ river bank erosions/ water logging?	Higher incidence of natural disaster implies higher vulnerability
	7.2. Mean standard deviation of the daily average maximum temperature by month	Standard deviation of the average daily maximum temperature by month between	2004–2009: district level data	(www.barc.gov.bd, last accessed on 16 April, 2013)

Table 1 (*continued*)

Major components	Sub components	Explanation of sub-components	Survey question	Relationship/explanation
		years 2004 and 2009 was averaged for each zone		
	7.3. Mean standard deviation of the daily average minimum temperature by month	Standard deviation of the average daily minimum temperature by month between years 2004 and 2009 was averaged for each zone	2004–2009: district level data	(www.barc.gov.bd, last accessed on 16 April, 2013)
	7.4. Mean standard deviation of average precipitation by month	Standard deviation of the average monthly precipitation between years 2004 and 2009 was averaged for each zone	2004–2009: district level data	(www.barc.gov.bd, last accessed on 16 April, 2013)

After each sub-component is standardised, they are averaged to calculate the value of each major component as shown in Eq. (2) below:

$$M_z = \frac{\sum \text{index}_{s_z i}}{n} \tag{2}$$

where M_z is one of the seven major components for zone z, $\text{index}_{s_z i}$ represents the sub-components, indexed by i, that make up each major component, and n is the number of sub-components in each major component.

Once values for each of the seven major components were calculated, they were averaged using Eq. (3) to obtain the LVI

$$\text{LVI}_z = \frac{\sum_{k=1}^{7} w_{Mk} M_{zk}}{\sum w_{Mk}} \tag{3}$$

Eq. (3) can also be expressed as follows:

$$\text{LVI}_z = \frac{W_{SDP}\text{SDP}_z + W_{LS}\text{LS}_z + W_{SN}\text{SN}_z + W_H H_z + W_F F_z + W_W W_z + W_{NDC}\text{NDC}_z}{W_{SDP} + W_{LS} + W_{SN} + W_H + W_F + Ww + W_{NDC}\text{NDC}} \tag{4}$$

LVI_z is the livelihood vulnerability index for zone z and equals the weighted average of the seven major components pertaining to the zone z. W_{mk}, or weights of each of the major components are determined by the number of sub-components that make up each major component. Weights are included so that all sub-components contribute equally to the overall LVI. In this paper, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable).

There are some obvious limitations of this index. One major limitation of this index is the use of equal weights. Eakin and Bojorquez-Tapia [15] and Vincent [42] have suggested alternative ways of determining the weights that are unequal. The indicators oversimplify a complex reality and there is inherently no straightforward way to validate indices comprised of disparate indicators (Vincent, 2007). The selection of sub-components and the assignment of directionality from less to more vulnerable involve normative judgment.

However, the index used by Hahn et al. [20] to measure livelihood vulnerability has several advantages. First, the index is constructed from primary data and as such the researcher has more control on the type of information as well as on the definitions of relevant categories. Second, it does not depend on climate models that focus on a larger scale and miss livelihood complexity at the local level. Third, the information used to measure the index is relevant for many developing countries as they often face very similar situations. Moreover, information related to household characteristics, assets, livelihoods etc., is routinely collected by studies focused on various aspects of livelihoods. Finally, as already hinted to, it proposes a framework for grouping and aggregating indicators at the regional level to capture differential impacts of climate change on households living in different climatic conditions. The factors that determine vulnerability can be adapted to the relevant parameters of the regions.

2.2. IPCC framework approach

The IPCC approach aggregates the seven major components into IPCC's three contributing factors to vulnerability – exposure, sensitivity, and adaptive capacity (Table 2).

IPCC [22] defines exposure as related to the magnitude and duration of climate-related factors such as change in temperature or rainfall. This is captured by the major component of natural disasters and climate variability. In this study we have captured exposure by number of natural disasters that have occurred in the zones in the last five years prior to the interview. Climate variability is proxied by variability of maximum and minimum temperature in the studied zones over the period 2004–2009 and by the variability of monthly average precipitation over the same period. Adaptive capacity relates to the ability of the system to recover from the exposure. This is indicated by the major components socio-demographic profile, livelihood strategies and social networks. Finally, sensitivity indicates the degree to which a system is affected by exposure. This is epitomised in the major components of health, food and water. These three contributing factors are combined to define the following equation:

$$\text{LVI} - \text{IPCC}_z = (e_z - a_z)s_z \tag{5}$$

where LVI–IPCC_z is the LVI for zone z using the IPCC vulnerability framework, e_z is the exposure and a_z is the adaptive capacity, and s_z is the sensitivity scores for region z. LVI–IPCC is scaled to limit between a minimum value of -1 representing least vulnerability to 1 representing most vulnerability.

Table 2
Categorisation of major components for measuring LVI–IPCC.

IPCC contributing factors to vulnerability	Major components
Exposure (*e*)	Natural disasters and climate variability
Adaptive capacity (*a*)	Socio-demographic profile, livelihood strategies, and Social networks
Sensitivity (*s*)	Health, food and water

3. The physiographic regions and the four disaster zones in Bangladesh

Bangladesh is a low-lying, riverine country located in South Asia with a largely marshy jungle coastline of 710 km (441 mi) on the northern littoral of the Bay of Bengal. It is bordered on the west, north, and east by a 4095-km land frontier with India and, in the southeast, by a short land and water frontier (193 km) with Myanmar. Bangladesh is outlined by the Indian Ocean in the south and the Bay of Bengal is the breeding place of catastrophic cyclones. Near the equator lies the Inter-Tropical Convergence Zone (ITCZ), where winds from the two hemispheres meet and this meeting of strong winds plays a vital role in the formation of tropical cyclones and harsh storm surge near the coastal areas.

The geographic location and geo-morphological conditions of Bangladesh have made the country one of the most vulnerable ones to climate change, particularly to sea level rise. Bangladesh is situated at the interface of two different environments, with the Bay of Bengal to the south and the Himalayas to the north. This peculiar geography of Bangladesh causes not only life-giving monsoons but also catastrophic ravages of natural disasters, to which now are added climate change and SLR (sea level rise). The country has a very low and flat topography, except the northeast and southeast regions. About 10% of the country is hardly 1 m above

The Comprehensive Disaster Management Programme (CDMP), a project launched by the Ministry of Food and Disaster Management of Bangladesh, characterised 40 districts of Bangladesh as vulnerable for four broad types of disasters viz. salinity, flood, drought, and flash-flood. The areas studied in this paper are selected from this set of districts. Note that these districts are also vulnerable to other climate induced risks and hazards like tidal surges, cyclones, erratic rainfall, fog, cold wave, hail storming, land slide, erosion, sand carpeting. At the same time these natural disasters are present in other districts and they are often overlapping. For example, the northwest may be the drought zone but it also experiences flash floods in the piedmont zone. Similarly, the northeast experiences not only flash floods but also extensive river floods. The latter also occurs in the coastal zone.

The saline prone area is found in the coastal areas which are also characterised by cyclone and storm surge. Flood prone areas are concentrated in the floodplains of Brahmaputra–Jamuna, the Ganges–Padma and the Meghna river system. Flash floods are mostly observed in the Haor Basins of the North-east region and South-eastern hilly areas. While generally associated with semi-arid or desert climates, drought can also occur in areas that normally enjoy adequate rainfall, and moisture levels. Drought tends to affect western districts more severely, especially when the monsoon is curtailed [28,29,38]. Droughts mainly occur in the western parts of Bangladesh (Rajshahi Division) and in the Chittagong Hill tracts.

Salinity has been increasing in the coastal districts of Bangladesh [31]. It is expected that sea-level rise would accelerate the salinity impact in three fronts: surface water, groundwater and soil [33]. Increase in salinity means decrease in agriculture production as lands severely affected by salinity cannot be productively used for crop production. In Bangladesh, the percentage of salinity affected land is quite significant and this has been further aggravated by sea level rise [27,37,26,35]. About 830,000 million hectares of arable land is affected by varying degrees of soil salinity [13]. Increasing salinity has decreased the availability of safe drinking water. Scarcity of safe drinking water has been addressed by increasing access to ground water but this has generated other problems such as arsenic contamination, lowering of the water table, and non-availability of suitable aquifers [26]. About 20 million people in the coastal areas of Bangladesh are already affected by salinity in their drinking water [44]. Ahmed et al. [1] found that most fisher households (87%) in the coastal district of Bagerhat suffered from chronic drinking water shortages because of groundwater salinity and inadequate tube-well facilities. The problem of drinking water in the coastal districts has been studied by many [6,17,25]. Salinity has created many health problems in the coastal region of Bangladesh which include diarrhoea, fever, high blood pressure, gastric problem, skin problem and so on [26].

The issue of low dry season water availability and monsoon tidal flooding is addressed by construction of embankments and regulation of water flowing into the coastal areas. Poor maintenance and management of these physical structures have often done more harm than benefits in some parts of the coastal belt. The coastal zone is also frequently affected by cyclones, tidal surges, floods, dislocation of households, particularly from smaller islands and so on [14,34].

Bangladesh has a monsoonal climate which creates frequent rainfalls. But over the years the pattern of rainfall has changed and the sporadic rainfall causes flooding, which sometimes submerges more than 50% of the land area. Some 30–35% of the total land surface is flooded every year during the wet monsoon season [24]. In the last 25 years, Bangladesh has experienced six severe floods. In 2007, two successive and damaging floods inundated the country in the same season. The most disastrous flood occurred in 1988 and affected almost 61% of the country ([16], undated).

Flood causes multiple problems-loss of human lives and biodiversity, disruption of communication, agriculture production and livelihood system, damage and destruction of infrastructure, disruption to essential services, displacement and sufferings of a large number of populations, spread of outbreak of diseases like diarrhoea, and malaria. Agricultural wages have been observed to decline in the aftermath of flood [7,30].

Flash floods arise from excessive rain over a short period of time. The water level rises and falls rapidly with hardly

any warning. It causes damage to crops, livestock and other properties. Flash floods occur more in April and May or even in June. Other climate induced natural disasters in this region include tornadoes and hailstorm. Landslides brought about by excessive rainfall are also observed. Sandification of arable land results in soil degradation while fishing grounds are increasingly lost due to siltation of the river beds and other water bodies. This region is also vulnerable to river flood.

Drought affects production of rice the most in Bangladesh. Typically, uncertainty of rainfall and prevalence of dry days and lack of soil moisture reduce potential yields of major rice crops ([16]). Depending on the intensity of drought, estimated yield reduction of different crops varies from 10% to 70% [27].

4. Household survey

The data used for the measurement of LVI came from a survey of 2558 households carried out during July–September in 2011 by the Centre for Natural Resource Studies in Bangladesh [12]. The household survey was administered for a study on non-farm livelihood adaptation approaches and technologies. One of the main objectives of the study was to identify climate change induced risks on farm and non-farm livelihood options of the disaster vulnerable poor people in different disaster zones in Bangladesh. Four disaster prone zones were identified, namely, saline, flood, flash-flood, and drought. The study therefore was not entirely designed to measure LVI but there were many questions in the survey questionnaire that are here used to define the sub-components and thereby measure the LVIs. We therefore decided to develop the sub-components on the basis of those already selected by Hahn et al. [20] and adjust them according to the livelihood realities of Bangladesh. Many of the sub-components used in Hahn et al [20] are valid for capturing vulnerabilities in a South Asian context in general and in a Bangladesh context in particular. Most sub-components fall into this category (socio-demographic profile, livelihood strategy, social and food). Some sub-components were dropped because they were not very relevant for Bangladesh. For example, average malaria exposure prevention index has been dropped because malaria is only concentrated in the eastern part of Bangladesh. Some information such as disaster warning or injury from disaster was not collected at all while others were slightly modified. For example, we considered migration (within Bangladesh and international) explicitly rather than considering those working in different communities as migrants. We have also added some new sub-components. For example, percent of households with no sanitary toilet facilities was included as a sub-component of the major component of health. The survey contained routine questions on demographic characteristics, labour use pattern, assets, incomes, cropping pattern, natural disasters and so on. These were used as subcomponents for the major components social demographic profile (SDP) and livelihood strategy (LS). A review of the literature on the livelihoods in the disaster zones justified the selection of the sub-components. Table 1 lists and defines each of the sub-components and the survey questions associated with them.

4.1. Selection of the households

Bangladesh has 64 administrative districts which are further divided into about 1009 sub-districts called upazilas. The 20 districts selected for the study were already identified by the Comprehensive Disaster Management Programme-II (CDMP-II) as the most vulnerable districts in the four disasters zones in Bangladesh (Table 3). CDMP-I (2004–2009) was launched by the Ministry of Food and Disaster Management of the Government of Bangladesh in partnership with DFID and UNDP and aimed to improve Bangladesh's disaster management system's ability to reduce unacceptable risks and improve response and recovery activities [19]. The project covered almost half of the 64 districts in Bangladesh. CDMP-II (2010–2014) was designed as a vertical and horizontal expansion of CDMP-I and is based on the achievements and lessons learned from implementing CDMP-I. The number of high risk, vulnerable districts was raised from 31 to 40 [18] in CDMP-II.

We selected the study districts on the basis of literature review, secondary information and discussions with the managers of the CDMP-II project. The following factors were taken into consideration:

1. Proportionate number of districts under each of the broad four disaster areas.
2. Extent of poverty.
3. Geographic distribution of the districts.

After selection of the districts, the upazilas were selected purposively for each district on the basis of the following rules:

a. For each district, the upazilas were ranked in terms of exposure to natural shocks. The extent of poverty for each upazila was then written down. Natural disaster ranking was done in consultation with people well informed about the district while information on poverty in these upazilas was obtained from BBS [10]. Two most natural disaster affected poor upazilas were selected for each district.
b. In case of more than two upazilas with similar vulnerability to natural disaster, the one characterised by higher incidence of poverty was selected.
c. In case of similar poverty rates and exposures to disaster, the first odd numbered upazilas were picked. When even numbered upazilas were only left for selection, the first upazila was picked. Each upazila was arbitrarily numbered by those who ranked them in terms of natural disaster vulnerability.

Table 3
Distribution of the households by geographic and disaster zones.

	Salinity prone	Flood prone	Flash flood prone	Drought prone	Total
Districts	8	6	4	2	20
Upazilas	16	12	8	4	40
Villages	32	24	16	8	80
Households	1023	767	512	256	2558

d. From each selected upazila, two villages were randomly selected from the list of villages located within the respective upazila. This resulted in the selection of 80 villages. In the absence of a sampling frame, a complete census of all the households from the randomly selected villages was conducted. From each village, 32 households were then randomly selected (Table 3).

Meteorological data comprising of precipitation and temperature were collected from weather station records made available from the website of the Bangladesh Agricultural Research Council (www.barc.gov.bd).

5. Results and discussions

The flash flood zone has turned out to be the most vulnerable disaster zone in Bangladesh, followed by the saline, drought and the flood zone. The flash flood zone has poor health conditions and services. Very few households have proper toilet facilities and health services are inadequate in a situation where a high proportion of individuals living there get frequently ill. The flash flood zone cannot produce many crops because of flash-floods and frequent rainfalls and as a result the households face a longer period of food shortages and very few households could diversify their livelihoods. Access to land is highly unequal. Social and demographic situation is also not favourable in the flash flood zone. Dependency ratio as well as average size of the households is very high. It has the highest proportion of households headed by women and education levels of the household heads are very low. Variation in rainfall and temperature has resulted in some changes in cropping practices in the flash flood zone. The saline zone, being located on the coastal belt of Bangladesh, witnessed the highest occurrence of natural disasters. The drought zone is most vulnerable to water as the households living there have to depend more on natural source of water which is not generally safe. The households in the saline zone have the least consistent source of water. Increasing salinity of water in the saline zone has not only affected drinking water but also water used for irrigation croplands. Dependence of the households on social network and the institutions of local government who play increasing role in the aftermath of disasters is high indicating that these households cannot cope with their own resources. The ranking of vulnerability using the LVI–IPCC framework produced the same ordering.

Results and discussions to follow are based on the information provided in Tables 4 and 5. Table 4 provides the values for each sub-component for each zone. It also provides the minimum and maximum values for the sub-components. Table 5, on the other hand, provides the values of the major components and calculates the composite LVI for each zone. The major components and the LVIs are presented in Fig. 1.

Based on the LVIs (Table 5), the flash flood zone is estimated to be the most vulnerable disaster zone in Bangladesh (0.307). This is followed by the saline zone with LVI of 0.264.The drought zone ranked third with LVI of 0.263 and the flood zone fourth with LVI of 0.259. The LVI for the flash flood zone is very high as compared to the other zones that vary less. The major components that make the flash flood zone the most vulnerable zone are health, food, socio-demographic profile, livelihood strategy, natural disaster and climate variability.

5.1. Health (H)

In the flash flood zone, over 56% of the households have no sanitary toilet facilities. Most of the households use hanging latrines that are not hygienic. Almost half of the households use hanging latrines in the study villages in the flash flood zone. Only 4% of the households have proper sanitary latrines.

The quality of public health services is generally believed to be very poor in the flash flood zone. We have estimated it takes almost 1 h to reach the nearest health facility. Emergency patients and pregnant women suffer most. The poor state of public health services is explained both by the lack of medical facilities available in the region as well by poor road infrastructure. The quality of roads is very poor as they remain under water for long and get eroded prematurely. Poor road infrastructure therefore makes whatever health services available in this region even less accessible. Doctors do not like to be posted in the flood prone region and other medical staffs are also reluctant to be stationed there. As a result, people have to depend more on traditional healers who are readily available.

About 30% of the households had family members who missed work or school due to illness in the two weeks prior to the survey. This indicates that a higher proportion of individuals living in flash flood zone get frequently ill. This may be exacerbated by poor health services as described above. About a quarter of the households in the flash flood prone zone have family members who are chronically ill. The extent of households with chronically ill members is higher in other zones, being the highest in the drought zone.

5.2. Food (F)

The flash flood zone cannot produce many crops because of flash-floods and frequent rainfalls. Besides, a vast tract of land remains submerged under water for a prolong period of time making crop production impossible. Most of the lands in the drought prone zone cannot produce the wet season *aman* rice and the farmers living in that region have to depend solely on dry season *boro* rice. The total number of other crops grown in the flash-flood zone is also very low. The households reported of only 6 types of crops they have grown during the reference period. This can be compared to the maximum of 20 types of crops grown in the flood prone zone. The saline and drought prone zones produced 17 types of crops.

The households living in the flash flood zone also face a longer period of food scarcity. On the average they have difficulty to feed themselves for 1.78 months in a calendar year. A household in the saline zone, in contrast, is least food-insecure as it faces food shortages for only 0.65 months. Since this zone mainly produces a single rice crop in an uncertain rain and flood conditions, these two factors

Table 4
Livelihoods vulnerability index (LVI) sub-component values and minimum and maximum sub-component values for the disaster zones.

Major components (6)	Sub components	Units	Salinity	Flood	Flash flood	Drought	Maximum in all zones	Minimum in all zones
1. Social and demographic profile, SDP (4)	1.1. Dependency ratio	Ratio	0.583	0.579	0.747	0.515	5	0
	1.2. Percent of female headed households	Percent	7.44	6.52	7.62	5.08	100	0
	1.3. Percent of households where head of household has not attended school	Percent	12.92	24.51	32.81	16.02	100	0
	1.4. Average age of female head of the households	1/Years	0.022	0.02	0.021	0.022	0.05	0.012
2.Livelihood strategies, LS (8)	2.1. Percent of households dependent solely on agricultural activities	Percent	1.3	3.9	4.7	3.1	100	0
	2.2. Average Agricultural Livelihood diversification index	1/No. of livelihoods	0.33	0.566	0.478	0.416	1	0.2
	2.3.Percent of household having no migrant member	Percent	77.81	65.97	82.81	77.34	100	0
	2.4. Ratio of agricultural income to total income	Ratio	0.463	0.392	0.574	0.562	4.6	0
3. Health, H (4)	3.1. Average time to health facility	Minutes	39.81	35.10	57.68	24.43	180	0
	3.2. Percent of households with family member who are chronically ill	Percent	26.61	24.25	24.22	30.86	100	0
	3.3. Percent of household where a family member missed work or school in past two weeks due to illness	Percent	12.82	16.69	29.88	19.92	100	0
	3.4. Percent of households with no sanitary toilet facilities	Percent	22.87	37.29	56.45	45.31	100	0
4. Water, W (4)	4.1. Percentage of households reporting water conflicts	Percent	9.8	4	13.3	6.3	100	0
	4.2. Percentage of households that utilises a natural source of water	Percent	20.35	1.17	2.54	40.23	100	0
	4.3. Average time taken to reach the source of drinking water	Minutes	8.607	2.365	4.164	2.254	60	0
	4.4 Percentage of households that do not have a consistent supply of water	Percent	11.84	1.96	3.32	2.73	100	0
5. Social networks, SN (3)	5.1. Average borrow: lend money ratio	Ratio	1.133	1.203	1.12	1.17	2	0
	5.2. Average receive: give ratio (range 0–7)	Ratio	1.323	1.44	1.519	1.192	7	0.143
	5.3. Percentage of households that have gone to their local government authorities or well-off households for assistance in the past 12 months	Percent	21.9	18.5	9.6	6.6	100	0
6. Food, F (4)	6.1. Average crop diversity index	1/No. of crops	0.43	0.381	0.493	0.362	0.5	0.125
	6.2. Percentage of households that do not get food from family farm	Percent	78.59	85.77	61.52	63.67	100	0
	6.3. Average number of months households struggle to get food	Count	0.649	1.051	1.781	1.047	12	0
	6.4. Percentage of households that do not save rice seeds	Percent	27.57	26.24	31.64	35.55	100	0
7. Natural disaster and climate variability, NDCV (4)	7.1.Average number of natural disasters in the last 5years	Count	12.35	5.318	3.859	4.898	65	0
	7.2. Mean standard deviation of the daily average maximum temperature by month	Celsius	0.806	0.828	1.133	0.973	1.71	0.439
	7.3. Mean standard deviation of the daily average minimum temperature by month	Celsius	0.847	0.706	0.702	0.703	1.453	0.492
	7.4. Mean standard deviation of average precipitation by month	Millimetres	63.537	96.857	126.261	80.995	171.076	3.825

mainly explain why the period of food shortages is long. Dependence on a single rice crop means that the local economy cannot support livelihoods throughout the year.

About a third of the households in the flash flood zone are unable to save rice seed. A slightly higher percentage of households in the drought zone are not able to save rice seed. Jaim and Akter [23] have found that about half of the farmers in Bangladesh save rice seed while the rest depend on the market. This study finds that a higher proportion of households save seed in the disaster prone areas in Bangladesh. This may be explained by poor access to the market for seed or poor government extension services available in these fragile ecological zones. The farmers in this region possibly do not want to take risk from unavailability or shortage of rice seed in the market. If the market is less accessible and small, as is the case in the flash flood zone, quality of seed offered in the market may also turn out to be a serious concern [21].

Percentage of households who get food from their own farms is the largest in the flash flood zone. This is much

Table 5
Indexed sub-components, major components, and overall LVI for the four disaster prone zones.

Major components (6)	Sub components	Salinity	Flood	Flash flood	Drought
1. Social and demographic profile, SDP (4)	1.1. Dependency ratio	0.117	0.116	0.149	0.103
	1.2. Percent of female headed households	0.074	0.065	0.076	0.051
	1.3. Percent of households where head of household has not attended school	0.129	0.245	0.328	0.160
	1.4. Average age of female head of the households	0.263	0.211	0.237	0.263
	SDP	**0.146**	**0.159**	**0.198**	**0.144**
2. Livelihood strategies, LS (8)	2.1. Percent of households dependent solely on agriculture as a source of income	0.013	0.039	0.047	0.031
	2.2. Average Agricultural Livelihood diversification index	0.163	0.458	0.348	0.270
	2.3.Percent of household having no migrant member	0.778	0.660	0.828	0.773
	2.5. Ratio of agricultural income to total income	0.101	0.085	0.125	0.122
	LS	**0.101**	**0.085**	**0.125**	**0.122**
3. Health, H (4)	3.1. Average time to health facility	0.221	0.195	0.320	0.136
	3.2. Percent of households with family member who are chronically ill	0.266	0.243	0.242	0.309
	3.3. Percent of household where a family member missed work or school in last 15 days due to illness	0.128	0.167	0.299	0.199
	3.4. Percent of households with no sanitary toilet facilities	0.229	0.373	0.565	0.453
	Health	**0.189**	**0.213**	**0.310**	**0.244**
4. Water, W (4)	4.1. Percentage of households reporting water conflicts	0.098	0.040	0.133	0.063
	4.2. Percentage of households that utilises a natural source of water	0.204	0.012	0.025	0.402
	4.3. Average time taken to reach the source of water	0.143	0.039	0.069	0.038
	4.4 Percentage of households that do not have a consistent supply of water	0.118	0.020	0.033	0.027
	Water	**0.150**	**0.065**	**0.114**	**0.155**
5. Social networks, SN (3)	5.1. Average borrow: lend money ratio	0.567	0.602	0.560	0.585
	5.2. Average receive: give ratio (range 0–7)	0.172	0.189	0.201	0.153
	5.3. Percentage of households that have gone to their local government authorities or well-off households for assistance in the past 12 months	0.219	0.185	0.096	0.066
	Social networks	**0.319**	**0.325**	**0.286**	**0.268**
6. Food, F (4)	6.1. Average crop diversity index	0.813	0.683	0.981	0.632
	6.2. Percentage of households that do not get food from family farm	0.786	0.858	0.615	0.637
	6.3. Average number of months households struggle to get food	0.054	0.088	0.148	0.087
	6.4. Percentage of households that do not save rice seeds	0.276	0.262	0.316	0.356
	Food	**0.482**	**0.473**	**0.515**	**0.428**
7. Natural disaster and climate variability, NDCV (4)	7.1.Average number of natural disasters in the last 5years	0.190	0.082	0.059	0.075
	7.2. Mean standard deviation of the daily average maximum temperature by month	0.289	0.306	0.546	0.420
	7.3. Mean standard deviation of the daily average minimum temperature by month	0.369	0.223	0.219	0.220
	7.4. Mean standard deviation of average precipitation by month	0.357	0.556	0.732	0.461
	Natural disaster and climate variability	**0.301**	**0.292**	**0.389**	**0.294**
	LVI	**0.264**	**0.259**	**0.307**	**0.263**

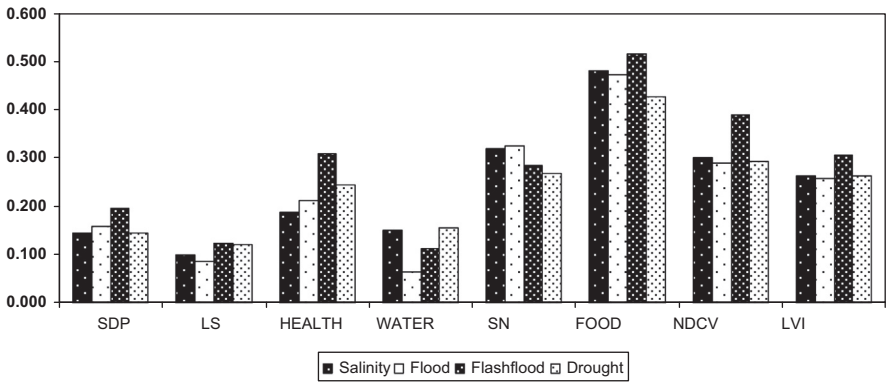

Fig. 1. Major components and LVIs for the four disaster zones.

less in other zones where the households depend more on the market for food. The presence of farming households is much less in other zones. This makes the households from the flash flood zone less vulnerable in terms of their opportunity to obtain food from the farms they operate. Irrigation is based on surface water drawn from rivers, canals and ditches. Since irrigation costs are low, profitability from farming is relatively higher. In other regions of Bangladesh irrigation costs are high as they are based on ground water pumped out by tube wells powered by

electricity or gasoline. Basak [8] has estimated STW (shallow tube well)-based irrigation costs to represent 21% of total cost of production of rice.

Although this zone produces a limited number of crops in an uncertain environment, it is most dependent on agricultural livelihoods. Average size of the farm is the highest, 267 decimal. It also has the largest proportion of households who are medium (owning 250–749 decimal land) and large (owning 750 decimal land or higher) farmers. The Gini coefficient for cultivable land ownership is also highest as compared to the other disaster zones. Self-employment in agriculture is the most frequently pursued livelihoods in this region. More than 52% of the households are involved in farming as their main occupation in this region.

5.3. Social and demographic profile (SDP)

The households living in the flash flood zone are found to be more vulnerable than those living in the other zones. Dependency ratio is the highest, 0.75.The nearest dependency ratio of 0.58 is found in the flood zone. The average size of the households, not considered here as a major or sub-component, is also the highest in the flash-flood zone, 5.49 members. The nearest average households size of 4.05 persons is found in the saline zone. Approximately 8% of the households in this zone are headed by female – the highest amongst all zones. About a third of the head of the households in this zone have not attended any formal school. The flood-zone ranks second with about a fourth of the head of the households never attending school. Average age of the female headed households is slightly higher in this zone as compared to those in the drought and saline zones. The female headed households in drought and salinity prone zones, being younger, are therefore more vulnerable. The average age of head of the household, irrespective of the sex, does not vary much between the four disaster zones. They vary from 43 to 45 years. On the other hand, average age of female headed households vary to some extent. It is almost the same between saline and drought zones (45 years), being highest in the flood zone (50 years) followed by 48 years in the flash flood zone.

5.4. Livelihood strategy (LS)

The proportion of households depending exclusively on agriculture as a source of income is low in all the zones. It is highest in the flash flood zone where about 5% of the households have failed to diversify from agricultural income. The ratio of agricultural income to total household income is also highest for this zone, 57%. About 39% of total household income comes from agriculture in the flood zone. The villages we visited in the flood-prone zone produce only dry season rice crop. This limited agricultural based livelihoods. Besides, the villages were prone to river erosion and people regularly lost land to the rivers. Many had to become either wage labourers or had to migrate out for work. Most of the households (83%) in the flash flood zone do not have any member who has migrated out. This is surprising because livelihood opportunities are very limited. Migration may be constrained by poor road infrastructure. Since a large part of the flash flood zone remains under water for several months, there is opportunity for fishing. Almost half of the households catch fish from the wild in this zone. This may also dissuade individuals from migrating out. It is clear that the extent of migration will also depend on the extent of natural disaster. A female participant from the flash-flood zone mentioned during an FGD that even the women have to migrate when flash flood hits very bad. In normal flash floods women normally do not migrate.

The extent of agricultural livelihoods diversification is the lowest in the flood zone. The households living in the flood zone have to concentrate on a limited number of agricultural livelihoods. The flash flood zone comes next as it also can offer only a limited number of agriculture based livelihoods.

5.5. Natural disasters and climate variability (NDCV)

Two sub-components are mainly responsible for making the flash flood zone most vulnerable in this aspect; variability in maximum daily temperature and variability in the maximum monthly average precipitation. The saline zone is characterised by highest occurrence of natural disasters. The largest number of natural disasters has been reported by the households living in the saline zone. Over a 10-year time horizon, they have reported around 11 types of natural disasters that include cyclones, high tide and so on. On the other hand the households in the flash-flood zone have reported of 8 types of natural disasters. These include floods, water-logging etc. The saline zone also has the highest variability in the monthly average minimum daily temperature.

Though the exact impact of variation in temperature and rainfall on livelihoods is not known, the study attempted to understand how households cope with these variations. We have observed changes in cropping practices in the flash flood zone and this change has been the most pronounced. About 9% of the households have changed crops or crop varieties over 10 years. Climate change factors have been mentioned by the farmers for this change in cropping pattern but other factors have also been emphasised. These include market opportunities for outputs, availability of seed and so on. Crop choice is also determined by availability of seed in the market. We have already mentioned that most households tend to rely on saved seed rather than on the market in the disaster prone zones of Bangladesh.

Though the cropping pattern has not changed significantly in all the zones over the last decade, there could be changes at different stages of cultivation such as during land preparation, sowing, harvesting, and so on. About one-fourth of the households have reported that the time for land preparation has changed and the extent of this change is the highest in the flash-flood prone zone. Delaying the time for land preparation occurred more than moving the time rearward. Lack of timely rainfall is reported to be the most important reason for this change in timing for land preparation in the flash-flood prone and drought prone areas.

The flash flood zone does not have the highest vulnerability scores in all seven major components. For instance, the flood zone has the highest vulnerability from social

networks (SN). Water issues are the major contributor to vulnerability in drought zone. On the other hand, the saline zone ranked second in terms of overall LVI score but has not got a highest score for any major component.

5.6. Social network (SN)

The flood zone is the most vulnerable from the perspective of social network. Average borrow to lend ratio is the highest in this zone. The give-ratio is also high and holds the second position after the flash flood zone. This means that a large number of households in the flood zone do not have their own capacity to withstand losses from natural disasters and have to depend on relatively better off households for support. Relatively well-off households generally lend to the poorer households so that they can face the aftermath of disasters.

Note that the saline zone is almost as vulnerable as the flood zone in terms of the major component social network. Heavy dependence on local government institutions is the key factor here. In terms of percentage of households who had to seek help from the local government authorities, the saline zone ranked first. These indicate that the households living in the saline and flood zones depend more on their social networks and local authorities for coping with livelihood vulnerabilities. Normally, response to natural disasters from the government and the NGOs is relatively quick and widespread during (and after) natural disasters in the coastal and flood regions. The impact of these natural disasters is also intense, instant/visible and more widespread. Besides, the media is very quick to respond to these natural disasters and create pressure on the government and the NGOs.

5.7. Water

Both the drought and saline zones are vulnerable to water related factors, the drought zone being the most vulnerable in this regard. The drought zone has to depend most on natural source of water such as well, pond, river etc. which are not generally considered to be safe for drinking. The households from the saline zone also depend heavily on natural source of drinking water. Tube well is the main source of drinking water in both regions. While 79% of the households drink water from tube wells in the saline zone, only 52% of households in the drought prone zone get water from this source. The second most important source of water for the households in the dry zone is well, about 40%. In the saline zone, pond is the second major source of water, for about 15% of the households living there. While asked whether the water they get is safe, 13% of the households from the saline zone reported that it was not. The corresponding figure for the households in the drought zone was 16%.

The saline zone has least consistent source of water supply. The households from this zone also have to spend most time to reach their source of water. Water is the key problem, either for drinking or for irrigation. In the drought zone we visited, the households reported that it took 15 min to go to the nearest source of water (well) and another 5 min to withdraw the water because the level of water in the well was too low. The people we spoke to do not get enough water for bathing. A small pond is the only source of water for washing utensils, bathing etc. The cattle hardly get a bath because of scarcity of water. Availability of drinking water is the key problem in drought and saline zones but the latter is also burdened with increased salinity.

5.8. LVI–IPCC for the disaster prone zones

The ranking of vulnerability remained the same when the LVI–IPCC approach was used (Table 6 and Fig. 2). In all three counts of exposure, adaptive capacity and sensitivity, the flash flood zone has come out as the most vulnerable region with a vulnerability score of 0.0122. The salinity

Table 6
LVI–IPCC contributing factors for the disaster zones.

IPCC contributing factors to vulnerability	Corresponding major components	Salinity (rank 2)	Flood (rank 4)	Flash flood (rank 1)	Drought (rank 3)
Exposure (e)	NDCC	0.301	0.292	0.389	0.294
Adaptive Capacity (a)	SDP, LS, SN	0.297	0.314	0.350	0.290
Sensitivity (s)	H, F, W	0.278	0.248	0.312	0.278
LVI–IPCC	$(e-a)s$	0.0011	-0.0055	0.0122	0.0010

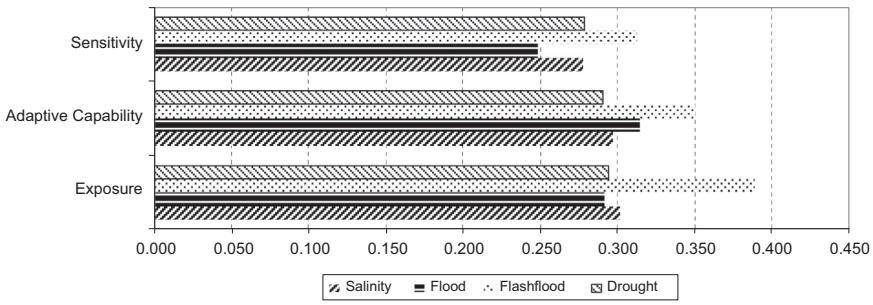

Fig. 2. LVI–IPCC for the four disaster prone zones.

zone, ranking second with a score of 0.0011, may be slightly more exposed to climate change impacts when compared to the drought zone, ranking third with a score of 0.0010. Note that in terms of sensitivity, the saline and drought zones are almost equally vulnerable as they have the same sensitivity score. We have already pointed out that water issues are as crucial for the saline zone as they are for the drought zone. The saline zone has a higher vulnerability than the drought zone arising from exposure. The crucial factors here are higher incidence of natural disasters and higher variability of minimum daily temperature. The drought zone has slightly lower adaptive capacity than the saline zone mainly because of dependence on limited agricultural livelihood opportunities and higher proportion of illiterate heads of households. The saline zone has been able to diversify more than the households in the drought zone and literacy rate amongst the head of the households is also higher. Thus the drought zone has a lower exposure but it has a lower adaptive capacity making it more vulnerable than the saline zone in terms of LVI–IPCC.

We also see higher variability of LVI–IPCC indices across all the regions as compared to the LVI scores. Though the salinity and drought zones have similar LVI–IPCC values, they are well below that of the Flash flood zone and well above that of the flood zone.

6. Summary and conclusions

Bangladesh is one of the most climate vulnerable countries in the world and will continue to remain so as a result of climate change. Floods, tropical cyclones, storm surges, tidal surge, saline intrusion, droughts, etc. are likely to become more frequent and severe in the coming years. These changes are threatening the livelihoods of the people of Bangladesh. The poor and marginalised section of the society, particularly women and children and those dependent more on natural resources will continue to suffer most. These changes will threaten the significant achievements Bangladesh has made over the last 20 years in increasing incomes and reducing poverty, and will make it more difficult to achieve the MDGs [18]. Despite these known adverse impacts of climate vulnerabilities no systematic assessments of livelihoods vulnerability in Bangladesh has been assessed for disaster and poverty prone areas of Bangladesh. This study has made an attempt to fill this gap.

This paper has extended the scope of the domain of application of the LVIs as developed by Hahn et al. [20] by estimating them for four disaster prone zones of Bangladesh; namely saline, flood, flash flood and drought. The regions selected for the study are not only highly vulnerable to natural disasters but they are also very poor. We have found the flash flood zone has the largest livelihoods vulnerability followed in decreasing magnitude by the saline, drought and flood zones. Livelihoods vulnerabilities in the other zones are comparable but well below than that of the flash flood zone. Vulnerability of the flash flood zone stems from factors associated with health (poor toilet and health facilities), food (fewer crops are grown and longer period of food insecurity), unfavourable socio-demographic profile (higher dependency ratio, more female-headed and illiterate households), livelihood strategies (higher dependence on agriculture), and natural disaster and climate variability (highest variability in temperature and precipitation). The flash flood zone can produce only one rice crop and livelihoods opportunities are limited. Farming is risky because of flash floods. The road infrastructure is poor and public health services are under-provided. Both drought and saline zone have higher livelihood vulnerability because of water related issues; in the former it is scarce, in the latter it is not only scarce but also highly saline. In both regions safe drinking water is scarce but in the saline zone salinity has affected productivity of crop land. The dependence on social networks and local government is high in the saline zone as many households fail to withstand natural disaster shocks with their own endowments.

Livelihoods vulnerability ordering remained the same when IPCC–LVI framework was used. On all counts (exposure, adaptive capacity, and sensitivity) the flash flood zone has the highest vulnerability. In terms of sensitivity, the drought and saline zones are equally vulnerable and this is possibly due to issue of water in these zones. Water is important on only for drinking (particularly due to high salinity in the saline zone) but also for irrigation in these zones. While the drought zone is less exposed to natural disasters and climate change factors (unlike the saline zone), it has a lower adaptive capacity mainly because of limited agricultural opportunities there.

It becomes clear from a policy perspective that public goods have a major role to play in reducing livelihood vulnerabilities in the disaster zones in Bangladesh. Road infrastructure, particularly in the flash flood zone, drinking and irrigation water supplies, particularly in drought and saline zones and health services provided and promoted by the state can have a positive impact on enhancing the capacity of the households to withstand the shocks from natural disasters. Bangladesh has been pursuing a rural development strategy where provision of rural roads, development of the rural markets, supply of safe drinking water etc. are included. But these interventions are not adequately funded. For example, public spending on sanitation and drinking water in Bangladesh is one of the lowest in the world. Bangladesh spends 0.4% of GDP on sanitation and drinking water. Expenditure on health is also one of the lowest in the world. Bangladesh spends 1.1% of GDP on health [45]. It is true that with development these factors will be improved over time but they will remain a key concern at many local levels and particularly in the disaster-prone poor zones in Bangladesh. These disaster zones, particularly where poverty is higher, require special attention.

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