frontiers | Frontiers in Water

TYPE Mini Review
PUBLISHED 15 August 2022
DOI 10.3389/frwa.2022.913840

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to
Water and Climate,
a section of the journal
Frontiers in Water

RECEIVED 06 April 2022
ACCEPTED 25 July 2022
PUBLISHED 15 August 2022

CITATION
Borah L, Kalita B, Boro P, Kulnu AS and Hazarika N (2022) Climate change impacts on socio-hydrological spaces of the Brahmaputra floodplain in Assam, Northeast India: A review. *Front. Water* 4:913840.
doi: 10.3389/frwa.2022.913840

Climate change impacts on socio-hydrological spaces of the Brahmaputra floodplain in Assam, Northeast India: A review

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Intensification of the water cycle mediated by global warming increases the risk of hydrological disasters by modifying precipitation patterns across the globe which leads to adverse socio-economic impacts, especially in developing countries. Socio-hydrological spaces in the vicinity of major river systems are prone to the devastating effects of hydrological disasters yet attract human settlements due to the availability of fertile lands that support agriculture. The Brahmaputra floodplain (BFP) of Assam in Northeast India (NEI) is one such region that supports a high population in spite of being ravaged by annual floods and occasional droughts. The current study attempts to critically review the climate change impacts on socio-hydrological spaces of the BFP exploring climate change-hazard-lives and livelihood linkages of floodplain dwellers. This work utilizes peer reviewed articles along with reports of government and international/national organizations to critically appraise the following-(i) existing climate and fluvial hazard scenario in the BFP, (ii) impacts of climate change on the fluvial hazard and agriculture in the BFP, and (iii) the adaptation and mitigation measures that exist in the BFP. Shifts in the long-term trends of temperature and rainfall have occurred over this region leading to speculations on future scenarios of hydrological hazards and their impacts. Studies project an alteration in the hydrology and flow regime of the Brahmaputra River under climate warming scenarios which will influence the hazard characteristics with implications for agriculture and food security. Integrating disaster risk reduction with agricultural management can provide better climate resilience to the farming communities in the BFP.

KEYWORDS

climate change, hydrological disasters, socio-hydrological spaces, Brahmaputra floodplain, agriculture, food security, livelihood

Introduction

Earth's climate system has undergone significant changes owing to anthropogenic global warming (IPCC, 2021). India is one of the most populous and disaster-prone countries in the world and has a predominantly agriculture-based economy. The average temperature in India has risen by 0.7°C from the period 1901–2018, which is further projected to rise by ∼4.4°C (relative to the 1976–2005 average) by the end of this century (Krishnan et al., 2020). Climate change vulnerability varies across countries, regions, and communities depending on geographical, socioeconomic, cultural, and political factors (Thomas et al., 2019). Developing nations often tend to be more vulnerable to climate change due to their fragile locations, greater propensity for natural hazards, heavy reliance on climate sensitive activities such as agriculture, poor socioeconomic conditions, and limited resources for adaptation (Wijaya, 2014).

Northeast India (NEI) is one of the highest rainfall receiving regions in the country owing to a strong summer monsoon. Floods are regularly occurring major hydrological disasters in this region due to the prevalence of short duration intense rainfall events (Goswami et al., 2010; Varikoden and Revadekar, 2020). Long term meteorological data over this region have revealed a rising trend in temperature which is projected to rise further in the future (Dash et al., 2012; Jain et al., 2013; Laskar et al., 2014). NEI has witnessed a rapid decrease in summer monsoon rainfall during 1979–2014 (Choudhury et al., 2019). The increase in the frequency of extreme events over a period of 90 years reveals that the vulnerability of NEI to hydrological disasters over the coming years is much higher than in the rest of India (Zahan et al., 2021).

The Brahmaputra, one of the largest braided river systems, is the seventh largest river in the world (Tandon and Sinha, 2007) and has created an extensive flat floodplain in the state of Assam, India (Figure 1). The Brahmaputra floodplain (BFP) supports about 27 million people by providing land for agriculture and human habitat. About 86% of the total area of the State is rural and of the total land available for agriculture (4 million hectares), 70% is cultivated. The wet rice paddy constitutes about 60% of overall cultivated crops. The harvesting season coincides with the summer monsoon during which heavy precipitation often leads to flooding in the adjacent plains (Economic Survey of Assam, 2021). More than 83% of the farmer families are small and marginal with an average operational holding as low as 1.15 hectares (Agricultural Census of Assam, 2006). Climate change in this region may trigger a cascading effect on the hydrometeorological hazards influencing the lives and livelihoods of the floodplain dwellers. Hence, the objective of the present review is to critically analyze the climate change vulnerabilities of this region using a socio-hydrological approach.

Socio-hydrology is a science that centralizes understanding of the dynamics and co-evolution of coupled human-water systems. It considers human actions as part and parcel of water dynamics which is often challenging as the fluvial geomorphology is dynamic (Sivapalan et al., 2012). Human civilization and societies developed on floodplains along major rivers, including in the BFP. Despite the periodical inundations, floodplains are preferred for settlements due to their favorable conditions for agriculture production, transportation, and economic growth (Di Baldassarre et al., 2013). The socio-hydrological approach is therefore indispensable to understanding and evolving climate change mitigation measures in this region.

Methodology

This review interrogates published literature for the last two decades (2001–2021). Scopus, ISI Web of Science database, Science Direct, and Google Scholar were queried within the restricted time frame. These journal databases were chosen based on their reputation and accessibility to authors. Boolean search string that included keywords such as "Climate change*," "Flood hazard*," "erosion*," "Brahmaputra*," "Vulnerability*," "adaptation*," in combination with "climate change adaptation," "Indigenous knowledge," "agriculture," "India," "Assam," "Brahmaputra floodplain" were utilized to filter out the relevant article. The peer reviewed articles that contained these terms in their title, abstract, and keywords were acquired. The abstract of the articles was read and the ones that matched our themes and the study area were selected to be included in this study. The inclusion of papers for the present review is based on two criteria-(1) the articles are published in peer reviewed journals and (2) they are published during 2001–2021. Besides the peer reviewed articles government reports, and reports by recognized International and National bodies/organizations were also included. After the preliminary screening of the databases more than 100 articles along with reports were collected which were then thoroughly read by the authors. Based on their direct utility the number was filtered down to 83 which were finally utilized to carry out the present review.

Climate change-fluvial hazard-livelihood impacts in the BFP: Past, present, and future

An increasing trend in temperature in Assam was reported for the period 1986–2015 by Tamuly et al. (2019). The BFP itself is reported to have warmed by 0.90°C between 1986 and 2015 (Tamuly et al., 2019). A significant increase in mean annual temperature and decline in rainfall over the eastern part of the Indus, Ganga, and Brahmaputra River basins from 1998 to 2017 were reported by Patel et al. (2021). A similar study by Begum and Mahanta (2022) found a significant increase in annual minimum temperature in Assam. Future projections are uncertain and show an increase in temperature over the Brahmaputra basin by the end of this century and a 25% increase in the number of consecutive dry days during the monsoon season in Assam (Dobler et al., 2011). From an

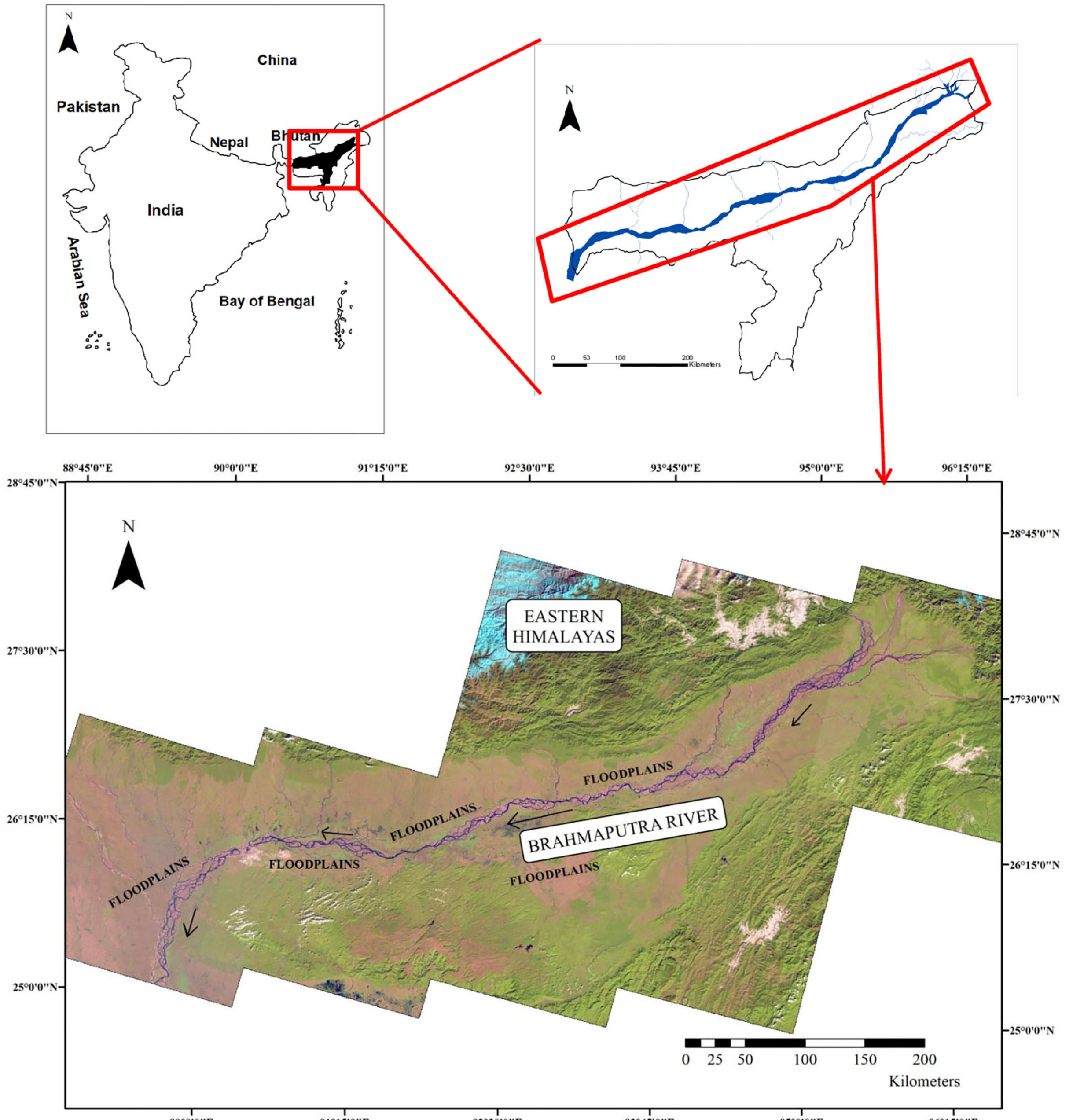

FIGURE 1
Location map of the study area highlighting the Brahmaputra floodplain (BFP).

analysis of the outputs of 22 General Circulation Models, it was found that temperatures over the Brahmaputra basin are expected to increase from 1.3 to 2.4°C by 2050, and from 2.0 to 4.5°C by 2100; monthly evapotranspiration is likely to increase by 5–18% and 7–36% by 2050 and 2100, respectively; monthly rainfall may vary from 14% decrease to 15% increase by 2050, and 28% decrease to 22% increase by 2100 (Mahanta et al., 2014).

Global studies suggest that climate change could increase the risk of hydrological disasters in the future (Van Aalst, 2006; Lane and Kay, 2021). The fluvial processes of the Brahmaputra River and its tributaries continuously alter the floodplains, at times to an undesired magnitude (Sarma and Phukan, 2004; Kotoky et al., 2005, 2012; Das et al., 2012; Lahiri and Sinha, 2012). The river regularly inundates and erodes owing to high orographic precipitation on a narrow drainage basin (Shampa and Ali, 2019). The BFP experienced high magnitude floods in 1954, 1962, 1972, 1977, 1984, 1988, 1998, 2002, 2004, 2012, and 2020 over the past half-a-century. Three to four recurrent flood waves ravage the floodplain annually destroying the lives and livelihood of the floodplain dwellers. Average annual losses are estimated to be $2 billion due to floods (WRD, 2022). Substantial investment in flood management schemes has been made which mostly constitute the construction and repair of structural measures such as embankments, porcupines (i.e., flood control and river training structures made of concrete, bamboo, or other locally available materials often utilized to protect the river bank from erosion), and geobags (Table 1). These measures are mostly targeted at prohibiting the flood water from inundating the cultivated area and homesteads in the adjacent plains, but of late these measures have been found wanting (Das et al., 2012; Hazarika et al., 2015, 2016, 2018). Moreover, newer facets of riverine hazards are also emerging in the form of sand casting (i.e., deposition of coarse grained sediments unsuitable for cultivation by flooding due to breach in embankments) which renders the area unsuitable for cultivation jeopardizing the lives and livelihood of the floodplain dwellers.

The Brahmaputra River is usually subjected to severe bank erosion leading to the widening of the river and adding more deposits forming permanent islands or chars (Sarker et al., 2003). The river is highly dynamic with erosion rates up to 1 km per year and the total erosion rate is 1.5–2 times higher than that of the Ganga River and much higher than the world average (Galy and France-Lanord, 2001). Erosion-deposition phenomenon is a typical characteristic feature of the Brahmaputra River leading to changes in the channel pattern and bankline shifts that have a severe impact on the agrarian communities. The erosion of fertile cultivable land leads to marginalization of the floodplain dwellers increasing poverty. This also leads to displacement at times which results in conflict and impoverishment.

In addition to the impacts of anthropogenic global warming, hydrological processes, fluvial dynamics, and future weather patterns will also be influenced by natural climate variability. With the observed increase in the number and intensity of extreme precipitation events over the Indian region (Goswami et al., 2006; Joshi and Rajeevan, 2006; Khaladkar et al., 2009) and the increase in developmental activities in hazard-prone areas, the exposure and vulnerability to flood disasters are anticipated to increase in the future (IPCC, 2012). A study in the Bangladesh delta region predicted alterations in the hydrological cycles and the flow regime of Ganga-Brahmaputra-Meghna (GBM) basins due to changes in global climate (Islam et al., 2018) leading to more serious floods in Bangladesh. According to Wijngaard et al. (2017), there will be an alteration in the magnitude of climatic means and extremes by the end of the twenty-first century where climatic extremes tend to increase stronger than climatic means. Regional climate models (RCMs) show a growing tendency of the discharge of the Brahmaputra River at Bahadurabad station during monsoon season when floods usually take place in Bangladesh (Islam et al., 2018). Kamal et al. (2013) highlighted an increasing trend in monsoon flows during the periods of 2020's, 2050's, and 2080's scenarios with a projected shift in the seasonal distribution of flows. Similarly, the pre-monsoon and monsoon sediment loads in the GBM delta are projected to increase from the 2020's to the 2080's (Fischer et al., 2017). Climate change is likely to have a significant effect on the hydrology and water resources of the Brahmaputra River basin as well as a rise in mean peak discharge which would lead to more frequent flooding, while dry-season is likely to increase (Nepal and Shrestha, 2015).

A recent study by Dutta et al. (2021), predicted an increase in rainfall as well as mean annual temperature by 2.5 mm/year and 0.062°C/year, respectively in the Brahmaputra basin. This will result in a rise in stream flow by 13% in annual discharge. Flood waves in the monsoon season were found to be lesser with increased flood volume in the basin under a projected climate change scenario, whereas in the pre-monsoonal period the number of waves and their peak discharges is predicted to be increased by Ghosh and Dutta (2012). Climate change will also impact the sediment load of the river which is projected to rise by 40% annually by the end of the period 2075–2100 compared to 1986–1991 affecting the region's ecosystem and agricultural fields.

These projected hydrological alterations in the Brahmaputra Basin under climate change are projected to have devastating impacts on agriculture-dependent livelihoods and food security of the floodplain dwellers. Direct impacts of rising temperatures and erratic rainfall patterns on crops, livestock, fisheries, etc. have been extensively studied globally. Using InfoCrop model studies, Kumar et al. (2011) showed that by the year 2030, the yield of irrigated rice is likely to reduce by about—10–5%, rainfed rice by—35–5%, irrigated maize by 40% and wheat by 20% under future climate warming scenarios projected for NEI. In BFP during 2001–2012, heavy and erratic rainfall patterns were found to affect rice yields negatively, whereas increased temperature and relative humidity had a positive effect (Buragohain et al., 2019). Nath and Mandal (2018) found that an increase in mean daily temperature positively affected autumn rice yield whereas it negatively affected winter and summer rice yields during 1978–2005. Mandal and Singha (2020) reported that yield variability of summer rice reduced with the rise in daily average temperature up to 20.74°C and beyond. Goswami et al. (2016) found that the vulnerability of rice cultivation to the impacts of projected temperature rise varied with sowing/transplanting time and the variety grown. Summer rice seedlings grown under future projected temperature conditions were found to exhibit stunted growth with a reduction in root lengths and biomass as well as reduced physiological activity (Rehman and Tanti, 2021). An average monthly warming of 1°C was found to decline the yield of tea by 3.8% during the period 2004–2013 (Duncan et al., 2016). Dutta (2014) reported that under a projected temperature

TABLE 1 Flood management and embankment schemes taken up by Water Resource Department in 2019–2020*.

Sl no.	Scheme/funding agency	Cost (in US $)	Year
1	NABARD (RIDF- XXV)	13.2 Million	2019–2020
2	State Plan	18.6 Million	2019–2020
3	CM Package in Barak Valley	4.8 Million	2019–2020
4	Comprehensive plan for raising and strengthening of Brahmaputra River embankment	586.4 Million	Ongoing projects
5	Aegis of Asian Development Bank (ADB)	68 Million	Ongoing projects
		82 Million	Ongoing projects
6	Rejuvenation of Kollong river (SOPD-ODS)	1.9 Million	2019–2020 (work will start soon)
7	SOPD-FDR (First phase)	46.2 Million	2019–2020
8	SOPD-FDR (Second phase)	33.9 Million	2019–2020
9	SDRF (40th SEC meeting)	22.7 Million	2019–2020
10	SDRF (41st SEC meeting)	11.8 Million	2019–2020
11	National Hydrology Project	6.2 Million	Ongoing projects

*Compiled from Economic Survey of Assam (2020–2021), Government of Assam, India.

increase of 2°C, a shift in the peak tea production period is likely to occur during 2050.

In addition to direct impacts, the agriculture sector is also likely to be indirectly affected by an increase in hydrometeorological hazards in future warming scenarios. Das (2015) reported that the frequency of climate change induced hydrological hazards such as flood, erosion, and siltation has increased in Majuli, the largest river island in the Brahmaputra River basin. This has devastated agricultural lands and declined farm productivity, forcing people to migrate to nearby cities in search of alternative livelihoods. The frequency of unprecedented droughts is reported to have increased in recent decades in NEI leading to adverse agricultural impacts (Parida and Oinam, 2015).

Climate-induced hazard mitigation and adaptation strategies in the BFP

For millennia, floodplain dwellers have coexisted with fluvial hazards in the BFP. The coexistence has been possible because of adaptation and mitigation strategies that evolved through experiences and became a part of the local culture. Be it the *Chang-Ghar* (houses with raised plinth) of the *Mising* and *Deuri* communities, raised granary, ethnic fishing devices or practice of community fishing, or knowledge of the construction of country boats. All of these adaptations reflect indigenous coping mechanisms for recurrent floods and erosion (Das, 2015; Hazarika et al., 2016). These are now practiced as the culture which has taken many centuries to evolve to its present form. However, the question of how climate change is going to affect the hazard scenario in the region is still uncertain. Changes in local precipitation and facets of riverine hazards such as deposition of coarse sediment have prompted the local population to take adaptive measures in the cultivation process. Whether these measures will be sufficient for the future and withstand time remains to be tested.

Diversified farming practices can provide smallholder farmers with optional income sources during periods of unfavorable climate (Bacon et al., 2017). Cultivation of improved crop varieties with resilience to abiotic and biotic stresses can sustain food production in a changing climate (Avelino et al., 2015; Verhage et al., 2017). Cultivation of flood tolerant varieties in flood prone areas and preference of high yielding varieties over traditional varieties are seen among the farmers of this region. The selection of rice varieties with lower greenhouse gas emitting potential and higher grain production is reported to reduce methane emissions from rice fields of Assam (Bharali et al., 2017).

Adopting water conservation and management practices in agriculture enable farmers to overcome situations such as droughts (Das et al., 2009; Devi, 2018; Mandal and Singha, 2020). Mid-season drainage/ alternate wet and dry method of irrigation is reported to reduce methane emissions from rice fields (Manjunath et al., 2009; Li et al., 2018; Surendran et al., 2021; Win et al., 2021). Techniques such as adjustment of sowing time, double transplanted rice, direct seeded rice, aerobic rice, and System of Rice Intensification (SRI) are found to be effective in sustaining rice production in a changing climate (Goswami et al., 2016; Uphoff and Thakur, 2019; Mandal and Singha, 2020; Assefa et al., 2021).

Nutrient management techniques such as the application of starch coated urea, *Azolla* compost, and biochar mixed with farm yard manure were found to mitigate nitrous oxide and methane emissions from rice and mustard fields of Assam while enhancing the yields by improving nitrogen use efficiency and soil carbon sequestration (Bordoloi et al., 2020; Bharali et al., 2021; Chetia et al., 2021). Pramanik and Phukan (2020) reported that tea bushes in the gardens of Assam can sequester significant amounts of atmospheric carbon dioxide. Gogoi et al. (2021) found that 39-year-old planted forests in the BFP can act as a major sink of carbon. Traditional knowledge exists among the floodplain dwellers of Assam regarding water, nutrient, pests, and disease management in agriculture (Sarmah and Sarmah, 2002; Deka et al., 2006; Barooah and Pathak, 2009) which can aid in climate change adaptation.

Discussion and conclusion

Changes in precipitation patterns, stream flow, peak discharge, and facets of fluvial hazards due to climate change have been projected by several studies. The facets of fluvial hazard are changing now at such a pace that the floodplain dwellers are struggling to cope with the changes using the existing indigenous adaptation strategies (Das et al., 2012; Hazarika et al., 2016, 2018). This has a serious implication, as it significantly influences the lives and livelihood of the floodplain dwellers. Changes in the hazards can impact agriculture, the mainstay of the economy. Therefore, it is uncertain whether conventional approaches to flood management using existing measures are going to sustain livelihoods in their present form (Hazarika et al., 2016). Sand casting in the Upper Brahmaputra plains has emerged as a new threat (Hazarika et al., 2015), against which the floodplain dwellers are yet to come up with a solution, and many such changes could be easily anticipated in view of climate change.

Global warming and resultant climate change are altering the magnitude and timing of hydrological hazards (Lane and Kay, 2021), putting additional stress on agriculture. Therefore, disaster management should be considered an integral part of agricultural management strategies. Moreover, indigenous traditional knowledge prevalent in the BFP should be sufficiently documented and promoted. Training, extension, education, and awareness programs enhance farmers' knowledge of climate resilient techniques and enable them to take more scientifically sound decisions while farming (Kumar and Sharma, 2013; Kingra et al., 2018; Chandio et al., 2021). Government initiatives could greatly enhance the adaptive capacity of the farming communities (Ranjitkar et al., 2016; Jayakumar et al., 2017; Jiang et al., 2018; Rehman and Tanti, 2021). Promotion of alternative livelihoods such as eco-tourism and incorporation of indigenous traditional knowledge into community flood management are suggested to enhance social resilience to climate change in the BFP (Das, 2015). This review is expected to trigger the policy makers and scientists to accelerate mitigation policy formulation and arm the floodplain dwellers with devices to sustain their lives and livelihood in a changing climate.

Author contributions

LB and NH contributed to the conceptualization and design of the basic framework of the review and contributed equally to the data analysis and writing of the manuscript. NH made the study area map. BK, PB, and AK provided inputs by surveying the literature. All the authors contributed to the article and approved the submitted version.

Acknowledgments

BK is the recipient of the ICSSR fellowship and acknowledges the same. PB is the recipient of NFST by MoTA and acknowledges the agency. AK is a DST Inspire fellow and acknowledges DST for the fellowship.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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