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Research paper

FLOOD RESEARCH IN BANGLADESH AND FUTURE DIRECTION: AN INSIGHT FROM LAST THREE DECADES

Md. Nazmul Hossen[1], **Shahpara Nawaz**[1], **Md. Humayain Kabir**[1,2*]

[1]Institute of Forestry and Environmental Sciences, University of Chittagong, Chattogram - 4331, Bangladesh

[2] Wegener Center for Climate and Global Change, University of Graz, Austria

[*] Corresponding author: mhkabir@cu.ac.bd

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Abstract: Flooding is a critical concern that causes substantial economic damages and social issues for different regions of Bangladesh every year. Approximately one-third of the country's total area is highly vulnerable to floods, and people's sufferings from the flooding are beyond description. Despite the magnitude and extent of floods, coma prehensive study on flood research in Bangladesh is inadequate. Therefore, this study analyses research articles published on floods, and their implications in Bangladesh over the last three decades. We used a systematic literature review to precisely understand the trend and pattern of published flood research in Bangladesh by summarizing, categorizing, and visualizing the existing research articles. This review revealed that research on integrated flood adaptation and management, effective flood modeling, and reliable forecasting is considerably less emphasized than studying the causes and impacts of the flood. In order to detect changes in flood causes and impacts over time and establish links between physical exposure, risk experience, and socio-demographic data in research to develop integrated flood management mechanisms, it is possible to operationalize systematic study in a specific location for an extended period. We also found that a considerable increase in interest in doing flood research following the year 2000, as the country experienced an increase in the frequency and severity of floods across the country. Based on findings of this study, we suggested an agenda of future flood research in Bangladesh.

Keywords: Flood risk, Bangladesh, systematic review, adaptation, impact assessment.

Introduction

Natural disaster frequency has been amplified globally (Kabir and Hossen, 2019). Because of frequent natural catastrophic events, the death of humans, damage of properties and devastation of the environment are increasing considerably, and one-third of these losses are primarily attributed to the flood (Adhikari et al., 2010). Flood is a natural phenomenon that occurs naturally and regularly worldwide. Floods are correlated with the rising population tensions in third-world countries and economic growth. This connection affects the deterioration of the catchment and the waterway invasion. In addition, inadequate development of the river basins, incorrect land use and procedures, inadequate legal and policy tools, and poor governance enhance the chances of flood damage (Plate, 2002; Merz et al., 2010). In addition, flooding is also correlated with storm surge or extreme tidal events and global warming (Nied et al., 2014; (Kundzewicz et al., 2014, 2018). Approximately 2.4 Million fatalities worldwide and about $82 billion economic loss occurred due to flood disasters from 1950 to 2021 (Guha-Sapir, 2021). Around 11% of the world's population lives in flood-prone areas, and an estimated 1% of the world's population is susceptible to flooding annually (Kundzewicz et al., 2014). The average number of deaths per year in 1990–2021 was thousands, with the highest mortality in South and Southeast Asia driven by floods. However, uneven distribution of economic loss can be noticed among the continents. For instance, Asia experienced the highest financial loss, more than 50% of the global damage from 1990 to 2021. On the contrary, Europe and America share the same economic loss, around 17% and other continents suffered a lower economic loss (Guha-Sapir, 2021). Asia's developing countries witnessed the highest fatality, at 96% of the total flood-related deaths (Guha-Sapir, 2021).

South Asia is seen as Asia's vulnerable and disadvantaged region owing to the high risk of floods (Khalequzzaman, 1994; Ahmad and Ahmed, 2003; Dastagir, 2015; Dewan, 2015; Ozaki, 2016). Population increase, poverty, and climatic change. Floods are increasing in frequency across the country (Abbas et al., 2016). South Asian countries including Bangladesh, India, Nepal, and Pakistan are especially vulnerable to floods due to a lack of adaptive capacity. Bangladesh, ranked second in Asia, is the world's fifth most vulnerable country to disasters (Dastagir, 2015). Losses by floods in Asia is more than USD 55 billion between 1950 and 2021 (Guha-Sapir, 2021). The highest loss was India and Bangladesh losing a significant amount (Abbas et al., 2016). In terms of casualties, the second-highest number of people died in Bangladesh in that period (Abbas et al., 2016; Dewan, 2013). Bangladesh's location on the Ganges, Brahmaputra, and Meghna river deltas made it more vulnerable to disasters in South Asia (Wester et al., 2019). Wester et al., 2019 stated that 97.1 % of Bangladesh and 139.6 million people are at risk of confronting frequent floods because of hindu kush himalayan river systems. Glaciers melting of the Himalayans region and change of rainfall pattern add to the cause of flash floods and riverine floods in Bangladesh. About 80% of the land in-country is flood plain, making it incredibly vulnerable to recurrent floods. It is estimated that seven devastating floods happened in Bangladesh in the last 50 years (Kabir and Hossen, 2019).

It is crucial to establish integrated planning to prevent flood-related suffering and financial losses due to property destruction. Such methods, which should reduce people's vulnerability to flooding and enhance their adaptability capacities, can be developed by understanding flood occurrence and patterns. As a result, several studies have been conducted in Bangladesh on causes, predictions, modeling, impacts, patterns, vulnerability, and adaptation.

In order to grasp the concept of historical flood patterns and flood mitigation, it is necessary to assess existing flood-related research. In the accessible Bangladesh flood research paper, there was no deep investigation of historical flood events. This paper attempts to classify existing floods research based on specific characteristics and determine the research trend of floods in Bangladesh. This study helps to identify new dimensions of flood research in Bangladesh which should receive more attention in the future.

Flood in the context of Bangladesh

Bangladesh is the sixth most vulnerable country to flood due to its topographic condition and adverse consequences of climate change (Ozaki, 2016). In addition, many undecorated floods occurred in this country on account of exhaustive and robust monsoon season rainfalls in the Ganges-Brahmaputra-Meghna (GBM) basin area (e. g., 1987, 1988, 1998, and 2007) (Ikeuchi et al., 2015). Bangladesh has only 7% of the overall catchment area of the Ganges-Brahmaputra-Meghna basin and must discharge around 92 percent of the river water into the Bay of Bengal (Dastagir, 2015; Baten et al., 2018).

Ninety flood events happened in Bangladesh from 1990 to 2021 (Guha-Sapir, 2021). In the last three-decade, riverine floods dominated the flooding events by constituting more than 50% of the total flood (D. Guha-Sapir, 2021). Usually, about 30% of the land area is submerged though sometimes it reaches 50% to70% (Ahmad and Ahmed, 2003). Though flood mainly affects flood plains, it causes fatalities and damage crops, homesteads, livestock, plants, and infrastructure through inundation (Whitehead et al., 2015). However, It also creates extensive riverbank erosion (Roy et al., 2019).

As a result, from 1990 to 2021, 90 significant flood events, including massive floods of the year 1998, 2003, 2004, 2007 and 2012, were reported with about 6279 death, 152 million people adversely affected by the economic loss of approximately USD 136 million (Guha-Sapir, 2021).

During the extreme flood events of 1998, 2004, 2007 and 2012, more than 50% were inundated, consisting of more than 30 districts (Baten et al., 2018). Also, in 1998 and 2007, flood events took the highest life (Guha-Sapir, 2021). Last three decades, approximately all of the districts of Bangladesh have been affected by floods, according to the EM-DAT database though districts of Chattogram were affected most (Figure 1). Rangpur, Dhaka and Rajshahi were impacted by inundation after Chattogram and Barishal were least impacted. Mymensingh and Sylhet suffered from flooding events in a moderate amount. The flood effects constitute various losses, including environmental degradation, economic loss and death (Jonkman and Vrijling, 2008). In total, about 2/3 of the lives lost due to drowning and 1/3 to physical injuries, heart attack, and electrocutions in Bangladesh were attributed to floods (Dewan, 2015).

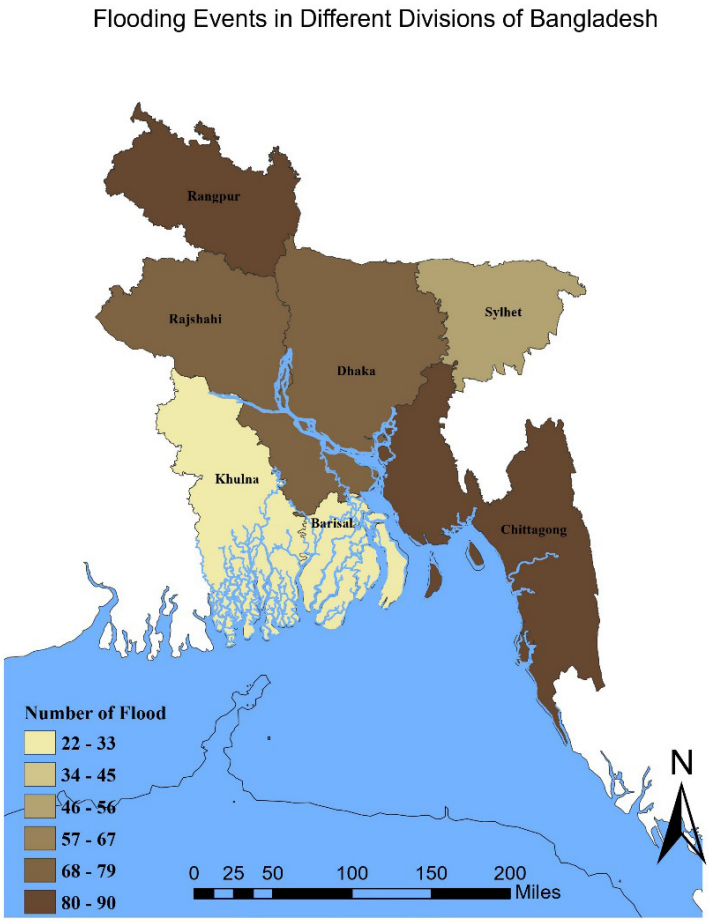

Figure 1. Flooding events from 1990-2021 in different divisions of Bangladesh. Data source: (Guha-Sapir, 2021)

Table 1: Damage comparison of extreme flooding events in Bangladesh

Recent damaging floods in Bangladesh			
Impact	**1998**	**2004**	**2007**
Area affected (1000 km²)	100	56	62
Total land area inundated (1000 km²)	69	39	42
Fatalities (no.)	918	285	1110
Houses damaged (1000s)	2647	895	1000
Roads damaged (Km)	15,927	27,970	31,523
Asset losses (million US$)	2128	1860	1100
GDP (million US$)	44,092	55,900	68,400
Asset losses (% of GDP)	4.8	3.3	1.6
Total land area inundated	69	39	42
Crops damaged (millions of ha)	1.7	1.3	2.1
Revisit Time (years)	90	12	14

Source: Modified from Guha-Sapir, 2021; Dewan, 2015; Kabir and Hossen, 2019

The data of the previous five extremely damaging floods of the country represent that more than 35% of the area was underwater during those flood events (Table 1). Moreover, Numerous research found that a flood happens every four to five years during the monsoon. Therefore, over 40 percent of this country's territory is submerged (Dewan, 2015). Among the other flood events, 2007's flood created the highest people affected record and economic damage and flood inundated 42% of the total land area and affected 14 million people with 1110 people died (Table 1). Moreover, this flood destroyed 2.1 million ha of crops and 31,533 km of roads were damaged and the country suffered a loss in G.D.P. by 1.6%, with more than US$1.1 billion economic losses (Dewan, 2015; Guha-Sapir, 2021).

Methodology

The focus of this study design allowed for investigation of the researches conducted on different aspects of floods in Bangladesh. Therefore, the study focuses on reviewing the existing flood research of Bangladesh from the year 1990 till February 2019.

Data Collection and Analyzing

Collection of the existing researches of different aspects of floods in Bangladesh through literature review includes searching literature from online sources. The primary basis of information for collecting research papers was from the journal articles published by different authors and related to floods of Bangladesh. In this study, a systematic literature review method was followed and the literature was selected according to relevancy with objectives. The selected searched researches were categorized, assessed and summarised. Three standards were applied to categorize searched literature: (1) The research is published in an international journal and peer-reviewed (2) The research is done by analyzing data of different aspects of floods in Bangladesh; (3) The research is connected with flood causes, impacts, mitigation and management. The systematic process applied in this study is explained in the following sections and presented in Figure 2.

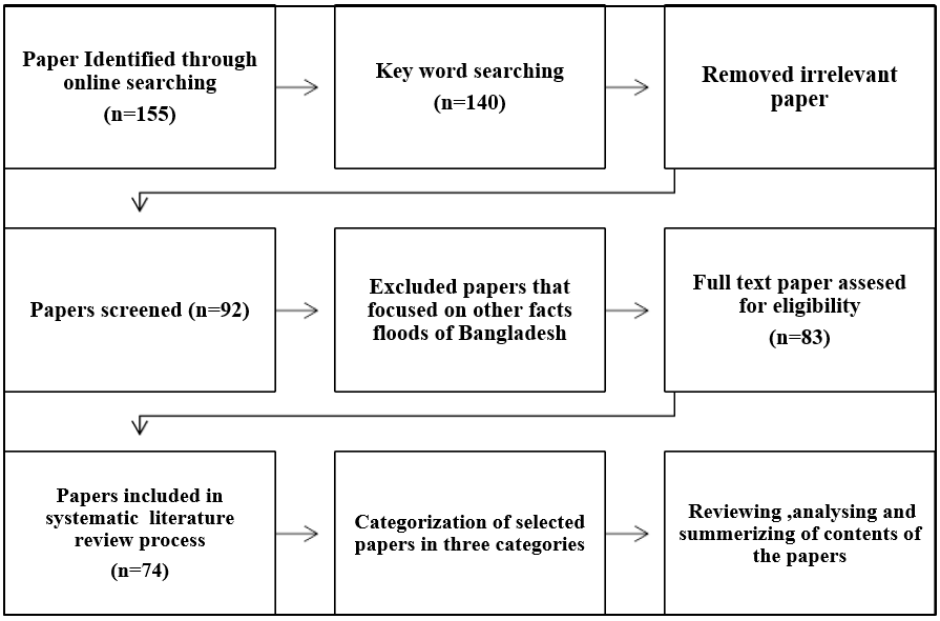

Figure 2: Steps of systematic review of flood research in Bangladesh

The use of the keywords used finding articles were "flood," "floods," or "flooding"; "floods of Bangladesh" or "flood impact"; "flood cause" or "flood vulnerability"; and "flood risk analysis", "flood management", "flood adaption", "flood modeling" "flood forecasting" in the title or abstract. The total number of articles found in both (Google scholar, Chittagong university weblink) was 140 in total. The total number of articles was reduced to 126 after removing 14 duplicates. However, the titles found out that 13 of these articles did not fit with those three established standards and the number of fitting articles was 113. Then 113 articles were thoroughly reviewed and 21 papers were rejected because of incomplete information. Then 83 papers were fully assessed by applying the three selection standards. Finally, 74 papers met all three selection criteria and these papers were selected for in-depth analysis according to objectives (Appendix 1). The papers were categorized under six groups: 1) Flood modeling, 2) Flood forecasting, 3) Flood causes and vulnerability, 4) Flood impact assessment, 5) Flood Adaption and 6) Flood management. Each category's paper was analyzed and summarized, and Bangladesh floods were documented when the categorization was completed.

Results and Discussion

The Indian subcontinent contains numerous rivers with vast river basins, contributing to severe floods. Studies showed that flooding is one of the major environmental disasters from 1970 to 2009 that happened in the subcontinent, especially in Bangladesh, India, Pakistan, and flood accounts for 35% of the natural disasters in Bangladesh (Abbas et al., 2016). As a result, policymakers and implementers around the world struggle to establish effective flood mitigation strategies. This endeavor is particularly difficult in Bangladesh because of the number of catastrophes and the country's geographical vulnerability (Paudyal, 2002). Therefore, studying the flood and socioeconomic conditions of people living in vulnerable areas is necessary to plan a proper adaptation strategy (Paudyal, 2002; Mirza et al., 2003; Sai et al., 2018). Therefore, various national and international researchers investigated floods to identify and investigate the causes, consequences, and management approaches of floods in Bangladesh.

4.2. Categorization of Reviewed articles

The selected 74 research papers on flood are classified according to the topic into six categories. The categories are 1) Flood modeling, 2) Flood forecasting, 3) Flood causes and vulnerability, 4) Flood impact assessment, 5) Flood Adaption, and 6) Flood management (Figure 3).

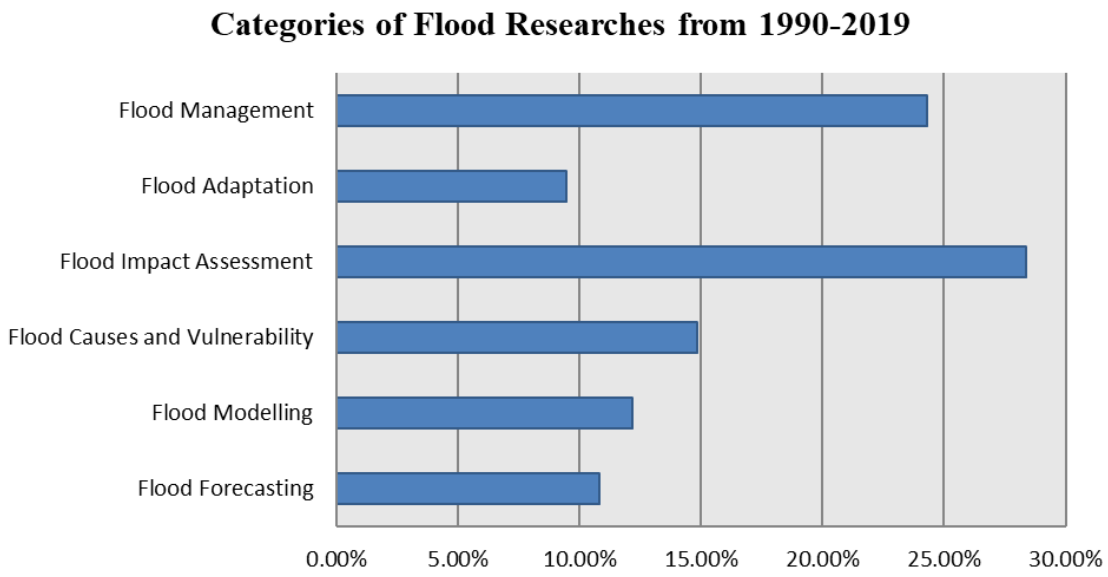

Figure 3: Categorization of selected articles on flood research in Bangladesh

Among the conducted research from 1990-2019 on different aspects of floods in Bangladesh, most research was found in the flood impact assessment category, where the flood adaptation category holds the lowest number of investigations. On the other hand, the flood management category constituted 24% of the selected studies. It indicates that most flood-associated research performed from 1990-2019 in Bangladesh focused on impact assessment and management, and fewer studies were conducted on flood adaptation, forecasting, and modeling. Additionally, 15% of the research was slightly more concerned with flood causes and vulnerability than flood forecasting and modeling.

4.2. Flood Events and Evolution of flood research in Bangladesh

Flood is a common natural disaster in Bangladesh. Last three decades, many researchers did their research based on their research interests on the Bangladeshi flood. In 1990-1999, the most flood-affected areas were Bogura, Chattogram, Gaibanda, Cox's Bazar, Hobiganj, Lalmonirhat, Pabna, Rajshahi, Sirajganj, and Sylhet (Dewan et al., 2003; Guha-Sapir, 2021). About 3000 people died and 60 million people were affected by flooding in this decade, which is more than any other period of the last three decades. In this decade, the total economic loss was likewise the greatest (Guha-Sapir, 2021). Despite many floods, casualties, and economic losses, this decade saw remarkably few flood researches. From 1990 to 1999, just a few studies on flood modeling and forecasting were found (Figure 4).

In the decade 2000-2009, flood events were dispersed throughout the country though Chattogram, Cumilla, Gaibandha, Sylhet, Rangpur, Rajshahi, and Sirajganj were highly affected by floods (Guha-Sapir, 2021). About 2500 people died during 2000-2009 due to floods, slightly less than 1990-1999 (Guha-Sapir, 2021). Most of the flood causalities of this decade were caused by flood events of 2004 and 2007. However, almost the same people were impacted in 1990-1999 and 2000-2009. This decade was the beginning of conducting diverse researches on different aspects of the flood. In 2000-2009, research on flood modeling and forecasting, flood causes

and vulnerability, flood adaptation, and flood management was found in a small number. Though researchers conducted their research on different flood topics, the number of investigations on flood impact assessment and flood causes and vulnerability studies were higher than other studies (Figure 4).

From 2010 to 2019, last decade, 653 people died because of the flood. Moreover, in 2017's flood, about 144 people lost their lives, the highest number of deaths (Guha-Sapir, 2021). Nevertheless, compared with the other two decades, 2009-2019 had the lowest number of dead and affected people(Guha-Sapir, 2021).

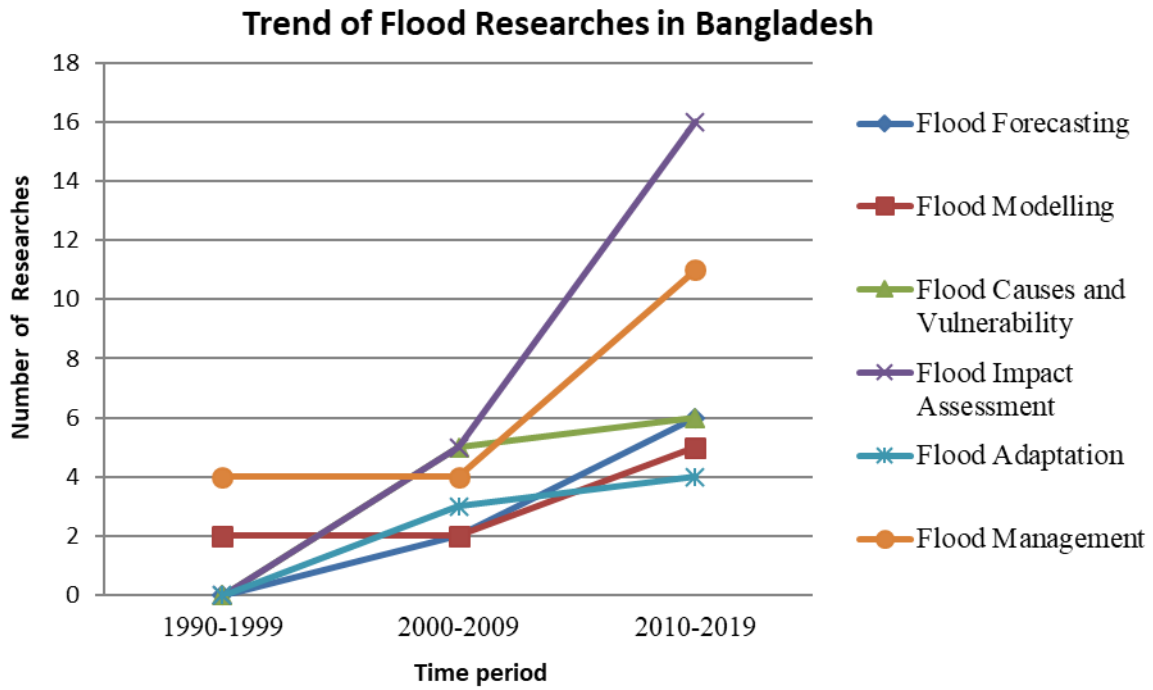

Figure 4: Categorization of flood researches in Bangladesh over the last three decades

In 2010- 2019, research related to different aspects of floods in Bangladesh increased in a noticeable number as 48 types of research on floods were found. It can be observed from the data that conducting studies on the category of flood impact assessment and flood management escalated with time. However, flood research on flood adaptation, forecasting, and modeling was lower than other categories. The flood impact assessment and management study considerably increased in 2010-2019 than in previous years (**Figure 4**). Flood research related to adaptation, modeling, and forecasting gradually increased in number this decade compared to 1990-1999 and 2000-2009.

4.3. Categories literature of flood

Data were extracted from the selected literature and organized into categories. Furthermore, the key findings from each paper were noted in the following tables

Flood Forecasting

Eight papers discussed flood monitoring and forecasting, and those papers were published between 1990-2019 (up to February) (Table 2). To reduce the risk of flood damage, we need developed planning based on continuous climate change. The flood risk reduction and mitigation process were entirely concentrated on structural measures in Bangladesh. However, it is not a complete and desirable strategy to control floods properly. Thus, the scientists proposed an efficient immediate and long-term flood forecasting mechanism focused on advanced technology and capacity building (Paudyal, 2002; Moffitt et al., 2011).

Table 2: Major findings of the flood forecasting related research in Bangladesh

References	Major findings
(Paudyal, 2002)	Floods in Bangladesh, emphasizing real-time forecasting and warning features of mathematical models built.
(Mirza, 2003)	These floods ranged in size, depth, and length. Intuitive and external hydro-meteorological dynamics differed
(Moffitt et al., 2011)	TRMM-based F.D.S. can yield accurate flood predictions, but it can also generate false alarm notifications when used in well-managed basins.
(Hossain et al., 2014)	In addition, JASON-2 assesses flood threats with negligible tidal impacts.
(Whitehead et al., 2015)	Models for 2050 and 2090 predicted significant monsoon flows and flooding potential increases. Droughts will be prolonged due to low flows.
(Khan et al., 2018)	Due to urban growth, flood damage may increase in Dhaka city in the year 2050 if flooding event happens with the same intensity and frequency as the flood of 2004
(Sai et al., 2018)	Compared to the present F.F.W.C. advisory, color-coded impact-based warnings were more straightforward and understandable.
(Roy et al., 2019)	Flash flood risk was lower than current monsoon flooding risk.

Thus, several advanced warning models are widely used in developed countries for flood forecasting. This warning is circulated to the media for broadcast and government and non-government organizations (Khan et al., 2018; Roy et al., 2019; Sai et al., 2018). Most of the research in this category suggested models that can be used for flood forecasting and in the case of a long-term warning, the studies predicted that the severity and frequency of floods in Bangladesh would increase in the coming 10 to 30 years.

Flood Modeling

Flood modelings in Bangladesh attempt to solve river flow complexities that contribute to future flood hazards driven by changing climate and sea-level rise in the Ganges-Brahmaputra-Meghna Delta (Bhattacharya et al., 2016; Ikeuchi et al., 2015). During 1990-2019, only 9 research papers developed and analyzed different flood models in other aspects of the flood (Table 3). Few models demonstrated how floodwater of the significant channels flows into tributaries (Ikeuchi et al., 2015; Yang et al., 2015), and few predicted the future flood inundation and produced a future flood hazard map (Rasid and Pramanik, 1993; Islam and Sado, 2000; Bhattacharya et al., 2016).

Table 3. Summary of flood modeling related research in Bangladesh

References	Major findings
(Rasid and Pramanik, 1993)	According to satellite images, the 1988 flood inundation was more significant than the government's projections.
(Karim and Chowdhury, 1995)	For flood frequency study in Bangladesh, researchers recommend using a three-parameter distribution.
(Bala et al., 2009)	Flood inundation maps can integrate water resource management with flood and wetland conservation.
(Di Baldassarre et al., 2014)	Floodplains and populations in Bangladesh's floodplains interact complicatedly, influenced by floodplain behaviour and the human-water system.
(Ikeuchi et al., 2015)	Floodwater enters tributaries via bifurcation channels, increasing inundation depth. Sea level rise. and backwater impact caused increased inundation depth and period.
(Yang et al., 2015)	Utilizing in-stream water level and flood-affected area data for formating flood damage functions for Bangladesh.
(Bhattacharya et al., 2016)	Flood index developed for haor region in Bangladesh.
(Biswas, 2018)	Assessment of flood risk in Bangladesh's historic Brahmaputra River Basin using hydromorphometric modeling

The research paper on the flood modeling category principally concentrated on developing flood inundation, flood risk, and hazard maps. Few studies developed formulas and methods to investigate floodwater routing, flood frequency analysis and causes of flood intensification in Bangladesh.

Flood Causes and Vulnerability

Floods are responsible for numerous harmful impacts like mortality, migration, indirect displacement, and extensive destruction of crops, infrastructure, and property worldwide. Post-flood effects involve water pollution, water-borne diseases and other epidemics in flood-affected communities. Flood-affected regions suffer immensely due to lost livestock, increased prices, social insecurity and costs of repairing infrastructure flood recovery activities (Dewan, 2015). Therefore is compulsory to assess the causes and vulnerability of floods for sustainable management. 11 research journals have found flood causes and vulnerability (**Figure 4).** There was no research on flood causes and vulnerability during 1990-1999.

Table 4. Summary of flood causes and vulnerability related research in Bangladesh

References	Major findings
(Tingsanchali and Karim, 2005)	A flood hazard map and risk map were created where 26% of the area was highly vulnerable.
(Jakobsen et al., 2005)	High upstream inflows and rainfall produce catastrophic flooding in Bangladesh. Local rainfall contributes to local flash floods in Bangladesh's northeast.
(Saha, 2007)	The simultaneous peak in both GBM basins is the primary source of catastrophic flooding in Bangladesh. The Jamuna and Surma rivers flow in the GBM basins.
(Brouwer et al., 2007)	Flooding is especially likely to affect low-income and resource-limited households. Those most at risk of flooding have a minor household and communal preparedness.
(Karim and Mimura, 2008)	Storm surge heights, flood area, and depth increase as sea surface temperature and sea levels rise. Flooding depths are expected to be 30–40 percent greater within 20km of the shore.
(Braun and Aßheuer, 2011)	Slum-dwellers need social capital to survive floods. Their lack of education and resources makes them especially vulnerable to external shocks, though they can cope with natural disasters.
(Bhuiyan and Dutta, 2012)	Sea level is increased by flooding up to 3.5 m depth, affecting the population and structures of the central and western zones.
(Masood and Takeuchi, 2012)	The simulation suggested that the most remarkable inundation depth is 7.55 m in the southern section of Dhaka.
(Ali, Mahjabin and Hosoda, 2013)	The inundation depth elevated due to the climate change-induced increase in river discharge during monsoon
(Gain and Hoque, 2013)	Land-use change and economic property value played a significant role in determining flood risk.
(Xenarios et al., 2016)	The flood-prone southern region of Bangladesh appears less susceptible to climate change than the northern drought-prone region of the country.

The papers in this category found the causes that render Bangladesh extremely vulnerable to flood damages. Flows upstream, heavy monsoon rain, synchronized flow peak reaching of the major river system, unplanned infrastructure, and low coping ability are the primary reasons for severe flood damage.

Flood Impact Assessment

In this study, we considered 21 research papers (Figure 5) connected with flood impact assessment. In case of flood impacts, principally affecting human lives and livelihoods, agriculture is considered. Several papers conducted impact analysis by understanding causes, the extent of the impact, socioeconomic aspects, and solutions.

The research on flood impact assessment in Bangladesh initiated in the 2000-2009 period. During 2010-2019 the amount of research in this category grew radically, including maximum flood associated research in this division. (Table 5).

Table 5. Summary of major findings of flood impact studies in Bangladesh

References	Short description of findings
(Kunii et al., 2002)	Low socioeconomic status, lack of water purification tablets, water storage vessels, household sanitation, had an extensive connection with diarrhea during and after the 1998 flood.
(Dewan et al., 2003)	The 1998 flood caused by heavy rainfall was more acute than 1988 one, and structural solutions should not only mitigate flood damages.
(Mirza, 2003)	Heavy rainfall in the basins and the Ganges and Brahmaputra rivers' flood maxima twice triggered severe flooding in 1988 and 1998.
(Dewan et al., 2003)	Most Dhaka is in the moderate to high hazard zone, and just a tiny portion is in the low hazard zone.
(Sirajul Islam et al., 2007)	After a flood, water contamination and water contamination diseases are increased.
(Biswas et al., 2010)	During the floods, households with lower socioeconomic and occupational status had more child injuries and parental aggression.
(Banerjee, 2010)	Floods have a significant impact on agricultural output during the monsoon season. Because of this watering input provided by flooding, there is the possibility for a large harvest in subsequent dry seasons.
(Shimi et al., 2010)	Water supplies and sanitation were severely affected during the flood, causing water-borne infections.
(Khan et al., 2012)	Boro is the main crop a Rabi season in the Haor area and flash floods destroyed the production due to lack of flood control measures
(Azad et al., 2013)	A shortage of food, clothing and fuel is a significant concern for women: disease exposure, water quality issues, and eviction. Policies and programs for disaster management should include gender mainstreaming.
(Basak et al., 2015)	Many plantings were done in the last four decades, ignoring plant features, habitat and the consequences of flooding and waterlogging.
(Gusyev et al., 2015)	Flood water flow and inundation were amplified during 50- and 100-year floods as a result of climate change-induced amplification of flood hazards.
(Thiele-Eich et al., 2015)	High water levels of two flood events in 2004 and 2007 had not caused a considerable rise in relative mortality.
(Haque and Jahan, 2015)	Floods threaten Dhaka, Rajshahi, and Sylhet more than coastal areas.
(Dewan, 2015)	Bottom-up approaches, traditional knowledge, and indigenous traditions should be combined to mitigate flood impacts and vulnerabilities.
(Md. Sirajul Islam, Md. Solaiman, M. S. Islam, 2015)	Floods devastated crops and buried agricultural grounds for two or three months, affecting most farmers in the char area.
(Lu et al., 2016)	Floods have a negligible direct effect on the vocational and migratory choices of inland residents, while cyclones have a negligible effect on coastal residents' choices.
(Parvin et al., 2016)	Flooding reduces rural communities' ability to prepare, respond, and recover. Fluctuations cause large debts and asset losses.
(Paul and Mahmood, 2016)	The magnitude of inundation, the number of distressed people, frequency and duration of the flood, and interactions of these factors significantly affect flood deaths.

(Uddin, 2017)	The use of safe water and sanitation, proper site planning, primary healthcare, early warning systems, and malaria and dengue vaccinations can play an essential role in reducing flood impact.
(Islam et al., 2018)	Many factors contribute to storm surge-induced flood risk reduction, dike breaching and damage, including land-use planning and flood risk maps.

People, cattle, homes, crops, water and sewage systems, and other infrastructure were all wiped out due to the flooding. People of low socioeconomic status living in remote areas experience difficulty collecting daily necessities, which create health problems and malnutrition (Sultana and Thompson, 2010). Many factors contribute to an increased risk of waterborne pathogens during a flood, including poor water quality, unsanitary living circumstances, and a lack of proper treatment of health hazards. (Sirajul Islam et al., 2007; Uddin, 2017). Studies showed that western districts are affected more by floods than other parts of Bangladesh in agriculture and forest (Basak et al., 2015). The excessive rainfall stimulated by global climate change and the accelerated population expansion, political power, lack of sound policy, and less public knowledge influence the consequences of the flood (Osti et al., 2011).

Flood Adaptation

Flood is a perennial problem for Bangladesh, and mitigate and prevent flood; coping strategies should be applied to help affected people. After reviewing 74 nominated papers, only seven papers were found focusing on flood adaptation (Figure 5) and all the papers published in the last two decades.

Table 5: Summary of flood adaptation research in Bangladesh over the last three decades

Sources	Major findings
(Alam and Ali, 2002)	The geography and the amount of floodwater intrusion during the monsoon period make constructing embankments unsuitable and therefore building flood shelter will be effective
(Khandker, 2007)	Due to flood, consumption and assets were decreased, and affected households were compelled to adopt their coping mechanisms to mitigate the adverse impacts.
(Alam and Zakaria, 2008)	The duration of water flooding impacts the strength of pavement layers. Thus, continuous inundation should be considered when designing roadways in Bangladesh.
(Sultana et al., 2014)	Flood risk is the sum of danger, exposure, susceptibility, and inability to respond. Flooding in the Gangetic char region is associated with prolonged monsoon rainfall, physical, social, economic, and environmental vulnerability, resilience, and local adaptation.
(Younus, 2014)	Integrated vulnerability and adaptation evaluations at the micro- and community-level are necessary to mitigate local riverine floods, coastal flooding, flash flooding, and urban flooding impacts.
(Tanvir Rahman et al., 2015)	Flood-affected people involve in temporary work, emergency house reconstruction, disease treatment, seeking shelter on embankments and altering professions to cope with disasters.

Those papers' findings (Table 5) suggested that both structural such as embankments construction and non-structural such as awareness and warning procedure are helpful for flood adaptation. Management suggested introducing micro flood insurance for flood-affected people as a coping mechanism. Furthermore, introducing flood insurance, creating alternative temporary employment opportunities, rebuilding disaster resilience houses, precaution and prevention for disease and changing professions can be viable options for adaptation (Alam and Ali, 2002; Tanvir Rahman et al., 2015). Moreover, some authors suggested using specific approaches to improve the flood-stricken condition. Including the Local Scale Disaster Risk (L.S.D.R.) model to implement disaster risk reduction method locally, linked with climate change, and local people should be included in the integrated prevention and mitigation program (Khandker, 2007; Sultana et al., 2014).

Flood Management

To minimize the volume of flood-caused damage, it is badly needed to develop and implement appropriate management policies that can regulate every step in the process, from a flood warning to flood rehabilitation of the affected people. Flood management is a holistic procedure that creates an environment for operating enhanced economic activities to reduce flood events and flood impacts in the future (Baten et al., 2018). It is observed that 18 of the selected research papers are related to flood management (Figure 6) which contains the second-highest number of articles among the classification. Moreover, attention on flood management intensified mainly in the last decade, and 11 papers were published during 2020-2019 (Table 6). We suggest that flood management strategies should be practical and active in response to flood threats rather than responsive to flood events. Flood risk reduction and management should include establishing and developing resilience infrastructure and rapid early warnings (Cook, 2010; Gain et al., 2017).

Table 6: Insights from flood management research in Bangladesh

Sources	Major findings
(Haque, 1993)	Flood prevention and mitigation strategies should follow a holistic approach from sustainability and development.
(Khalequzzaman, 1994)	Bangladesh is a critical hydrodynamic system in South Asia. Cooperation and mutual understanding among co-riparian nations are vital for long-term and sustainable flood-related solutions.
(Alexander et al., 1998)	In six years, soil qualities have changed significantly due to flood control, drainage, and irrigation projects, including acidity and nutrient deficit.
(Islam, 2001)	Bangladesh's geographic location and climatic condition are suitable for adopting the open approach to flood control efficiently than the existing cordon approach.
(Ahmad and Ahmed, 2003)	Upstream data from runoff generating stations inside the GBM catchment could improve Bangladesh's flood forecasting and warning capability. Regional integration with India, Nepal, and Bhutan is required.
(Sultana et al., 2008)	While the urban populace in England is not motivated to participate in flood management choices and actions, rural Bangladesh is.

(Bala et al., 2009)	Except for the 1998 flood, city embankments and elevated highways worked well.
(Sultana and Thompson, 2010)	Local groups helped sustain floodplain resource management. Effectiveness was impacted by facilitation, stakeholder agreement, and resource fit.
(Akter et al., 2011)	The administrative costs of micro-insurance are essential in evaluating its sustainability. A government-led approach is required to resolve conflicts between non-profit micro-lenders and for-profit insurance companies.
(Walters, 2015)	In Dhaka, the presence of the local community provided minute aid to poverty-stricken residents who were isolated and dependent on their insufficient resources.
(Kwak et al., 2015)	Alteration of flood risk strongly correlates with the temporal and spatial dynamics of susceptibility and exposure, population distribution and efficacy of water infrastructure.
(Gain et al., 2017)	River basin management must solve complex flooding and water-related challenges at institutional and project levels through transboundary cooperation and equity and social issues.
(Baten et al., 2018)	Women have a significant and positive role in preparedness, response, and mitigating the flood, though the importance of playing a role in decision-making is disregarded.
(Baten et al., 2018)	Bangladesh has an institutional, regulatory, and statutory structure for disaster prevention and mitigation but needs proper monitoring.
(Shah et al., 2018)	Climate variability and river form pose challenges to good flood prediction. Land-use changes in floodplains limit the risk assessment of flood damage mitigation programs. Flood management should adopt a 'Dynamic Sustainability' approach.

Certain researches on this category suggested some particular open approaches and methods for flood management in Bangladesh, including regional cooperation and basin-scale management with transboundary countries, collecting real-time data from runoff point, ensuring participation of local people, especially woman in floodplain resource management, co-management in implementing the flood action plan. Other papers highlighted the need for and process of monitoring and assessing the effectiveness of existing mechanisms and activities of implementing authorities in detail for flood management.

Future direction and policy recommendation

As 80% area of Bangladesh is composed of the flood plain and global climate change is exerting negative impacts increasingly, Bangladesh is considered one of the most threatened countries due to flood (Brouwer et al., 2007; Masood and Takeuchi, 2012; Tingsanchali and Karim, 2005). Therefore, the country is attempting to reduce the vulnerability to floods by ensuring maximum preservation of natural environments with their habitats and biodiversity and conducting large-scale water management projects integrated (Gain et al., 2017). More detailed and practical research should be done on sustainable flood adaptation and integrated flood man-

agement methods to make this attempt successful. The findings of investigations on flood causes, vulnerability, and impact assessment should be logically used to study and apply appropriate coping mechanisms for the susceptible community. Moreover, the affected area and duration of the flood are increasing with time. It is projected in the different discussed papers under the flood forecasting and flood modeling category that the severity will be more intense in the upcoming decade. Thus, a reliable flood forecasting system should develop an adequate land use-based zonal inundation, hazard, and flood risk map. With flood adaptation, more research on flood modeling and forecasting should be conducted. Additionally, integrated flood management, which combines structural and non-structural flood mitigation methods with flood risk reduction and flood adaptation, should be more studied and adopted by authorities. The respective responsible organization should include experts from different disciplines to collaborate with neighboring country for regional river basin management and flood control. The concept of integrated flood management, socio-hydrology and applied eco-hydrology for flood risk reduction and adaptation are not being studied elaborately in Bangladesh. Therefore, with existing research on flood, studies should be conducted under these categories to ensure sustainable flood adaptation and management.

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Appendix 1

No	Title	Journal name
01	Areal Extent of the 1988 Flood in Bangladesh: How Much Did the Satellite Imagery Show?	Natural Hazards
02	Flood Prevention And Mitigation Actions In Bangladesh: The 'Sustainable Floodplain Development' Approach	Impact Assessment
03	Recent Floods In Bangladesh: Possible Causes And Solutions	Natural Hazards
04	A comparison of four distributions used in flood frequency analysis in Bangladesh	Hydrological Sciences Journal
05	Flood Control, Drainage And Irrigation Projects In Bangladesh And Their Impact On Soils: An Empirical Study	Land Degradation & Developmen
06	Development of flood hazard maps of Bangladesh using NOAA-AVHRR images with G.I.S.	Hydrologîcal Sciences-Jonrnal-des Sciences Hydrologiques
07	The Open Approach of flood Control: The Way To The Future In Bangladesh	Futures
08	Forecasting and warning of water-related disasters in a complex hydraulic setting—the case of Bangladesh	Hydrological Sciences Journal
09	Concept of Flood Shelter to Cope with Flood	Engineering Concerns of Flood
10	Design and construction of roads in flood affected areas	Engineering Concerns of Flood
11	The Impact On Health And Risk Factors Of The Diarrhoea Epidemics In The 1998 Bangladesh floods	Public Health
12	The Implications of Climate Change on Floods of The Ganges, Brahmaputra and Meghna Rivers in Bangladesh	Climatic Change
13	Regional Cooperation in Flood Management in the Ganges-Brahmaputra-Meghna Region: Bangladesh Perspective	Natural Hazards
14	Three Recent Extreme Floods in Bangladesh: A Hydro-Meteorological Analysis	Natural Hazards
15	Floods in Bangladesh: A Comparative Hydrological Investigation on Two Catastrophic Events	Journal of the Faculty of Environmental Science and Technology, Okayama University
16	Evaluation of the Short-Term Processes Forcing the Monsoon River Floods in Bangladesh	Water International
17	Flood Hazard And Risk Analysis In The Southwest Region Of Bangladesh	Hydrological Processes
18	Evaluating Flood Hazard for Land-Use Planning in Greater Dhaka of Bangladesh Using Remote Sensing and G.I.S. Techniques	Water Resour Manage
19	Flood Characteristics Analysis For Seven Hydrological Regions of Bangladesh	Flood Management
20	Faecal contamination of drinking water sources of Dhaka city during the 2004 flood in Bangladesh and use of disinfectants for water treatment	Journal of Applied Microbiology

21	Socioeconomic Vulnerability and Adaptation to Environmental Risk: A Case Study of Climate Change and Flooding in Bangladesh	Risk Analysis
22	Coping With flood: Role Of Institutions In Bangladesh	Agricultural Economics
23	Impacts of Climate Change and Sea-Level Rise on Cyclonic Storm Surge Floods in Bangladesh	Global Environmental Change
24	Can England Learn Lessons from Bangladesh in Introducing Participatory Floodplain Management?	Water resources management
25	Performance Of Flood Control Works Around Dhaka City During Major Floods In Bangladesh	International Conference on Water & Flood Management
26	Flood inundation map of Bangladesh using M.O.D.I.S. time-series images	Journal of Flood risk management
27	Creative destruction: Analyzing flood and flood control in Bangladesh	Environmental Hazards
28	Unintentional injuries and parental violence against children during flood: a study in rural Bangladesh	Rural and Remote Health
29	Flood Knowledge and Management in Bangladesh: Increasing Diversity, Complexity and Uncertainty	Geography Compass
30	Local institutions for floodplain management in Bangladesh and the influence of the Flood Action Plan	Environmental Hazards
31	Impact and adaptation to flood	Disaster Prevention Management
32	The search for appropriate latrine solutions for flood-prone areas of Bangladesh	Waterlines
33	Validation of a TRMM-based global Flood Detection System in Bangladesh	International journal of applied earth and observation and geo information
34	Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh	Natural hazards
35	Exploring the feasibility of private micro flood insurance provision in Bangladesh	Disasters
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37	Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using D.E.M. and 1D hydrodynamic model	Natural hazards
38	Impact Of Climate Change On Floods Of Bangladesh And Introducing Flood Intensity Index To Characterize The Flooding Scenario	Journal of Engineering Science
39	Impacts of Flood on Crop Production in Haor Areas of Two Upazillas in Kishoregonj	Journal of Environmental Science Natural Resources
40	Flooding in Bangladesh and Australia: Applying an Interdisciplinary Model	The International Journal of Interdisciplinary Social Sciences

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43	A Promising Radar Altimetry Satellite System for Operational Flood Forecasting in Flood-Prone Bangladesh	IEEE Geoscience and remote sensing magazine
44	The interplay between human population dynamics and flooding in Bangladesh: a spatial analysis	The International Association of Hydrological Sciences
45	Climate Change Induced Flood Risk And Adaptation In The Padma River Island, Bangladesh: A Local Scale Approach	Journal of Life Earth Science
46	Lood Vulnerability And Adaptation To Climate Change In Bangladesh: A Review	Journal of Environmental Assessment Policy and Management
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49	Societal impacts and vulnerability to floods in Bangladesh and Nepal	Weather and Climate Extremes
50	Impacts of climate change and socioeconomic scenarios on flow and water quality of the Ganges, Brahmaputra and Meghna (G.B.M.) river systems: low flow and flood statistics	Environmental Science Processes & Impacts
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55	Effectiveness Of Water Infrastructure For River flood Management – Part 1: Flood Hazard Assessment Using Hydrological Models In Bangladesh	International Association of Hydrological Sciences
56	Effectiveness of Water Infrastructure for River Flood Management: Part 2 – Flood Risk Assessment and Its Changes in Bangladesh	International Association of Hydrological Sciences
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71	Challenges for achieving sustainable flood risk management	Journal of Flood Risk Management
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74	Flood risk assessment due to cyclone-induced dike breaching in coastal areas of Bangladesh	Nature Hazards Earth System Science