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RESEARCH PAPER

Measurement of Vulnerability to Climate Change in *Char* Areas: A Survey

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Abstract: Threats caused to the environment and human life by climate change have become an urgent issue. Climate change often aggravates hazards in a given area and has harmful effects on the people residing there. Affected by massive floods, land erosion, and the destruction of agricultural lands, *char* people live a risky life. Char dwellers are among the communities that suffer the most as a result of the effects of climate change. Few studies discuss the vulnerabilities of communities living in char areas to climate change. This paper attempts to summarize the existing research. It also discusses data-related issues in the measurement of vulnerability to climate change. It ends by raising some policy-related considerations.

Keywords: Char, LVI, LVI-IPCC, CVI, vulnerability index

Journal of Economic Literature (JEL) Classification Code: Q540, Q560

1. INTRODUCTION

Vulnerabilities induced by floods and soil erosion render it difficult for *char* dwellers to make a living[1] and cohabitate with the river (Lahiri-Dutt 2014). Floods and sand deposition on cultivable land impact char livelihoods and vulnerability (Ashley *et al.* 2000). Char land erosion is highly unpredictable, leading to traumatic shocks to the livelihoods of char dwellers and causing households to lose their land, assets, and shelter (EGIS 2000; Kamal 2011;

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[1] Char areas are "the new riverine lands and islands created by the continual shifting of the rivers, and emerge from the deposition of sand and silt from upstream. Chars are found along all the major river systems, both lining the banks of rivers and as mid-river islands" (DFID 2000, 3).

Rakiba *et al.* 2019). In the Indian subcontinent, char areas are located in the Ganga–Brahmaputra–Meghna plains (Lahiri-Dutt 2014). According to Lahiri-Dutt and Samanta (2013), char areas are vastly different from other wetlands; the closest geographical structures to char areas are the mouths of deltas. In North-East India, char areas are spread across the Brahmaputra valley of Assam, across four agro-climatic zones: the upper Brahmaputra valley, north-bank plain zone, middle Brahmaputra valley, and lower Brahmaputra valley (GOA 2002–2003). These unique landforms in Assam are affected by several types of natural disasters, making char dwellers one of the poorest and most vulnerable groups in Assam (Kamal 2011). The intensity of soil formation in the river, and hence, the survival and formation of chars, is influenced by several factors such as riverbank erosion, river flow patterns, soil loss, and floods (Goswami 2014; Chakraborty 2012/2014). In addition to floods, chars are highly impacted by erosion, which makes the lives and livelihoods of char dwellers uncertain and highly prone to vulnerability (HDR 2014). In the char areas of Assam, income opportunities, health and educational facilities, and so on are limited and are further hindered by floods and other climate-driven factors (Kumar and Das 2019).

Following the views of Birkmann (2013, 29), "Environment is the shaper where natural hazards and climate variability originated; it is at the same time an important resource for many people who are highly exposed to these hazards." Natural hazards have detrimental effects on communities and hinder their socio-economic development. Climate change, through its effects on natural and human systems, plays a significant role in determining the intensity and frequency of these natural hazards and the risks associated with them (Islam *et al.* 2015a; Panthi *et al.* 2016; Simotwo *et al.* 2018; Azam *et al.* 2019; IPCC 2014). These climate-induced hazards and risks can cause considerable damage to human life and property globally (Rakiba *et al.* 2019). A huge section of the world population lives in earthquake zones, floodplains, riverine islands, and low-lying coastal areas that are inherently risky (Lahiri-Dutt and Samanta 2007).

A population's vulnerability to climate impacts is influenced by local factors that vary with time and space (Alam 2017). The study of vulnerability to climate change is important in the context of risk assessment; this need has also been emphasized by the Intergovernmental Panel on Climate Change (IPCC) (2014). Climate vulnerability can be studied using two approaches: qualitative and quantitative. Measurement or assessment of vulnerability is a quantitative approach to studying vulnerability. Assessment of vulnerability is important as it helps identify suitable adaptation techniques (O'Brien *et al.* 2009). Quantitative approaches to vulnerability may be either indicator-based or econometric. In indicator-based approaches, an index representing vulnerability is constructed, while in econometric approaches, econometric tools are used. Econometric methods are useful for understanding the factors that influence the extent of which climate hazards impact people's lives and livelihoods and the economic impacts of vulnerability (Noy and Yonson 2016). A vulnerability index is important for making comparisons across different contexts, monitoring vulnerabilities over space and time, and allocating resources to undertake mitigation and adaptation strategies (Preston *et al.* 2011). It can also be used to evaluate the effectiveness of development policy frameworks (Eriksen and Kelly 2007). As vulnerability is influenced by local factors, several researchers have argued in favour of context- and place-specific assessments of vulnerability (Cutter *et al.* 2003; Füssel 2010; Fraser *et al.* 2011; Wood *et al.* 2014; Alam 2016; Alam 2017). To estimate the extent of vulnerability of char areas, researchers have used a variety of indicator-based methods such as the Livelihood Vulnerability Index (LVI), LVI-IPCC, and Climate Change Vulnerability Index (CVI). Although several methods have been used to measure vulnerability, there is no consensus on which tool is best to measure vulnerability, specifically in char areas. Hence, this paper briefly describes the methods available to measure vulnerability in char areas, discusses various issues related to those methods, and identifies the most suitable method of vulnerability measurement.

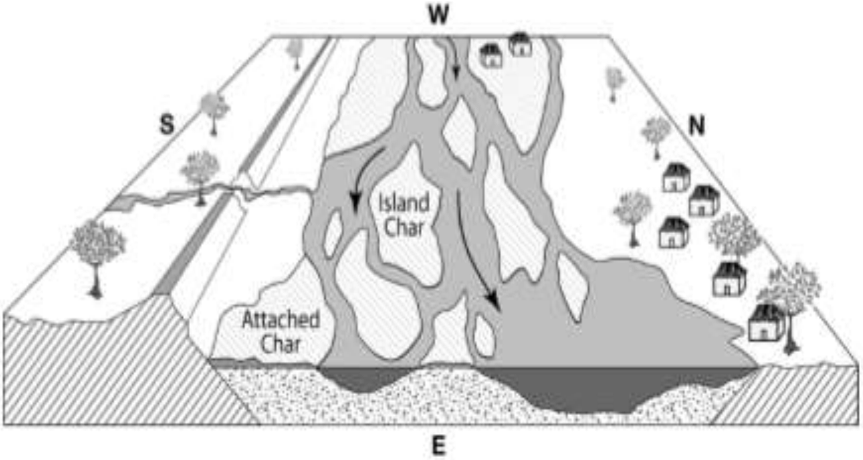
The paper is divided into six sections. In Section 2, a discussion is presented on char areas and how the idea of vulnerability is linked with them. Section 3 includes a detailed discussion on the methods used to measure vulnerability to climate change in char areas. Section 4 examines the data and the measurement-related issues associated with these methods. Section 5 summarizes the results of various quantitative studies on vulnerability in char areas. Section 6 concludes the paper.

2. CHAR AND VULNERABILITY

There are two types of char areas (Figure 1): island chars, or mid-river islands, and attached chars, which are connected to riverbanks (GOA 1983; Lahiri-Dutt 2014). The formation of a char at a particular time and in a specific area is highly dependent on varied factors such as the river's flow pattern, the occurrence of floods, discharge of sediment due to soil loss, and erosion of sand material from the riverbanks (Lahiri-Dutt 2014). Rivers like the Ganga and Brahmaputra change their courses frequently (Lahiri-Dutt 2014); this leads to erosion and the emergence of char lands (Sarker *et al.* 2015). Changes in the course of the river, its flow pattern, and the distance of the river from the char all significantly influence the permanence of a char (Khandakar 2016). Changes in the size and location of chars could adversely affect the habitations of char dwellers and the availability of land for agriculture and animal rearing (Mondal *et al.* 2016; Das *et al.* 2020).

In Assam, char areas result from sedimentation by the river Brahmaputra. The Brahmaputra is considered the second-most sediment-charged river in the world (Chakraborty 2009; Hoque 2015). As the river flows, its velocity reduces, as does its capacity to carry sediment (Chakraborty 2009). As a result, it deposits silt, which eventually gets covered by vegetation. A socio-economic survey of char areas in Assam estimates that there are 36,092 hectares of char land in Assam, occupying approximately 5% of the state's total geographical area (GOA 2002–2003).

Figure 1: Island Char and Attached Char



Source: Lahiri-Dutt (2014)

The morphology of rivers, the physical characteristics of their geographic locations, and the climate during the monsoons make char areas vulnerable to natural disasters (Coleman 1969; Baqee 1998; Islam *et al.* 2015a). Char dwellers are extremely vulnerable to hazards caused by climate change, such as storm surges, rising salinity, riverbank erosion, floods, irregular rainfall, droughts, hailstorms, water logging, and pest infestations. As water levels rise, saline water enters cultivable land, which drastically reduces fertility.

Char dwellers live in extreme conditions during floods, which adversely affect their crops, livestock, houses, and other property. Char dwellers consider normal floods—which are short, predictable, and low in intensity—as a blessing as they benefit them environmentally and economically by making their land more fertile and suitable for cultivation. Moreover, researchers describe char areas as lands ripe with possibility for their dwellers (Lahiri-Dutt and Samanta 2013; Hoque 2015; Lafaye de Micheaux *et al.* 2018). Though these lands are risky, unstable, and fragile, they attract the attention of some people, mainly those belonging to marginal communities, since these lands are fertile and suitable for cultivation (Lahiri-Dutt and Samanta 2013).

3. MEASURING VULNERABILITY IN CHAR AREAS

Two methods are used to measure vulnerability to climate change in char areas: the econometric approach and the index-based approach. The econometric approach considers factors such as vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU), and vulnerability as uninsured exposure to risk (VER). Under the indicator-based approach, a number of indices have been developed and used by various researchers. These include the Social Vulnerability Index (SoVI) by Cutter *et al.* (2003), another Social Vulnerability Index (SVI) by Vincent (2004), the Vulnerability Index by Deressa *et al.* (2008), LVI and LVI-IPCC by Hahn *et al.* (2009), the Livelihood Effect Index (LEI) by Urothody and Larsen (2010), the Climate Vulnerability Index (CVI) by Pandey and Jha (2012), the Social Vulnerability Index (SVI) by Ge *et al.* (2013), the Index of Social Vulnerability by Lee (2014), the Socio-economic Vulnerability Index (SeVI) by Ahsan and Warner (2014), and the Physical Vulnerability to Climate Change Index (PVCCI) by Feindouno *et al.* (2020).

A considerable number of researchers have studied vulnerability to climate change in char areas. Some of these studies are qualitative in nature (EGIS 2000; Ashley *et al.* 2000; Kamal 2011; Lahiri-Dutt and Samanta 2013; Chakraborty 2009/2012/2014; Islam and Hussain 2014; Islam *et al.* 2015b; Rakiba *et al.* 2019); other researchers use quantitative approaches (Toufique and Yunus 2013; Alam *et al.* 2017; Azam *et al.* 2019; Sarker *et al.* 2019; Das *et al.* 2020; Ahmed *et al.* 2021).

Econometric methods are widely used to study vulnerability to climate change. However, few studies on char areas use these methods. Most studies are qualitative in nature. These researchers draw on descriptive studies, ethnographic research, focus group discussions (FGD), participatory rural appraisals (PRA), and rapid rural appraisals (RRA), and generate descriptive statistics. A limited number of studies have used indices for quantitative analyses of vulnerability to climate change in char areas (Toufique and Yunus 2013; Alam *et al.* 2017; Azam *et al.* 2019; Sarker *et al.* 2019; Das *et al.* 2020; Ahmed *et al.* 2021). There are three main indices used by researchers: LVI, CVI, and LVI-IPCC. The LVI and LVI-IPCC were developed by Hahn *et al.* (2009) and the CVI is the updated version of the LVI, developed by Pandey and Jha (2012). This section discusses all three methods.

The three indices are based on the IPCC (2001) definition of vulnerability; that is, vulnerability is considered a function of exposure, sensitivity, and adaptive capacity. Therefore,

$$\text{Vulnerability} = f\,(\text{exposure, sensitivity, adaptive capacity})$$

However, it is to be noted that in the IPCC's (2014) definition on vulnerability, it has removed exposure component from the idea and expressed vulnerability as a function of sensitivity and adaptive capacity only.

The LVI aims to quantify the strength of communities' livelihoods; people's access to healthcare and water sources; and the capacity of communities to adjust to the threats posed by climate change (Hahn *et al.* 2009). The balanced weight approach is used under the LVI approach to calculate vulnerability; that is, even though each major component includes various subcomponents, each subcomponent contributes equally to the overall LVI. Hahn *et al.* (2009) consider seven major components—social networks, livelihood strategy, socio-demographic profile, access to food, healthcare, and water, and the impact of climate variability and natural disasters. Again, each major component has a number of subcomponents. This method is useful in that it allows the addition or subtraction of indicators on the basis of the need and scope for research in any particular area (Hahn *et al.* 2009; Pandey and Jha 2011; Alam *et al.* 2017).

Since the subcomponents are measured at different scales, it is important to standardize them using an index. Standardization is done as follows:

$$\text{Index } Y_a = \frac{Y_a - Y_{min}}{Y_{max} - Y_{min}}$$

Where Y_a is the original subcomponent of area '*a*'. Y_{max} and Y_{min} are the maximum and minimum values of each subcomponent, respectively. For variables measuring frequencies, like the percentage of households having access to clean water, the maximum value is considered as 100 and the minimum as 0.

After converting the values of the subcomponents into indices, one can derive the value of the major component by taking the average of the subcomponents.

$$X_a = \frac{\sum_{i=1}^{n} IndexY_{a_i}}{n}$$

Here, X_a is one of the seven major components of area '*a*'. $IndexY_{a_i}$ is the i^{th} standardized subcomponent of the respective major component. And '*n*' represents the number of subcomponents present under the major component.

Once the seven major components are calculated, LVI can be calculated using the given formula:

$$LVI_a = \frac{\sum_{z=1}^{7} W_{X_z} X_{a_z}}{W_{X_z}}$$

Where LVI_a is the Livelihood Vulnerability Index for area '*a*', a weighted average of all the seven major components, and W_{X_z} indicates the number of subcomponents under the Z^{th} major component. Weights are assigned so that all subcomponents contribute to the overall LVI.

The LVI-IPCC is an alternative to the LVI approach. It was developed to calculate the LVI by incorporating the IPCC (2001) definition of vulnerability; in the LVI-IPCC, the seven major components are organized into three dimensions of vulnerability, and the index value of these three dimensions are calculated separately. Hence, the LVI-IPCC approach comes one step closer to the IPCC (2001) definition of vulnerability to climate change. In the calculation of LVI-IPCC, the adaptive capacity dimension includes components such as households' socio-demographic profile, livelihood strategies, and social networks. Sensitivity includes access to health, food, and water; and exposure refers to the occurrence of natural disasters and climate variability in the district. The LVI-IPCC differs from the LVI in its method of calculation. The LVI-IPCC presents the overall index as the difference between the exposure value and the value of adaptive capacity multiplied by the sensitivity index. Now, let's have a look at how the LVI-IPCC is calculated for a district, say '*a*'.

$$D_a = \frac{\sum_{i=1}^{n} W_{X_i} X_{a_i}}{W_{X_i}}$$

Where D_a is a dimension of the LVI-IPCC for district '*a*'. X_{a_i} are the main components of the a^{th} district indexed by '*i*'. Each major component's weight is defined by W_{X_i} and the number of main components under each dimension is defined by '*n*'.

Now, LVI-IPCC can be calculated using the following formula:

$$LVI\text{-}IPCC_a = (E_a - Ad.C_a) * S_a$$

Where E_a is the estimated exposure score of district '*a*', $Ad.C_a$ represents the index value of the adaptive capacity of the respective district, and the sensitivity score of the district '*a*' is denoted by S_a. The value of LVI-IPCC varies from −1 to 1. A value closer to 1 indicates a higher state of vulnerability, whereas −1 denotes less vulnerability. The LVI and LVI-IPCC both consider the same major components and use the same method to measure the index value of each major component. The dimensions of the CVI are the same as those of the LVI. Each component has relevant subcomponents under it. A conceptual improvement of the CVI over the LVI is that despite measuring vulnerability, the CVI aims to define a society's capacity to attain a 'no vulnerability' status. Therefore, methodologically, according to Pandey and Jha (2011, 497), "The inverse relationship for sensitivity has been considered keeping in view of analysing the per unit strength of the system bearing capability on absolute performance under the climate threats." Based on the three dimensions of vulnerability, the major components have been segregated—adaptive capability includes socio-demographic profile, livelihood strategies, and social networks. The dimension of sensitivity contains the health, food, and water components; and exposure captures the occurrence of natural disasters and climate variability (Pandey and Jha 2011). The subcomponents can be standardized using the same formula used in the LVI. The index values for exposure, sensitivity, and adaptive capacity are calculated separately, as follows:

$$Exp = \frac{X_{b1} ND + X_{b2} CV}{X_{b1} + X_{b2}}$$

Where *Exp* is the index of exposure. X_{b1} and X_{b2} are considered weights of the indicators, which are the number of subcomponents under the indicators ND and CV, respectively.

$$Sen = \frac{X_{c1} H + X_{c2} F + X_{c3} W}{X_{c1} + X_{c2} + X_{c3}}$$

Where *Sen* stands for the index of sensitivity; X_{c1}, X_{c2}, X_{c3} are the weights; and the number of subcomponents are *H*, *F*, and *W*.

The index of adaptive capacity (*Ada.Cap*) is calculated as follows:

$$\text{Ada.Cap} = \frac{X_{d1} SD + X_{d2} LS + X_{d3} SN}{X_{d1} + X_{d2} + X_{d3}}$$

Where X_{d1}, X_{d2}, X_{d3} are the weights, which are the number of subcomponents of *SD*, *LS*, and *SN* respectively.

The CVI considers an inverse relationship between sensitivity and the ability of a system to perform under climate threats. It explains the capability of a society to attain the status of no vulnerability. The CVI is calculated as follows:

$$\text{CVI} = 1 - [\{\frac{N_1\,Exp - N_2\,Ada.Cap}{N_1 + N_2}\}]^*\{\frac{1}{Sen}\}$$

N_i is the number of major components under the i^{th} dimension of the CVI. No number has been assigned to the sensitivity dimension, because its components cancel out each other. The value of the CVI falls within the range of 0 to 1. As it reflects the capability of people to reduce their vulnerability, the higher the value of the CVI, the lower the level of vulnerability, and the smaller the value of the CVI, the greater the level of vulnerability.

4. CHALLANGES IN MEASURING VULNERABILITY IN THE CONTEXT OF RIVERINE ISLANDS

Various methods have been used in the literature to measure vulnerability. Some indices are more inclined towards the socio-economic dimension while others emphasize the physical or biophysical aspects of vulnerability. The biophysical aspect covers the sensitivity components of vulnerability, while adaptive capacity covers the socio-economic. However, adaptive capacity and sensitivity are interlinked, and it would not be appropriate to calculate one without mentioning the other (Deressa *et al.* 2008).

All three indices, LVI, LVI-IPCC, and CVI, cover both the socio-economic and biophysical aspects of vulnerability. Researchers use primary data on social networks, livelihood strategies, socio-demographic profiles; access to food, healthcare, and water; and climate variability and natural disasters to calculate vulnerability indices (Toufique and Yunus 2013; Alam *et al.* 2017; Azam *et al.* 2019; Sarker *et al.* 2019; Das *et al.* 2020; Ahmed *et al.* 2021).

5. OVERVIEW OF FINDINGS FROM EMPIRICAL STUDIES ON RIVERINE ISLANDS

India and Bangladesh share about 54 transboundary rivers that extensively support the livelihoods of a large number of riverine communities. However, various climate change associated factors, such as the increased frequency of floods, unpredictable changes in the courses of rivers, and a continuous increase in the width of these rivers, are having significant adverse effects on the lives and livelihoods of communities (Sentinel 2022). Sumanta Biswas, Senior Programme Officer, CUTS International, in an interview, said that along with climate change, deforestation, rising urbanization, and more intensive agricultural practices have adversely affected many rivers in South Asia by altering their courses and changing their flow rate (Suri 2021). As a result, increased erosion, siltation, and unexpected floods have become common in riverine communities. Transboundary river systems* are also under serious stress due to various factors, including the overuse of resources such as newly emerged sandbars for cultivation and sand mining, overfishing, and so on, thus increasing the variability of resources. Disruptions in the livelihoods of transboundary riverine communities can be clearly observed at the national and sub-national levels; flooding severely affects these regions and excessive rain leads to devastating conditions (Suri 2021). Alam *et al.* (2018), in their study on the vulnerability of people living in the char lands of the Brahmaputra–Jamuna river system of Bangladesh, argue that the livelihood strategies of those living on char lands are considerably different from those of people residing on the mainland. The majority of the population is engaged in agriculture, and during the off season, char dwellers also take up non-farm activities. Thus, their lives are severely affected by floods and land erosion compared to the people residing in the mainland. The main challenges include seasonal flooding, geographic isolation, and anthropogenic as well as climatic stressors. Though riverine communities have adjusted their livelihoods and cropping patterns to observed flooding patterns, due to climate variability, the occurrence of early floods has become a common issue linked to the washing away of crops. Bhuiyan *et al.* (2017) found that massive land erosion is the most significant vulnerability factor among char communities in Bangladesh. A study by Salam *et al.* (2019), on char lands in Bangladesh, showed that flooding is the main contributor to vulnerability among char dwellers. Floods in char lands affect various aspects, including people's health and habitation, agriculture, economic activities, the availability of clean water sources, and sanitation status.

To quantitatively analyse the livelihood vulnerabilities of char communities, three indices—the LVI, LVI-IPCC, and CVI—have been used by different researchers. Researchers study vulnerability to climate change in the char areas to compare it to the mainland (Toufique and Yunus 3013) and to compare island and riverbank chars (Alam *et al.* 2017; Das *et al.* 2020).

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[*] The Indus, Ganges, and Brahmaputra are known as the major transboundary river systems of South Asia. By providing energy, food, water, and ecosystem services, these river systems across the subcontinent support about 700 crore people (Suri 2014).

Studies have also analysed vulnerability to climate change in terms of the distance of the char villages from the administrative headquarters (Sarker *et al.* 2019). This section summarizes the major findings of the research on vulnerability to climate change in char areas using quantitative techniques.

Many studies report the high vulnerability of char areas. River erosion, floods, and droughts are the major climate-driven risks facing char dwellers, and these events have significant negative effects on char livelihoods, which are primarily based on agriculture (Ahmed *et al.* 2021). Char dwellers are highly sensitive and exposed to natural disasters and have a low level of adaptive capacity (Azam *et al.* 2019; Ahmed *et al.* 2021). Char communities with a large number of marginalized households are more vulnerable (Azam *et al.* 2019).

Char dwellers are more vulnerable to climate change compared to inhabitants on the mainland. The major components influencing this difference are social networks, food, and access to water (Toufique and Yunus 2013). Differences in vulnerability are also evident between the island chars and attached chars. Alam *et al.* (2017) found that the inhabitants of island chars are more vulnerable compared to attached ones due to relatively less access to educational, health, and financial institutions, greater exposure to natural disasters, and more limited crop diversification. Limited availability of food and water further exacerbate the vulnerability of char areas. Healthcare, education, and government services are less available to island char dwellers, making them more vulnerable. Again, island chars are more exposed to frequent floods and riverbank erosion compared to attached chars. Vulnerability to climate change is also determined by the distance of the char villages from the district headquarters. Char villages that are nearer the district administrative headquarters are comparatively less vulnerable than those char villages that are further away due to the latter's lower access to education, basic public services, healthcare, and financial assets. The latter have comparatively low social capital, making inhabitants of further away chars financially more vulnerable (Sarker *et al.* 2019).

6. CONCLUSION

Both socio-economic and environmental factors determine social groups' vulnerability to climate change (Deressa *et al.* 2008). In the discussion on the socio-economic impacts of climate change, vulnerability and adaptive capacity have been gaining importance over the last few years, more specifically, after the IPCC (2001) report on climate change, indicating a growing prioritization of the field of vulnerability research (Ahsan and Warner, 2014). According to Hoddinott and Quisumbing (2003), VEP and

VEU determine a benchmark of welfare (poverty or utility). The VER model studies both biophysical and socio-economic factors and the impact of these factors on loss of welfare in the form of a reduction in consumption (Narayanan and Sahu 2016). Researchers have used only indicator-based approaches to quantitatively study vulnerability to climate change in char areas. Three indices are used: the LVI, LVI-IPCC, and CVI.

It is important to note that all the three vulnerability indices are based on the IPCC (2001) definition, where vulnerability to climate change is a function of sensitivity, exposure, and adaptive capacity. However, the IPCC (2014) report separates the exposure component from the idea of vulnerability and expresses it as a function of sensitivity and adaptive capacity only. However, even after the reformulation of the concept of vulnerability in the report, later studies on vulnerability to climate change in char areas have continued to use the exposure component as part of the measurement (Alam *et al.* 2017; Azam *et al.* 2019; Sarker *et al.* 2019; Das *et al.* 2020; Ahmed *et al.* 2021) Therefore, some adjustments to these indices may be necessary to incorporate the updated idea of vulnerability to climate change.

As discussed earlier, the research on vulnerability to climate change in char areas using quantitative approaches employs indicator-based methods; an econometric approach has not yet been applied. However, since both the econometric and indicator-based approaches have advantages, using both in tandem may lead to a better understanding of vulnerability. For instance, an indicator-based approach will facilitate an understanding of the extent of vulnerability to climate change, while an econometric-based approach would help to study the economic impact.

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