Working Paper No. 105 l January 2026

DOI: 10.69814/wp/2025105

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INFOCLIM:

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Abstract

The risk of flooding is increasing due to unpredictable rainfall patterns, making effective early warning systems essential to reduce damage. The action research focused on two sub-districts, Char Rajibpur in Kurigram and Saghata in Gaibandha. This action research adopted multidisciplinary methods to generate evidence from both communities. It has measured flood-induced losses and damage for the years of 2017 (base year, 2021, and 2024 by the combination of Geographic Information Systems (GIS), Remote Sensing (satellite data), and hydrodynamic modeling to identify inundated areas and estimate damages. From 2019 to 2025, the action research is disseminating real-time localized user-friendly climate information services and early warning to the community people using voice SMS. The study also generated quasi-experimental data from the research participations for the years of 2017 (base year, 2021, and 2024. The study included a total of 180 families affected by floods, with 42 participants from Char Rajibpur and 138 from the Saghata sub-district. An easy-to-understand and well-organized data format was developed for the research participants to generate quarterly longitudinal data and loss and damage data beyond flood. The study also collected historical information related to flood, loss and damage, death toll from the District Statistics Office, District Relief and Rehabilitation Officer, Department of Agriculture Extension, Department of Livestock and Poultry, Civil Surgeon, Upazila Health Complex, and several NGOs. The action research finds that early actions using InfoClim are effective in flood-induced loss and damage reduction, household resilience, and community resilience by adopting location-specific real-time information. InfoClim, as an effective flood forecasting and early warning mechanism, should be enhanced and scaled up to reduce flood-induced loss and damage in flood-vulnerable areas.

Keywords: Flood, loss and damage, early warning, climate information, infoclim

1. Introduction

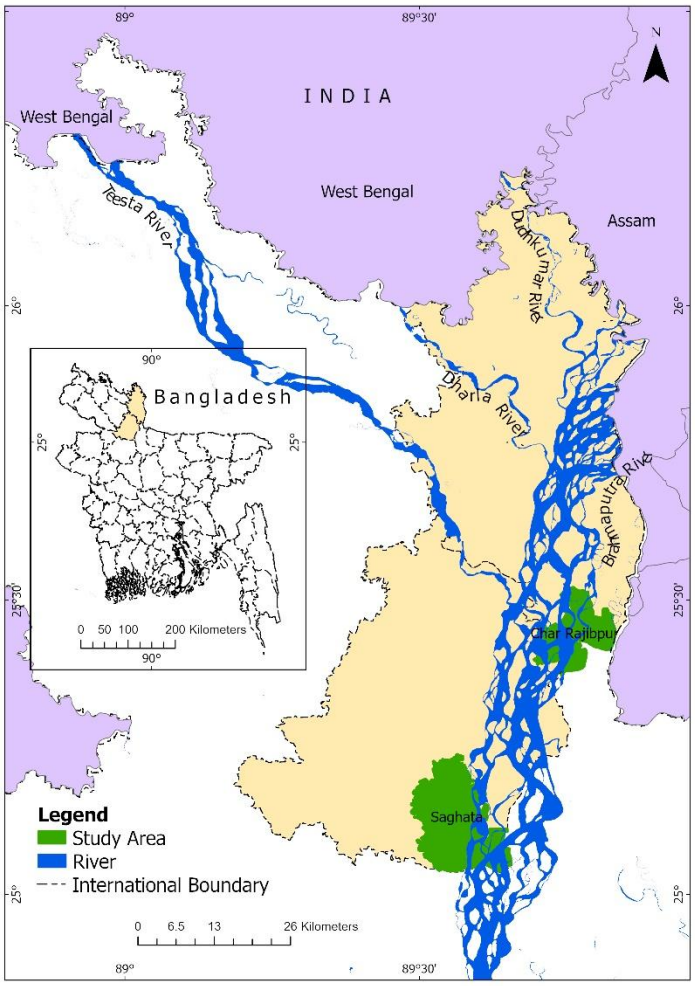
The likelihood of flooding is expected to rise due to the unpredictable nature of precipitation in terms of timing, intensity, and distribution (Boulange et al., 2021). It is crucial to disseminate early warning signals effectively, as flooding can lead to significant destruction. By the end of the twenty-first century, an estimated 9.1 to 15.3 million people are anticipated to be exposed to flooding annually (Boulange et al., 2021). In recent decades, the frequency and severity of flooding in Southeast Asia have increased. Many South Asian nations are currently facing flooding, which poses a serious issue. On July 17, 2019, heavy monsoon rainfall lasting over a week resulted in serious flooding in New Delhi, Dhaka, and Kathmandu, impacting 3.2 million children (Reliefweb, 2019). In July 2020, monsoon floods severely affected large areas of India, Bangladesh, and Nepal, impacting more than 9.6 million individuals. More than 2.8 million people were affected by this flooding, including over 1 million who continue to live amidst floodwaters (Reliefweb, 2020). Bangladesh sees at least one major disaster every decade. Over the last ten years, it has incurred an annual economic loss averaging 3.02% of its GDP and has the highest disaster fatality rate globally (Mohammad & Huq, 2016). The Char-lands (riverine islands) communities in northern Bangladesh are especially vulnerable to monsoon floods, riverbank erosion, and other climate-related disasters, leading to the loss of their livelihoods and belongings (Al Mamun et al., 2022). Natural disasters disrupt communication systems in Char land communities, preventing Char residents from accessing the same economic and social opportunities as those on the mainland (Alam et al., 2017). Their access to vital public and private sector services, such as banking, healthcare, education, and law enforcement, is severely limited (Siddiqui & Khandaker, 2007). Nearly every year, the char lands along the Jamuna and Teesta Rivers are inundated. On September 1, 2021, a catastrophic flood struck the Gaibandha district, wreaking havoc in four of its sub-districts, including Sundarganj, Gaibandha Sadar, Fulchari, and Saghata (Dhaka Tribune, 2021). Both developed and developing regions highlight the importance of early warning systems as effective tools for saving lives, minimizing damage, and enhancing community resilience. Despite notable technological advancements, significant operational obstacles remain to be addressed to fully harness the potential advantages of Early Warning Systems, particularly regarding the delivery of risk information and early warnings to emergency services and at-risk populations for timely interventions. Early Warning Systems are employed for flood emergency responses in Europe (Belgium) and

Africa (Egypt, Mali (Cools et al., 2016). In Bangladesh, the gradual development of flood forecasting and warning services has progressed through three distinct phases. Enhanced deterministic flood forecasting initiatives increased forecast lead times to 48 hours beginning in 1991. Significant advancements were made in the flood forecasting model for the Bangladesh Flood Action Plan between 1995 and 1999 to boost forecast accuracy. In the third phase, the FFWC received assistance to enhance the precision and promptness of flood forecasts, ensuring coverage for all flood-prone areas in the country, improving the dissemination of flood information to low-income communities, and establishing a lasting institution. Utilizing ensemble precipitation projections from the European Center for Medium-Range Weather Forecasts, it commenced the provision of medium-range flood forecasts. Since 2004, the FFWC has delivered both deterministic and probabilistic flood forecasts for a medium range of up to three days. The FFWC disseminates flood warning information through various channels, including the Internet, fax, phone, mobile SMS, and other communication media. Additionally, it publishes the anticipated information daily on its streamlined website (www.ffwc.gov.bd). The initiatives for flood forecasting and warning have been quite effective in recent years in mitigating flood-related destruction (FFWC, 2020). Early warning systems facilitate the proactive planning of actions such as evacuations and emergency relief operations, which can bolster disaster preparedness strategies. Recent endeavors to alleviate the adverse impacts of flooding have proven highly successful due to flood forecasting and warning mechanisms (Hossain, 2018). However, the end user of the remote hard-to-reach areas doesn't have access to the national early warning system. The FFWC doesn't generate real-time localized early warning and climate information, which is also responsible for increasing the death toll and loss, and damage.

2. Methods and materials

For this study, two sub-districts (Char Rajibpur in Kurigram and Saghata in Gaibandha) were chosen for the application of climate information, and early warning by InfoClim, a mobile-friendly app, and longitudinal data generation by survey (Map 1). Char Rajibpur covers an area of 111 square kilometers with a population of 78,434 and is located at the international border, while Saghata spans 120 square kilometers with a population of 299,398 and lies approximately 26 kilometers from the nearest international border.

Map-1: Study area



This action research adopted multidisciplinary methods to generate evidence from both communities. It has measured flood-induced losses and damage for the years of 2017 (base year, 2021, and 2024 by the combination of Geographic Information Systems (GIS), Remote Sensing (satellite data), and hydrodynamic modeling to identify inundated areas and estimate damages. From 2019 to 2025, the action research is disseminating real-time localized user-friendly climate information services and early warning to the community people using voice

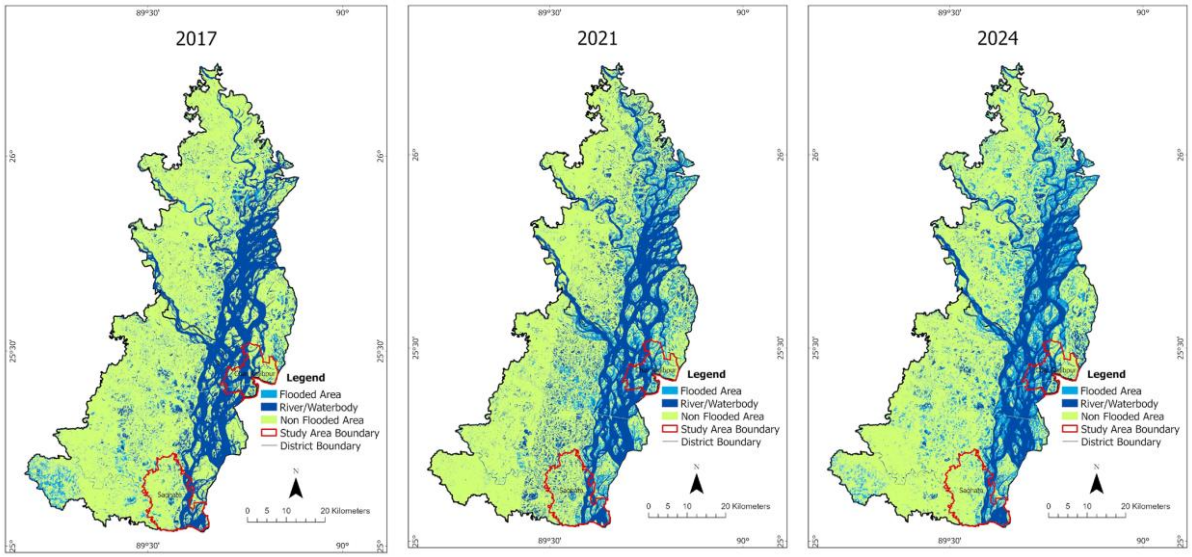
SMS. The study also generated quasi-experimental data from the research participations for the years of 2017 (base year, 2021, and 2024. The study included a total of 180 families affected by floods, with 42 participants from Char Rajibpur and 138 from the Saghata sub-district. An easy-to-understand and well-organized data format was developed for the research participants to generate quarterly longitudinal data and loss and damage data beyond flood. The study also collected historical information related to flood, loss and damage, death toll from the District Statistics Office, District Relief and Rehabilitation Officer, Department of Agriculture Extension, Department of Livestock and Poultry, Civil Surgeon, Upazila Health Complex, and several NGOs.

3. Result and Discussion

3.1 Flood vulnerability of the studied area:

The flood situation largely relies on the surrounding rivers and the total amount of rainfall. The devastating floods in 2017, 2021 & 2024 had a significant impact on the two districts, affecting social, environmental, and economic sectors. Hydrological and meteorological evaluations indicate that flood events are becoming more severe due to the absence of an early warning system and inadequate flood management. To create a map of the areas affected by floods within the study area, remote sensing data and geographic information tools were utilized. Map 2 illustrates the flood-affected regions of two upazilas in the Kurigram and Gaibandha districts for the years 2017, 2021 & 2024. The research focused on identifying flood-prone areas using Sentinel-1 SAR imagery through land cover classification and flood inundation analysis. The study covered the Kurigram and Gaibandha districts for the years 2017, 2021, and 2024, highlighting temporal variations in flood extent and affected croplands.

Map 2: Flood-affected area in the study area (2017, 2021 & 2024)



In 2017, Char Rajibpur Upazila of Kurigram District (total area 111 sq. km) experienced flooding over 6.13 sq. km, which represents 5.52% of the total area. In Saghata Upazila of Gaibandha District (total area 120 sq. km), flooding covered 17.90 sq. km (14.92%). The flooded cropland area for this year was 411 Ha in Char Rajibpur and 1505 Ha in Saghata.

By 2021, flood intensity increased in both upazilas. Char Rajibpur recorded a flooded area of 28.00 sq. km (25.23%). In Saghata, flooding affected 23.00 sq. km (19.17%). The total flooded cropland expanded to 2177 Ha in Char Rajibpur and 1525 Ha in Saghata.

In 2024, a slight decline in flood coverage was observed in Char Rajibpur, where 23.86 sq. km (21.50%) was flooded. In contrast, Saghata Upazila experienced a sharp rise in inundation, with 34.70 sq. km (28.92%) submerged. The corresponding flooded cropland areas were 1700.9 Ha in Char Rajibpur and 2582 Ha in Saghata.

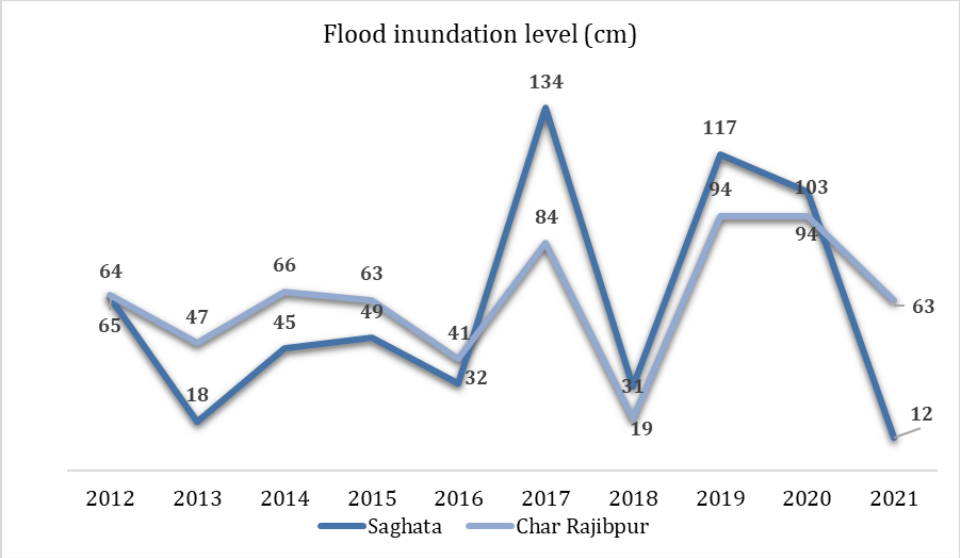
Overall, the findings demonstrate a progressive increase in flood-affected areas from 2017 to 2021, followed by a partial reduction in 2024 in Kurigram but a notable escalation in Gaibandha, indicating spatial variations in hydrological dynamics and local vulnerability. These temporal changes, summarized in Table 2, underscore the growing flood susceptibility of low-lying floodplain regions and the urgency for adaptive land-use and disaster management strategies.

Table 1: Upazila-wise flood-affected area in the study area (2017 & 2021)

Year	District	Upazila	Total area (Sq-KM)	Total Flooded Area (Sq-KM)	Flooded Area Percentage (%)	Total Flooded Cropland Area (Ha)
2017	Kurigram	Char Rajibpur	111.0	6.13	5.52%	411
	Gaibandha	Saghata	120	17.9	14.92%	1505
2021	Kurigram	CharRajibpur	111.0	28	25.23%	2177
	Gaibandha	Saghata	120	23	19.17%	1525
2024	Kurigram	Char Rajibpur	111.0	23.86	21.50%	1700.9
	Gaibandha	Saghata	120	34.7	28.92%	2582

Over the past decade, the Ghagot River has exceeded the danger level and flooded Saghata Upazila, which is located alongside the river. The minimum inundation recorded was 12 cm in 2021, while the maximum was 134 cm in 2017. Likewise, the Dharla River also surpassed the danger level, leading to flooding in Char Rajibpur Upazila, also situated adjacent to this river. The lowest inundation level was 37 cm in 2022, and the highest reached 84 cm in 2017. In 2021, the inundation levels recorded were 12 cm and 63 cm. Following the surpassing of danger levels in both 2021 and 2017, the affected areas are illustrated in Figure 1.

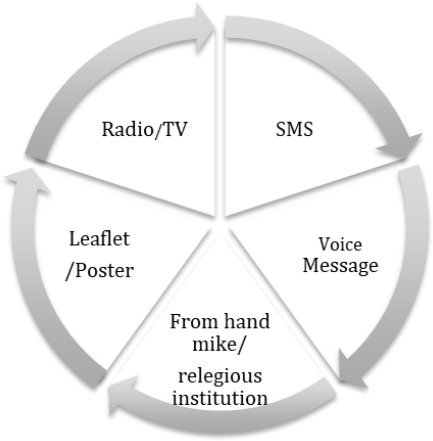
Figure 1: Last 10 years flood inundation levels above the danger level



4.2. Flood Early Warning Services in the Study Area

Since the 1960s, Bangladesh has been implementing drainage and flood management initiatives (Byomkesh & Shamsuddin, 2012). However, relying solely on structural defenses will not ensure complete safety for either the population or the infrastructure from flooding. In a country like Bangladesh, achieving total flood control is neither feasible nor realistic. Recognizing this, Bangladesh started to develop non-structural flood management approaches, such as flood forecasting and warning systems (Hossain, 2018). A dependable early warning system undoubtedly has the potential to safeguard both resources and individuals. Early warning systems facilitate proactive planning for measures like evacuations and emergency relief, which can support disaster preparedness strategies. Recent years have seen significant success in mitigating the adverse impacts of flooding due to the flood forecasting and warning center (Figure 2).

Figure 2: Various forms of flood warning service in the study area.



4.2.1. Present early warning and advisory service in the study area

The Bangladesh Water Development Board (BWDB) and the Flood Forecasting and Warning Center (FFWC) provide daily flood bulletins and alerts, but people living in remote and vulnerable regions seldom benefit from them due to a lack of appropriate technology (ReliefWeb, 2022). The weather forecasting system utilized in Bangladesh is derived from US technology, which is capable of predicting weather events up to 16 days ahead (NASA Earth Observatory, 2022). A fundamental aim of a disaster management system is to inform the public about looming disasters. Historically, radio and television have played this role (Ahsan & Khatun, 2020), but the rise of smartphones has led to a decline in the use of these traditional media. Numerous websites now offer both long- and short-term weather forecasts; however, many smallholder farmers do not have access to smartphones or the internet. Since SMS on mobile phones does not depend on smart devices or internet connectivity, it can reach any citizen in the country who possesses a mobile device, making it a viable solution to this issue (NASA Earth Observatory, 2022). In addition, several organizations are actively working to develop an early warning system across the nation. Short Message Service (SMS) is employed for collecting water level data from local to national levels, while Voice Message Broadcast (VMB) is utilized for disseminating warnings from the national level down to district and local levels concurrently (Islam & Svensson, 2021). Given that education is hard to access for marginalized communities in Bangladesh, many people we assist struggle to understand written communications. As a result, warnings are shared through brief voice messages rather than text. Additionally, numerous volunteers received training alongside project staff and government officials to enhance their ability to understand and react to the warnings. Organizations are currently working to improve the

skills of forecasters in areas such as observation, monitoring, data processing and analysis, forecasting, risk assessment, and the formulation and dissemination of warnings to the last mile. Early warning providers assess factors related to flood risk and vulnerability specific to the locality. They keep track of recent rainfall and river levels, subsequently making warning decisions. Forecast-based early warnings are communicated through government hotlines, community leaders, local youth volunteers, neighbors, and local religious groups. In the study area, local government institutions (LGIs) set up evacuation centers and conduct search and rescue operations during and after flooding events, followed by the distribution of relief supplies. Other organizations also contribute to assisting the community. The figure illustrates the forecast-based early warning mechanism in the study area.

Figure 3: Forecast-based early warning mechanism

4.3. InfoClim Forecast based on early actions

InfoClim is the process of reanalysis and digital transformation of climate information, and dissemination to the targeted participants as voice SMS, translating their local language. The system provides Wind (7-day prediction of wind direction and velocity), Hourly forecast (temperature, humidity, rainfall, wind), Heavy rainfall (7-day prediction), Flood danger level (7-day prediction), and Emergency support as an Offline Mode using Preloaded Data. It also provides Agriculture advisory (Soil health, Fertilizer recommendations, crop suitability), Climate Advisories (Weather parameters, Forecasting of climatic extremes), Livestock advisories (Climate-sensitive seasonal diseases, Vaccination period, Livestock management),

Health Advisories (Climate-sensitive diseases, precautionary measures, nature-based solution for health resilience), Community Led Warning System (Preparedness, Rescue), etc.

Figure 3: InfoClim process

Residents of Saghata and Char Rajibpur are engaging in proactive measures ahead of potential disasters by using a mobile-friendly app (InfoClim). The members of these communities now consistently practice listening to weather reports, storing food supplies, saving money, gathering information about shelter locations, stockpiling drinking water and medicine, and assembling emergency kits based on climate information and early warning disseminated by the InfoClim. They also compile a contact list for emergencies and relocate livestock to safer areas. The study revealed that the people of Saghata and Char Rajibpur occasionally preserved food before the implementation of early warning services, whereas they consistently did so afterward. Additionally, the residents had never sought shelter center information before the introduction of these services, but now they actively seek out this information. The study also showed that individuals in these areas have started to pay

attention to weather updates, a practice they had not engaged in before the early warning services. Furthermore, they now store medications, prepare emergency kits, and plan evacuation routes and safe areas, all of which were not part of their routine before the early warning services. In contrast, the inhabitants of Rowmari and Gaibandha Sadar Upazila do not receive forecasts or any warnings and do not implement any forecast-based actions.

4.3.1 Health

The research revealed that residents of Char Rajibpur and Saghata sub-district are implementing various precautionary measures in anticipation of future floods. They are elevating the platforms for tube wells and latrines, preserving and stockpiling food, as well as storing drinking water. Additionally, they are keeping medicine on hand.

4.3.2 Food Security Resilience

The research indicated that residents of Char Rajibpur and Saghata sub-district prepare food in anticipation of future floods. Currently, they accumulate supplies and utilize them during challenging times.

4.3.3 Household-Level Resilience

According to the research, residents of Char Rajibpur and Saghata sub-district are improving their household standards. They are also reinforcing their homes and planting trees in their vicinity. In their households, they store essential documents in designated containers.

4.3.4 Community Level Resilience

The research indicated that residents of Char Rajibpur and Saghata sub-district receive early warning information through the Government hotline number, union digital center, religious leaders or organizations, union disaster volunteers, union disaster management committees, and disaster risk reduction leaders.

4.3.5 Disaster-Induced Damage and Loss

The research aimed to investigate the quantitative trend of diminishing production losses across rice and homestead vegetable sectors among the participants. The findings indicate a significant decline in both rice and homestead vegetable production in the sub-districts of Char Rajibpur and Saghata from 2017 to 2024. In Char Rajibpur, rice production decreased from 4.1 Kg per decimal in 2017 to 1.5 Kg per decimal in 2024, while homestead vegetable production dropped from 9.4 Kg to 2.5 Kg per decimal over the same period. Similarly, in Saghata, rice production declined from 4.0 Kg to 1.6 Kg per decimal, and homestead vegetable production fell from 12.69 Kg to 4.6 Kg per decimal (Table 2).

Table 2: Reduction of rice production and homestead vegetables loss and damage.

Sub district	Rice (Kg per decimal/year)			Homestead vegetables		
	2017	2021	2024	2017	2021	2024
Char Rajibpur	4.1	3.2	1.5	9.4	8.8	2.5
Saghata	4	3	1.6	12.69	8.6	4.6

Source: Field survey

In the 2017 flood, there were 36 fatalities, 73 livestock casualties, and 77198 hectares of agricultural land were entirely ruined, with 211126 households suffering destruction in the research area. The extent of flood damage decreased in 2021, resulting in just 3 deaths, with 995 hectares of cropland affected and 100 homes damaged. But the livestock loss was 22 in the 2021 flood within our research area. Lastly, in 2024, crop damage was 160 (ha) and household damage was 510, with no human life and livestock lost (Table 3).

Table 3: Flood induces loss & damage

Year	Loss & Damage			
	Human death	Loss of livestock	Crop damage (ha)	House damage
2024	0	0	160	510
2021	3	22	995	100
2017	36	73	77198	211126

5. Discussion

5.1. Health

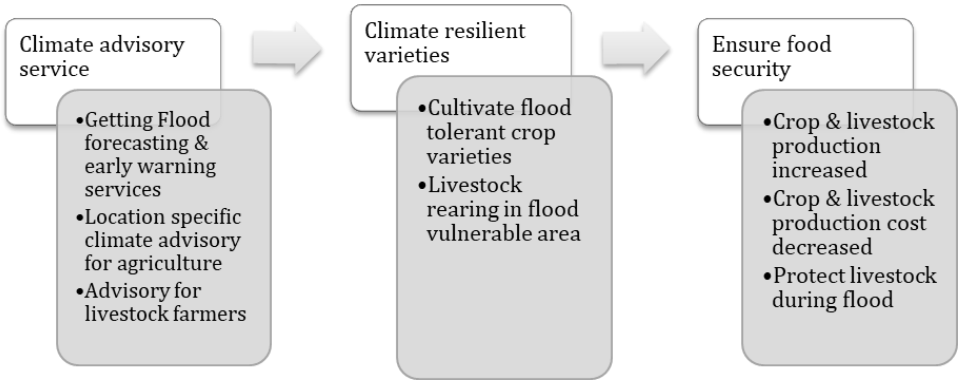
Access to safe drinking water has consistently been a significant concern for residents in the research areas. The lack of safe latrines became a major issue during and after flooding. However, with the introduction of early warning systems, they are implementing constructive measures. Currently, they are elevating the tube wells to safeguard against floodwater contamination. They are also increasing the height of the latrines. Based on recommendations, they are conserving drinking water for future use. A focus group discussion indicated that residents of the Saghata sub-district are now stockpiling food in anticipation of forthcoming floods. They mentioned that previously, floods led to food shortages that caused them to suffer from hunger. One participant from the focus group discussed how safe drinking water after flooding was a critical issue in the past. However, due

to their water storage systems, they now experience very few problems regarding this matter. Another participant explained that early warnings and advisory information enabled them to elevate both latrines and tube wells. As a result, they are experiencing a reduction in infections compared to previous times. He also mentioned that he stores medications to use during floods and afterward when medicines might be scarce, aiding in prompt recovery. Consequently, they are safeguarding their health and building a resilient community.

5.2. Food Security Resilience

Participants in the research area indicated that they obtained weather and flood predictions, along with agricultural and livestock advisories, and information for flood preparedness at various stages. After receiving flood warnings and advisories, many took proactive measures. They are now better informed about when floods might impact their region. To mitigate losses, they plant flood-resistant crops so they can harvest them before flooding. Additionally, they raise livestock as a source of income. Upon receiving early warning forecasts, they relocate their animals to secure locations to safeguard them during floods. As a result, agricultural production of crops and livestock has declined in the study area, which has contributed to food security. The figure illustrates how food safety has been maintained in the study region.

Figure 4: Ensuring food security by location-specific early warning & advisories



5.3. Household Level Resilience

Resilience has rapidly emerged as a key focus in development, being recognized as a vital conceptual framework for enhancing our comprehension of how individuals respond to and adapt to a variety of shocks and stresses that impact their livelihoods. Consequently, there is an increasing demand for methods to assess resilience levels among individuals and communities, driven by a concerted effort to build resilience within the humanitarian and development sectors. In theory, more accurate monitoring and measurement of resilience

can help ensure that policies and programs aimed at enhancing resilience support the right initiatives and target the correct groups. Monitoring resilience across different levels is essential for swift post-disaster assessments, precise social protection strategies, and evaluating the effectiveness of resilience initiatives (Jones & Tanner, 2015). Residents in the study area receive timely warnings and guidance on enhancing their household resilience. After previously experiencing flooding, they have raised their home's elevation, preventing floodwaters from entering and causing major property damage. They are in the process of reinforcing their home based on expert advice. Additionally, they are learning to plant trees near their residences. By doing this, they are boosting their capacity to adapt and minimize their losses from flooding. Focus group discussions revealed that before receiving information on household resilience, they were unaware of its concept; however, upon receiving early advisories and preparedness knowledge, they have elevated their homes. They also expressed that they now plant trees around their homes and reinforce their houses annually, making them more resilient than before.

5.4. Community Level Resilience

The process by which a community adapts and survives disturbances is referred to as community resilience (Patel et al., 2017). Understanding a community's ability to bounce back from shocks or stressors can provide insight into its resilience. Residents of Char Rajibpur and Saghata Sub-District receive early warning information through several channels, including a government hotline, the union digital center, religious organizations, union disaster volunteers, the union disaster management committee, and disaster risk reduction experts. To evaluate a community's resilience, factors such as social capital, economic resources, communication and information access, and community skills are considered. Early warning information reaches the community of Char Rajibpur and Saghata Sub-District via the government hotline. The FFWC consistently publishes critical information on its user-friendly website. The FFWC has also started sending flood warning notifications through IVR technology (Hossain, 2018). By dialing 1090, anyone in the country can receive timely updates about the latest flood information concerning Bangladesh's major rivers. Community leaders or institutions convey early warnings through the mosque's microphone, fostering reliance on these religious figures for guidance. The community members not only have faith in their religious leaders but also believe that the advice they receive is beneficial. The Union Disaster Volunteer (UDV) plays a crucial role in ensuring that early warnings are effectively

communicated. Additionally, various non-governmental organizations (NGOs) in the area have provided training to Disaster Risk Reduction (DRR) Leaders. Consequently, the community benefits from effective early warning services. A focus group discussion conducted in the Saghata sub-district revealed that the community lacked awareness of adaptive measures during past disasters, but with the assistance of training and early alerts from DRR leaders, they have learned to cope with flooding and support others in the community, enhancing social capital. Economic sustainability was also achieved through a savings association, enabling residents to hold onto surplus resources for emergencies. The community became more skilled as they adopted alternative livelihoods such as sewing, livestock rearing, gardening, and other activities, along with improvements in early warning services. Before receiving early warning services and training from DRR leaders, the community had no adaptive measures in place; however, these initiatives have significantly elevated their resilience and overall status.

5.5. Disaster-Induced Damage and Loss

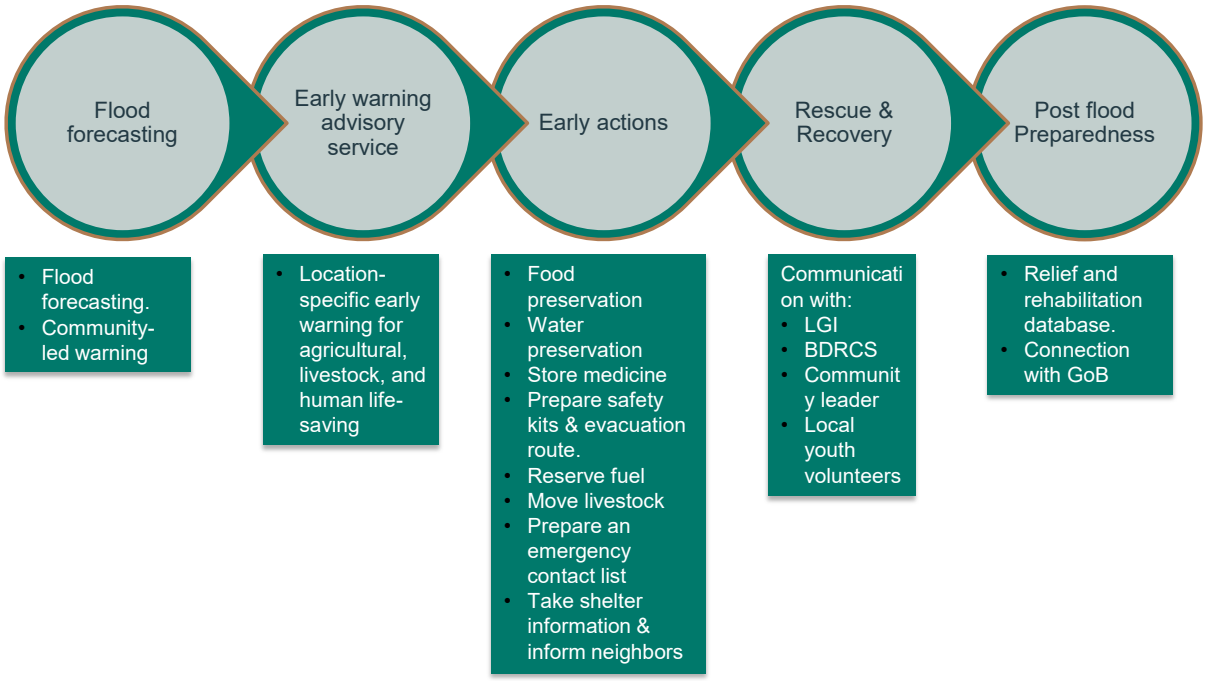
Before receiving flood early warnings, many people were unaware of the imminent threat of flooding. Consequently, the unexpected arrival of floods resulted in significant destruction, loss of life and livestock, and damage to agricultural output. After 2015, various government organizations, NGOs, and other entities began assisting vulnerable populations in flood-prone areas by providing early warnings and preparedness guidelines. The situation has significantly improved in these regions, as they now receive flood early alerts, enabling them to undertake preventive measures to safeguard their lives and livelihoods. Agricultural production has risen, and livestock losses have diminished due to the effectiveness of early warning and advisory systems. As a result, this community has become more resilient, as they now receive early warnings and can implement essential precautions before flooding occurs.

5.6. Community Preparedness and Resilience

Flood resilience is achieved through a community's proactive efforts to become flood-ready, both before and following flood events. It is not a spontaneous occurrence. Flood forecasting or the actions a community might undertake can provide advance notice of an impending flood. Effective strategies for flood resilience include early warning and advisories, which help raise awareness about the devastating impacts of floods and encourage timely actions to lessen flood risks, minimize vulnerability, strengthen community response capabilities during flooding, and create recovery plans after a flood. During the recovery phase following a flood,

building resilience often entails swiftly conveying information to residents, being aware of recovery resources available to the community and its members, and helping residents comprehend what mitigation efforts may be necessary for repairs or reconstruction, as well as what programs might be offered for property buy-outs or other mitigation initiatives.

Figure 5: Community flood resilient strategies



6. Conclusion

Though early actions using InfoClim are effective in the study areas, flood forecasting and early warning are insufficient in Bangladesh when applying location-specific real-time information. InfoClim, as an effective flood forecasting and early warning mechanism, should be enhanced and scaled up to reduce flood-induced loss and damage in flood-vulnerable areas.

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