IAC-22-E5.4.6

Remote-Sensing Technologies Towards Flood Mitigation in India's Northeast Region: A Case-Study

Priyanka D. Rajkakati [a]*, Jaan Sharma Pathak [b], Diganta Barman [c]

[a] *Independent researcher, France, contact@priyankarajkakati.space*
[b] *University of Minnesota, United States, sharm687@umn.edu*
[c] *Northeastern Space Applications Centre (NESAC), diganta_isro1@yahoo.co.in*
* *Corresponding Author*

Abstract

The present paper aims to bring to light India's flood-affected northeastern state of Assam, as part of an ongoing study on how space technologies, especially remote-sensing techniques, can benefit Assam towards flood prediction and mitigation and could further help understand the social and ecological dimensions of floods. The paper also discusses how the research would be applied in benefit of society towards grass-root level development of an educated "space workforce" in the local region. Assam has a complex fluvial system of rivers, with two major river valleys namely Brahmaputra and Barak, flowing into the Bay of Bengal. Originating from the Himalayan glacier of Angsi at 5210m, the Brahmaputra is the second highest sediment carrying river in the world, after the Yangtze in China, as well as one of the largest rivers in the world, discharging about 19830 cubic meters of water per second. Due to massive sediment flow from the upper catchment areas and subsequent lack of carrying capacity of the river channels, the Assam valley is subject to periodic severe flooding every year during the peak monsoon season, causing extensive damage to life and property. As flood mitigation, over 4000 kilometers of embankments have been constructed as the primary means to control floods. However, they have led to several environmental challenges like rise in riverbed levels, flash floods due to frequent breaches in embankments, soil erosion and water logging. Importantly, these hazards have their worst impact on the poorest and most marginalized population of Assam. Historically, Assamese society has adapted to floods by avoiding permanent habitation in flood-prone tracts. However, migration into Assam and population growth in the last century has resulted in extensive settlements along flood-prone riverine tracts, consequently leading to massive internal displacements during floods. This paper examines in detail the natural and social factors that make floods in Assam extremely damaging. This is followed by a discussion on the Flood Early Warning System (FLEWS) project, its success and challenges faced, as well as how recent advancements in Geographic Information System could be valuable for improving monitoring and decision-making. It further presents local narratives with the aim to understand the perceptions and experiences of local communities and forest officials due to damaging floods.

Keywords: floods, disaster management, space technology, remote sensing, GIS.

Acronyms/Abbreviations

Assam State Disaster Management Authority (ASDMA)
Central Water Commission (CWC)
FLood Early Warning System (FLEWS)
based Geographic Information System (GIS)
Indian Space Research Organisation (ISRO)
Northeastern Space Applications Centre (NESAC)

1. INTRODUCTION

India is one of the most flood-prone countries in the world. In fact, it ranks highest when it comes to the total population exposed to floods, according to estimates from the Global Flood Database, 2000–2018 [1]. However, the capacity to handle the impact of floods depends on the population at risk, with underdeveloped and marginalized communities suffering the most [2].

This year, India celebrates 75 years of independence after colonial rule, and although on one hand there has been enormous progress, including the country having established itself as a major space power, residues from the colonial imprint can still be felt especially in parts of the country where development has been slower, such as in the northeastern region. Even though there was a boom in India's economy post-2003-04, the northeast was not able to proportionately participate in it, contributing to less than 3% of India's GDP in 2019.

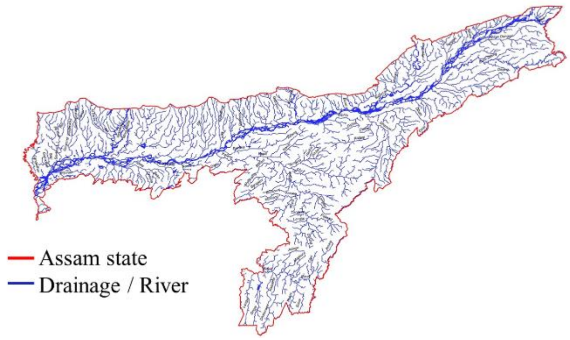

Fig 1: Assam – Drainage Network [3]

The present paper highlights the flood-affected northeast Indian state of Assam. Although it accounts for only 3% of the total population & less than 1% land mass of India, Assam has 9% of the total flood-prone area of the country [3]. With its very unique geography and a largely poor, agrarian population, it is especially vulnerable to floods, with the situation being further exacerbated by the climate crisis [4].

This section introduces the river system in Assam and provides data on the extent of the damage caused by floods. Subsequent sections will present detailed arguments on why floods are so disastrous in Assam from both technical as well as socio-economic points of view, as well as how remote sensing techniques can assist in mitigating these effects. The last section will share brief testimonies of flood-impacted communities from villages in Mayong in the Morigaon district of Assam. It aims to recover popular narratives and perceptions around floods to understand how the impact of floods and climate change are being experienced on the ground.

1.1 Assam and its River Systems

Located between 89°N to 96°N and 24°E to 28°E, the northeast Indian state of Assam lies in the foothills of the Eastern Himalayas, experiences a tropical climate, and is home to 31.2 million people (2011 census) from culturally and ethnically diverse origins. Known for the world-famous golden Muga silk, Assam is also one of the world's largest tea-growing regions, with a total production of 641.23Mn kg (2019). The state is a major biodiversity hotspot and is home to the Indian one-horned rhinoceros, wild water buffalo, several species of Asiatic birds, the Royal Bengal tiger and one of the last habitats of the Asian elephant.

With over 125 small, medium, and large rivers, the high density of rivers in Assam marks it out as a distinctly riverine landscape (Fig 1). A noted hydrologist of the region observes that "the profusion of rivers in North-East India is simply unparalleled" [3]. The watery landscape of Assam is not only assisted by glacial sources of the Himalayas, but also the immense quantity of rainfall brought upon Assam and neighboring regions by the south-west monsoon, making the region one of the wettest in the world.

Assam's two largest rivers are the Brahmaputra and the Barak, which divide the state into two distinct river valleys, with the former occupying a large part of the state. Within Assam, Brahmaputra has as many as 41 major tributaries whereas Barak is joined by 8 important tributaries [3]. In fact, the Brahmaputra is one of the largest and most dynamic rivers in the world – annually discharging about 19830 cubic meters of water per second, it's the fourth largest water carrying river in the world [5]. Originating in the Himalayan glacier of Angsi in Tibet, at an elevation of 5210m, the Brahmaputra River traverses 2900 kilometers through three different countries viz. China, India, and Bangladesh. In Assam, the river runs for almost 700 km before entering Bangladesh and eventually merging with the Bay of Bengal [6].

Another key geomorphologic feature of the Brahmaputra is that it is the second-highest sediment carrying river in the world, after the Yellow River in China. Due to the high elevation of Tibet and Arunachal Pradesh, the slope of the river is around 2.82 m/Km in the Tibetan plateau, and, upon entering the plains of Assam, the gradient drops abruptly to about 0.1m/km (Fig 2) [3][7]. Due to this sharp drop and the heavy sediment load, the channels regularly split off and rejoin each other, giving the river its braided character and resulting in extensive formation of river islands (Fig 3), locally

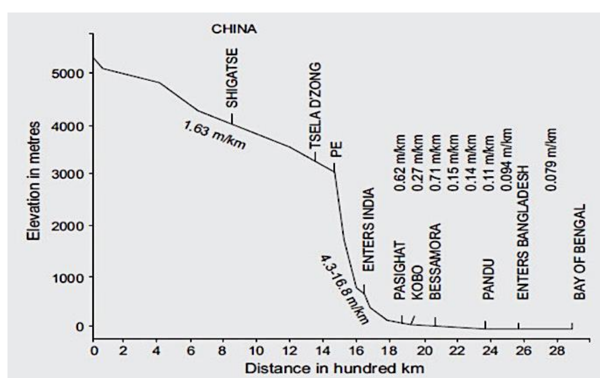

Fig 2: Length profile of the Brahmaputra river [3]

Fig 3: Braided nature of the Brahmaputra River, with the formation of "chars" or river islands [Google Maps]

known as "*chars*"; among which exists the largest riverine island in the world – Majuli.

1.2 Flooding and Extent of Flood Damage in Assam

Given the density, size, and dynamism of rivers in Assam, it is perhaps not surprising that floods are an important feature of the social and ecological life of the state. The National Commission of Floods data estimates that around 40% of Assam's land or about 3.1Mha out of a total of 7.85Mha of land are flood affected [8]. More importantly, the scale of devastation wrought by floods in Assam is immense. According to Central Water Commissions data between 1953—2016, on average 2.6Mn people were annually affected by floods. The average human causality due to floods in this period is estimated at 46 deaths every year [7].

In years of major floods such as this year (2022), the damage is manifold. This year's floods between the months of April-June recorded 195 deaths—the highest in Assam's recorded history. Floods affected almost 90 lakh people which is roughly a third of the state's entire population [9]. Alongside the loss of lives, the damage to livelihood and economic infrastructure was immense. These floods destroyed standing crops in in around 257kha of farmland. Another 86.9kha of crops that were ready for harvest were lost [10]. The floods damaged over 300k houses, 3611 roads and 193 bridges. The CEO of state disaster management estimated that loss due to floods in 2022 may amount to over INR 10000 crores (~USD 1.25Bn) [10] [11]. For a poor state like Assam such a loss is devastating. In fact, there is a clear trend to the economic devastation caused by floods. Between 2015- 21, the cumulated losses to floods are about 25000 crores or about 5 % of state GDP [12].

Another important facet of damages caused by floods in Assam is the severity of erosion of riverine land. Assam is estimated to have lost around 0.427MHa since the 1950. This translates to almost 7.5 % of total land area of the state [13]. The heavy erosion of land has been accompanied by the expansion of the Brahmaputra land cover, where surveys have shown that the area covered by the river has increased from 3870 km in 1912-28 to 6080 km in 2006 [7] [14].

2. WHY ARE FLOODS DISASTROUS IN ASSAM?

While Assam's topography, fluvial system and climate are critical drivers in the annual monsoonal flooding events, the nature, scale, and impact of floods on Assamese society cannot be attributed to 'natural' factors alone. While topography and climate may explain why a river floods, it does not explain why flood events are destructive. One of the fundamental insights of critical social science literature on hazards is captured in the pithy statement that "there's no such thing as a natural disaster" [15]. The different ways natural hazards like floods or drought impact particular individuals and communities are inextricable combinations of social and natural factors. Floods in Assam are no exception.

A comprehensive understanding of the major factors behind floods needs an analysis of not just topographic, climatic, and fluvial patterns, but also social and ecological transformations, government policy and even effects due to climate change. This section details arguments spanning each of these domains.

2.1 Topographic and Metrological Context of Floods

Firstly, a closer examination of the topographic, hydrological and metrological features of Assam would help understand why floods are an integral feature of Assam's geography.

The plain of Assam represented by the Brahmaputra valley are located between the hills and mountains of the Greater Himalayas in the North and the Purvanchal Range along with Khasi and Jaintia Hills in the South and East directions. The average width of the plains in the Brahmaputra valley is only about 80-90 km; including on average a 10 km wide area occupied by the river itself. More precisely, 48,000 sq km of plain area constituting the Brahmaputra valley is surrounded by 465,000 sq km of mountainous area. Thus, the latter is 10 times the size of the former. These mountains are also the source of numerous other major and minor tributaries of the Brahmaputra, which bring down immense quantities of water and sediment into the plains of Assam and further onward to the Bangladesh delta.

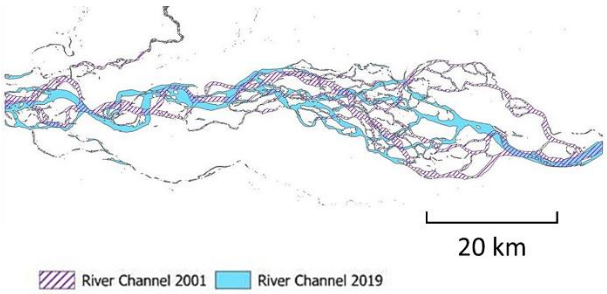

Fig 4: Comparison of Brahmaputra river channels (midsection of Assam) between 2001 and 2019

The topographic relief combined with metrological conditions of the region create conducive conditions for floods in Assam. The state and the broader catchment area of Brahmaputra and other rivers in the region receives extremely high annual rainfall, ranging from 248 cm to 635cm, most of which is received during the Southwest monsoon in the months of June, July and August. During the monsoon the flow in the river is almost 10 times that of its lean flow during the drier winter months [16].

Along with water, the river also brings down eroded matter from the Himalayan catchment region. One estimate suggests that over 95% of the annual sediment load of the Brahmaputra is carried by the river during this period [17]. It is also during these monsoon months that Assam experiences annual floods. During the monsoons, the width of the river may expand anywhere between 10-16 km across different areas of the plains. This dramatic seasonal variation in the river's annual cycle is due to increased snowmelt in the glaciers and precipitation. Annually glaciers contribute 35% of the river's discharge with the remaining provided by precipitation. The river profile also keeps changing drastically over short timespans. For example, Fig 4 shows how channels in the middle section of the river in Assam have changed course, sometimes over a span of 20km, in less than two decades (2001-2019).

Furthermore, the northeast region is situated in the highest seismological zone due to the presence of the Himalayan Frontal Thrust (HFT) and the Kopili Fault. Thus, Assam finds itself in a highly seismic and geologically unstable zone, with earthquakes a regular feature, leading to debris and loose earth from landslides being deposited in the riverbeds, making it shallow [16]. Indeed, the average depth of the Brahmaputra is only 30m, with a maximum depth of 135m at Sadiya. This results in a reduction in the carrying capacity of the rivers.

2.2 Socio-historical Transformations

A recourse into a deeper history of the Brahmaputra River Valley, as well as other rivers in South Asia, challenges our taken-for-granted framings of floods as disasters. Environmental histories have taught us that equating floods with disasters is, in important respects, a starkly modern phenomenon [18]. Historical accounts of the Brahmaputra valley have reminded us that up-until the 20th century, floods were considered a 'normal' part of the fluvial cycle, and the social and economic life evolved to 'live with floods' rather than attempt to control or prevent flooding. Some of the key hallmarks of the Brahmaputra valley 'floodplain agrarian ecology' included avoiding permanent settlements near riverbanks, periodic migrations to adapt to changes in riverine landscapes and optimizing the utilization of silt and other fertilizing matter transported by flood waters [5].

It is distinctly under colonial rule that seasonal floods came to be discursively coded as a calamity or disaster. The utilitarian philosophy of colonial rulers deemed the flood-adapted practices of the Assamese peasantry as wasteful and inefficient [5]. Colonial policies aimed to create permanent settlements on the low-lying floodplains which were previously only utilized during the dry winter seasons. The period of early 20th century under colonial rule also saw massive waves of migration from other parts of Eastern India to settle in these floodplains, which were facilitated to increase land revenue and export of cash crops like jute. The massive reclamation of floodplains marked the transformation of Brahmaputra valley from a flood adapted system to now being a flood vulnerable landscape. By the mid-20th century, large stretches of the floodplains came to be marked by permanent settlements and consequently floods emerged as a major challenge to the social well-being of Assam. Between 1901- 1947, the area under agriculture in the Brahmaputra valley nearly doubled. Almost 1.5 million hectares of land (1/5th of the state) were transformed from natural vegetation to human settlement and agriculture [5]. Apart from migration, demographic change, loss of uplands to tea plantations and forest departments, and peasant indebtedness, all contributed to the settlement of low-lying floodplains by the most marginalized communities of Assam.

The demographic changes in recent decades have resulted in more and more people residing in low-lying floodplains. In 1940, the population density of plain areas of Assam was only around 9-29 people per sq km whereas the same in 2011 is about 398 [7]. The population of river islands alone numbered close to 2.5 million inhabitants according to the last survey conducted by the government in 2003 [19]. The population in these islands is likely to much significantly higher now. The expansion of population in Assam has also been accompanied by extensive levels of deforestation and reclamation of wetlands, both of which act to soak up excess water during rainfall and flood events. In Assam, the loss of tree cover in the last two decades has been almost close to 10% [20]. Similar trends are at play in neighboring states part of the Brahmaputra watershed, such as Meghalaya and Arunachal Pradesh [7].

2.3 Failure of Structural Approach to Flood Control

Alongside the social and ecological transformation of the floodplains, Assam has witnessed what can be described as counter-productive structural flood control measures since the early 1950's. The immediate context for the implementation of extensive flood control measures was the crisis provoked by the 1950 earthquake, just three years after India's independence. Measuring 8.6 on the Richter scale, the tremors were one of the largest ever instrumentally recorded earthquakes. The earthquake had a severe impact on the agrarian economy and had altered the river course in detrimental ways [5].

2.3.1 Embankments

The first structural measure involved the widespread building of embankments. At present, Assam has about 423 embankments totaling a length of 4,459 km of embankments constructed by the Water Resource Department. This is supplemented by 851 km of drainage channels and about 681 town/village protection works which include engineering structures to protect banks and prevent erosion [21].

The extensive network of embankments has not only failed to prevent floods but arguably made matters worse by creating a false sense of security and allowing the buildup of settlements along the floodplains. When embankment breaches occur – which have been extremely frequent in the state due to primarily earthen-constructed embankments – protected areas get exposed to dangerous flash floods, resulting in immense damages to life and property. Although these breaches are common, the lack of a method to determine the exact location of a possible breach creates a precarious condition whereby the onset of flash floods always remains probable but difficult to predict.

In 2022, Assam witnessed as many as 187 embankment breaches. Embankment failure therefore is extremely common in Assam. Moreover, over 90% of the embankments have been constructed before 1980. 295/423 of them have crossed their lifespan and are alleged to be prone to breaches [22]. To make matters worse, a significant yet unquantified number of embankments have been constructed by entities other than WRD, which are alleged to not meet the requisite technical standards and said to be more prone to breaches.

2.3.2 Dams

Dams over the various rivers and tributaries are the second key important structural intervention which have had an important bearing on floods in Assam. Especially since the 1990's, the Indian government has already built several dams and planned others over the tributaries of the Brahmaputra, primarily to generate hydroelectric power. In fact, as many as 168 major dams are being planned over the river, the majority of which will be in the upstream state of Arunachal Pradesh [14]. Although government pronouncement has claimed that these dams will contribute towards flood management, experts have pointed out that dams built by India in the region have very little storage capacity and are being designed to generate hydroelectric power [23].

Apart from dams in the Indian territory, the neighboring country of Bhutan has built several dams over key tributaries of the Brahmaputra. China has also built several mega dams over the river. These have received a lot of media attention not only due to the gigantic scale of these projects but acute geopolitical tensions between India and China. Such extensive construction of dams has caused great consternation over the long-term future of rivers and, given that the region is one of the most seismically active zones and with some of the worst earthquakes in recorded history, downstream communities in Assam are extremely fearful of the threat posed by dams in case of a major earthquake.

Moreover, dams are alleged to be contributing to the unpredictability of floods. Over the past few years, downstream communities of Ranganadi, Kopili and others in Bhutan have complained of the devastation caused by sudden release of water by dams during the monsoons. Such stories abound local media in a concerningly consistent manner and are held up in popular discourse as a major reason for the devastation caused by floods.

2.4 Further Exacerbation due to Climate Change

In various reports prepared by the state, national and non-governmental agencies, Assam has been identified as the state that will be worst affected by climate change in India. According to latest data by Government think tank National Institution for Transforming India (NITI) Aayog, Assam has ten of the top thirteen districts that are predicted to be the worst affected by climate change [4][12]. Assam's State Action Plan on Climate Change observes that changes in rainfall pattern is one of the primary causes of vulnerability, with the effect of changes in rainfall pattern and consequently on floods already visible in the last few years.

Traditionally, annual floods have occurred during the monsoon months of June, July, and August. However, data from 2016-22 shows that floods have hit Assam as early as May and, in some years, lasted all the way till late October/November [12]. In other words, the agrarian-economy based state now suffers from the problem of floods for almost half the year, which implies much less time for recovery and therefore more vulnerability to future flood events.

The years 2017, 2019 and 2020 all witnessed floods for over 6 months in the state [12]. This year, heavy rainfall in the month of April and May meant that the first wave of flood had already hit the state well before the arrival of the monsoons. Furthermore, there has been an increase in the incidence and quantity of extreme rainfall events, with both Assam and Meghalaya receiving the highest rainfall in the month of June in 121 years [24] (Fig 5). This rise in these events has been attributed to an increasing variability of the monsoon westerlies over the Arabian Sea due to increased warming [25]. One of the impacts of such heavy rainfall in a short span of time has been the change in courses of rivers like Subansiri and Dibang, which have further aggravated the vulnerability to floods [12].

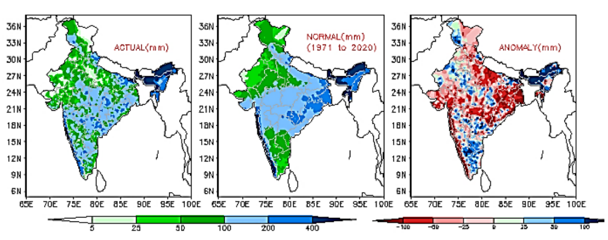

Fig 5: Observed spatial Rainfall pattern for the month of June 2022 over India and their departure from normal (1971 to 2020 period) [24]

It is also important to recognize that Assam's vulnerability to climate change due to extreme rainfall and flood events is compounded by a host of other social reasons. Being one of the poorer states in the country, the state's population lags on several key social indicators like health, access to credit and insurance, presence of infrastructure and access to alternate forms of livelihood and dependence on agriculture [26].

The agrarian sector and a population that majorly depends on it will be severely impacted by the effects of climate change. As mentioned earlier, in this year's flood, about 86.9kha of crops that were ready for harvest were lost due to high pre-monsoon rainfall in April-May [11].

3. SPACE TECHNOLOGIES TOWARDS FLOOD PREPAREDNESS AND MITIGATION

As presented above, marking seasonal floods as a calamity or disaster is a distinctly recent phenomenon. Historically, rather than attempt to control or prevent flooding, the social and economic life evolved to 'live with floods' by avoiding permanent settlements near riverbanks, building only in elevated areas or on stilts, practicing periodic migrations and optimization of fertilizing matter transported by flood waters.

Many traditional methods for flood exposure and vulnerability assessments have existed, but these ground-based empirical models are limited by lack of incorporation of rapid anthropogenic changes and low accuracy in topographical mapping. In recent times, there has been an important shift towards the adoption of space-based technologies in enhancing these models such as satellite-based remote sensing, which involves the use of onboard sensors and instruments to acquire data on the Earth's surface, without any direct contact [27].

Satellite-based remote sensing can indeed provide complementary data on inundations which can also account for climate effects and infrastructure changes that are not reflected in existing models [1]. Satellite remote sensing can have advantages over aerial or drone remote sensing by providing larger field of view and systematic revisit times. Remote sensing using other frequencies other than optical, such as radar, especially specifically Synthetic Aperture Radar (SAR), can help visualize topography even while subject to otherwise limiting weather conditions such as clouds – a constant challenge in the context of Assam – provide digital elevation models, and accurately model other terrain properties, which can help locate and assess natural disasters. Timely visualization of data obtained from these resources can also facilitate rescue missions [28]. Apart from using the Sentinel and Landsat data, India also has its own fleet of remote-sensing satellites such as the CARTOSAT and RESOURCESAT series, aimed at providing very high-resolution imagery in near real-time.

From an administrative and policy point of view, this additional data on flood-prone areas, with maps being available within hours after receiving raw satellite data, can equip authorities with near real-time information about inundations. Satellite maps are also useful as temporal archives of a region which can be analyzed and implemented in designing effective flood mitigation systems. More importantly, with respect to Assam, such new solutions would also be able to tackle the problems mentioned in Section 2, notably more accuracy in topographical models, demographical and anthropological changes, as well as monitoring of infrastructure and extreme climate change related events.

3.1 Flood Early Warning System (FLEWS)

Despite the regular annual occurrence of floods in Assam, there were no early warning mechanisms that could alert concerned districts and villages, with existing disaster management structures focused primarily on rescue and relief operations after a disaster event. Flood forecasts and warnings for major rivers would be issued by the Central Water Commission (CWC). However, as it did not account for smaller tributaries and was not location-specific to villages or revenue circles, the local administrative machinery was not able to determine target areas to warn or evacuate [29].

In June 2008, when a devasting flash flood occurred in the Lakhimpur district of Assam, affecting more than 0.3Mn people and 75kha of land, it drove the government of Assam to consult various organizations, such as Indian Meteorological Department, Brahmaputra Board, CWC, Assam Water Resources Department (AWRD), Assam Remote Sensing Application Centre, as well as the Northeast Space Applications Centre (NESAC), for developing a location-specific flood early warning advisory model. NESAC, in association with Assam State Disaster Management Authority (ASDMA), took up the responsibility of developing an effective mechanism called the Flood Early Warning System (FLEWS). Lakhimpur district was taken up as a pilot exercise, and, today, all districts of Assam are covered.

While natural hazards are inevitable, disaster losses can indeed be minimized. The development of flood forecasting and early warning systems is essential for flood preparedness strategies. The benefits of these early warning systems are reflected in the amount of reduction of damage due to floods [29]. FLEWS takes inputs from meteorology, hydrology and GIS on a watershed scale. The prime services under this activity include:

- Early warning of flood in magnitude (severity) with location (revenue circle) and probable time
- High rainfall warning with location and time
- Post monsoon status of embankments

3.1.1 Components of FLEWS

FLEWS comprises of three subcomponents [29]:

a) Hydrological component

This component involves a hybrid approach. The primary subcomponent is a quasi-distributed (i.e., dependent variables are functions of time and spatial variables) hydrological model, providing the forecast for the daily hydrograph for that basin. This open-source Hydrologic Modeling System (HEC-HMS), developed in ArcGIS software, is designed to simulate the precipitation-runoff processes of dendritic drainage basins, like that of the Brahmaputra. A hydrodynamic model using a customized DHI MIKE model, and a River Analysis System (HEC-RAS) is also being tested on an experimental basis for inundation mapping. A secondary subcomponent is a lumped (i.e., time-dependent variable) gray-box Rational model, which provides the forecast of the peak discharge for a river basin. This is used for quick assessments of peak discharge without hydrographs.

b) Meteorological component

This component comprises of two major subcomponents, namely a Weather Research Forecast (WRF) model for grid-based rainfall predictions through numerical schemes, and a multi-parametric synoptic (large-scale) weather monitoring for overall probability of rainfall in a particular basin. The WRF is a type of Numerical Weather Prediction (NWP), which predicts the weather at a given location based on atmospheric computational models. The model predicts the rainfall values in different grid resolutions such as 27km, 9km, 5km, and 3km at three hourly intervals over a 24-hour period.

c) Embankment monitoring

The third component is the post-flood identification of embankment breaches and general monitoring using satellite and aerial imagery (Fig 6).

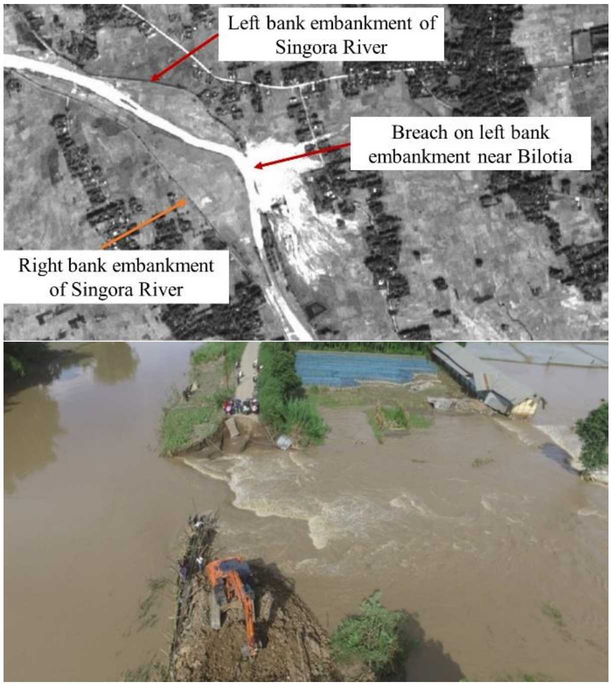

Fig 6: top) Satellite image of an embankment breach, (bottom) Field visit photo of the breach [30]

3.1.2 Warning Generation and Dissemination

Once the peak discharge from the rational model and the daily outflow hydrograph from the HEC-HMS are computed and compared with the flooding threshold and the synoptic weather monitoring advisory, a warning is issued for the concerned river and its corresponding revenue circle.

The FLEWS hydrology team then generates two types of early warning in parallel: a brief SMS alert and a more detailed email containing relevant maps. These are then disseminated by the NESAC FLEWS communication team to the ASDMA control room in three concerned user groups: Upper Assam, Middle/Barak Valley, and Lower Assam. The ASDMA control room then further forwards the alerts to the grassroot level (e.g., circle officers and '*gaon buras*', or village heads). Presently, the alerts issued are also uploaded in the ASDMA website (www.asdma.gov.in).

This information is then used at the revenue circle level towards ground preparedness in anticipation of an upcoming flood wave, such as keeping rescue and relief infrastructure on standby, evacuation of the community to a safer area and informing of concerned departments for necessary action.

3.1.3 Efficiency and Outcomes

FLEWS has proven itself to be capable of generating flood alerts at the district and revenue circle level with an average actionable lead time of 24 to 48 hours, and an average success rate of 75-80% regarding forecasts [29]. Starting with one pilot district having four tributaries of the Brahmaputra in 2009, with periodic requests from the Government of Assam for the inclusion of additional districts in annual phases, the project was extended to one other district in 2009, three more in 2010, and, with the achievement of some success, was extended to a total of 14 districts by 2012. Today, all flood-prone districts of Assam are covered, taking the total number of major watersheds to 43 covering both Brahmaputra and Barak valley. As per CWC reports, the percentage of population affected due to floods was 46.83% in 1987, 34.83% in 2007, and dropped to 8.16% in 2010, 2.92% in 2011. However, to be noted that climate change effects have adversely affected the situation in recent years.

FLEWS plays an important role in government flood management strategy and action. It was declared as a Professional Best Practice by the Department of Administrative reforms under Union ministry of Public Grievances and Pensions in the year 2012 and it also won the e-Northeast award for e-Governance and citizen services by the North East development foundation, New Delhi the following year in 2013.

Following the success of FLEWS, a full-fledged node for risk reduction of other relevant disasters (landslides, forest fires, cyclones, epidemics, etc.) in the northeast of India in the name of NER-DRR has also been set up at NESAC. FLEWS is being further extended to other states on experimental basis.

3.1.4 Future Prospects

Over the course of the project, several more robust flood hydrological modelling tools have been tested for implementation into the FLEWS operational block. Moreover, a plan is being set up for the FLEWS hydrology team to mentor on operational flood forecasting with AWRD, which will eventually transfer the operational component of FLEWS to the state government, allowing the FLEWS team more time and resources to test new models. A pilot project for testing higher accuracy models supported by the World Bank is being planned in three basins. Finally, to provide further support to the user community a web-enabled decision support system with dynamic update interface is planned.

Recent advances in machine-learning techniques (e.g., deep learning, support vector machines, random forests, etc.) could be an interesting avenue to explore, as they can even take into account uncertainties due to climatic and environmental factors. These AI-based models coupled with remote-sensing data from satellites, leading to AI-based GIS, could indeed help improve models through automated prediction, forecasting and analysis of disaster events [28]. GIS software are also become more accessible to researchers not necessarily trained in advanced programming, allowing them to conduct their research and analysis more fluidly (e.g. Google Earth Engine, which can also be used as a plug-in in open-source software such as QGIS).

4. LOCAL NARRATIVES ON FLOODS

4.1 Description of field visit

As part of this research, we conducted field visits to a few villages inhabited by marginalized rural communities in flood-prone areas, to find out more about the perceptions and experiences of local communities on floods. Some of the key questions included: what do people think is causing floods? How are flood patterns changing? Are government aid, relief, and flood management policies adequate?

4.2 Findings

The area of Mayong, located 40km from the capital city of Guwahati in the Morigaon district, was selected as a case study due to its proximity to the river, as well as due to its interesting cultural background, historically considered the cradle of *Tantra Kriya* (black magic) in India, and today home to several backward communities. The "*gaon buras"* or headman of nearby villages, as well as forest officials of Pobitora Wildlife Sanctuary were interviewed. These testimonies are summarized in the following subsections.

4.2.1 Devastating impact of early floods and excess rainfall on the agricultural cycle

This year's floods have been particularly devastating for farmers. By mid-May, the region experienced high levels of flooding, and this is significantly sooner than the 'normal' cycle of floods which generally arrive around mid-June. The intense and early flood waves damaged paddy and maize crops severely and very little of this harvest could be recovered. Even the limited amounts of crops that were saved could not be dried properly due to heavy and continuous rainfall experienced in May and June (Fig 7). Furthermore, the more well-off farmers did not have access to labor who used to carry out the task of harvesting due to the early arrival of floods.

Fig 7: Extent of flooding (right) destroyed crops [Photos taken during field visits]

Economically, this year's floods are expected to bring severe hardship to cultivators since the "Boro" crop cycle (harvested before monsoons) is the most important harvest. The headman and other villagers were particularly distressed since farmers are concerned about paying back loans they had taken for agricultural purposes. In other words, they are worried about greater levels of indebtedness due to the floods.

In terms of government relief measures, the headman noted that they did not expect the government to ensure any substantial material help to overcome the damage caused by floods. However, he noted the help provided by the Prime Minister's Kisan Yojna to farmers in his village.

The villages have also seen deteriorating prospects for agriculture over the decades. Apart from the shortage of economically viable land holdings due to the increase in population, the flood and erosion problems have also made agriculture less sustainable. The impact of this can be seen in the increasing trend towards outmigration. As much as 40% of the youth of the village were reported to have migrated out to distant places like Kerala in search of jobs.

4.2.2 Embankment construction

One of the villages was also witnessing the construction of an embankment which was being viewed with mixed feelings. On one hand, villagers would welcome keeping flood waters away even as they are wary of the devastation that breeches in embankments might bring about.

4.2.3 Concerns about dam water release

The villagers shared concerns about the impact of dam water release from the Kopili Hydro-Electric Dam run by NEEPCO in the upstream region. The villagers speculated that unseasonal rainfall and dams were behind the early and devastating floods experienced this year. The villagers noted that they relied on news channels and other media sources for information on floods. They did not receive early warnings on floods from government authorities and depended on print and visual media to get information, including on the impact of dams on downstream communities.

4.2.4 Impact on wildlife and preservation of nature

Forest officials at Pobitora Wildlife Sanctuary shared challenges in protecting animals during flood conditions. During floods, most of the patrolling work had to be done via the use of boats. One of the biggest challenges during floods is managing the movement of animals. During floods, animals move out of the core zone into higher grounds in nearby regions outside the wildlife reserve. However, movement into certain areas brings them into conflict with human settlements. Much like Kaziranga, Pobitoira's ecology and wildlife movement connect low-lying flood plains and hill areas.

The officials also underlined the importance of flood events for maintaining the vitality of Pobitora's ecology. They noted that the absence of extensive embankments has had a positive impact on the flood situation as it [23] allowed water to move freely in and out of the park.

The park officials shared concerns over the role of deforestation, particularly in exacerbating flood surges. They noted that deforestation in nearby hill regions like Karbi Anglong and NC hills contributed to unseasonal flash floods. They also discussed the possible negative role played by dams and called for better flood warning systems.

5. DISCUSSION

Although initiatives such as FLEWS have been shown to be effective towards flood preparedness since its inception in 2009, the highly destructive 2022 floods, considered unprecedented due to the unpredictability in the location, duration, and quantity of flooding, have shown how challenging it can be to develop an early warning system especially considering the current climate crisis.

Furthermore, as the FLEWS is not a community-based early water system, and the alerts are disseminated by ASDMA to the revenue circle administration rather than the flood-affected individuals to avoid generating chaos. Thus, effective last-mile communication is still dependent on the local machinery. Indeed, as the most flood-affected part of the population are the poorest and most marginalized people, as FLEWS is a flood warning and prevention system, the effectiveness of damage control due to warnings disseminated even 48 hours in advance is to be pondered on. It is further challenging for FLEWS to generate alerts with actionable lead-time in smaller basins.

One of the main complexities of the Brahmaputra river system is that it is purely sedimentation-based. The flooding is not due to over-topping but due to breaching. Furthermore, this means that the flooding becomes a probabilistic problem, depending on the probability of a breach, is not a deterministic problem, which makes it challenging to model mathematically. The river is also very dynamic, and flooding pattern is different each year. All these factors have to be kept in mind while devising a prediction model.

6. CONCLUSION

The flood-affected northeast Indian state of Assam was highlighted, with a focus on the extreme nature of rainfall events and subsequent damages caused in the year 2022. Important factors that explain the damaging nature of these floods were presented, spanning not just topographic, climatic, and fluvial patterns, but also social and ecological transformations, government policy and especially effects due to climate change. The GIS-based Flood Early Warning System, developed by NESAC (ISRO), its impact and challenges have been presented. Finally, local narratives from the area of Mayong and nearby Pobitora National Park were presented, to understand the perceptions and experiences of local communities and forest officials due to damaging floods.

7. FUTURE PROSPECTS

One of the next phases for this project would involve conducting an outreach program on flood awareness in remote flood-affected villages in Assam, made challenging in the current year due to the devastating floods. This would be followed by the assessment of the impact of a more educated workforce in future high-flood years.

Some project collaborations with other agencies are also under negotiation which could potentially fund comparative strategy studies in other flood-prone areas in other countries, as well as education and outreach programs, with the final objective to be able to propose policy briefs towards more effective flood management in Assam. One of the main challenges of setting up field-based projects remains gaining of statutory clearances and approvals.

With respect to FLEWS, several pilot projects are under way which would be studied via this project. There are further ideas of incorporating IOT-based community early-warning systems. There is also a need to continue looking for innovative methods that could tackle the complexity modelling of the Brahmaputra river system (as mentioned in discussion).

Finally, one of the main challenges highlighted by this research first challenge is the need to bridge the gap between existing technologies and their accessibility by the poorest (often uneducated) population. This brings to light the importance of involving crossdisciplinary approaches towards the development of engaging ways in making these technologies accessible to the local communities, a human-centred approach which falls under the umbrella term of “design thinking for social innovation”, a fairly new field especially in a context such as Assam. Setting up of such a system will also work as a feedback mechanism for the technology to improve iteratively.

8. ACKNOWLEDGEMENTS

This research would not have been possible without the support of officials from several government and private agencies such as NESAC, AWRD and ISRO. Sincere thanks to the Karman Project for their commitment initiative and Impact Fund that helped propel this project. A special mention to Alina Vizireanu, Roshni Sharma and Dr. H Bhoosnurmath for their insights.

9. REFERENCES

[1] B. Tellman, J. Sullivan, C. Kuhn, K. A. J., C. S. Doyle, G. R. Brakenridge, T. A. Erickson and D. A. Slayback, "Satellite imaging reveals increased proportion of population exposed to floods," *Nature,* vol. 596, pp. 80-86, 05 August 2021.

[2] S. Hallegatte, A. Vogt-Schilb, M. Bangalore and J. Rozenberg, Unbreakable : Building the Resilience of the Poor in the Face of Natural Disasters, World Bank, 2017.

[3] C. Mahanta, "State of India's River for India River's Week, 2016: Brahamputra," 2016.

[4] NITI Aayog, "SDG," 2016.

[5] A. Saikia, The Unquiet River: A Biography of the Brahmaputra, New Delhi: Oxford University Press, 2019.

[6] D. J. Borgohain, "And Quiet Flows the Mahabahu (Part-I)," *Northeast Now,* 14 May 2019.

[7] Sumeda, "Explained: Assam's Annual Tryst with Devastating Floods," *The Hindu,* 25 June 2022.

[8] Water Resources Government of Assam, "Flood and Erosion Problem," [Online]. Available: https://waterresources.assam.gov.in/portlets/flood-erosion-problems. [Accessed 1 September 2022].

[9] "Assam Exeperienced Worst Floods in Terms of Fatalities," *The Hindu,* 16 July 2022.

[10] G. Singh, "Life Gate," 6 August 2022. [Online]. Available: https://www.lifegate.com/flooding-in-assam-has-caused-a-devastating-loss-of-life-and-livelihoods. [Accessed 1 September 2022].

[11] U. Parashar, "Assam Flood Loss May be Around 1000 Crore: Offical," *Hindustan Times* , 13 July 2022.

[12] A. Songloma, S. Prasad and A. Dhar, "Not Just Another Deluge," *Down to Earth,* pp. 26-42, 16-31 July 2022.

[13] Asian Development Bank, "India: Preparing the North-East," Asian Development Bank.

[14] N. a. D. P. Vagholikar, "Damming North-East India: Juggernaut of Hydropower Threatens Social and Environmental Security of the Region," Palpavirksh, Action Aid India and Aranyak, 2010.

[15] N. Smith, "There's No Such Thing as a Natural Disaster," 11 June 2006. [Online]. Available:

https://items.ssrc.org/understanding-katrina/theres-no-such-thing-as-a-natural-disaster/. [Accessed 1 September 2022].

[16] D. J. Borgohain, "Assam Floods: The Annual ‘Tandava’ of the Brahmaputra (Part-III)," *Northeast Now,* 3 June 2019.

[17] D. J. Borgohain, "The Inexplicable Mahabahu Brahmaputra (Part-II)," *Northeast Now*, 28 May 2019.

[18] R. D’Souza, Drowned and Dammed: Colonial Capitalism and Flood Control in Eastern India, Oxford University Press, India, 2006.

[19] Directorate of Char Area Development, Government of Assam, [Online]. Available: https://dircad.assam.gov.in/about-us/history-0. [Accessed 1 September 2022].

[20] Global Forest Watch, "Tree cover loss in India / Assam," University of Maryland, 2021. [Online]. Available: https://www.globalforestwatch.org.

[21] P. J. Das, "Conflicts over embankments on the Jiadhal River in Dhemaji District, Assam," in *Water Conflicts in Northeast India*, University of Oxford: Routledge India, 2018.

[22] R. Karmakar, "In Assam, A Trail of Broken Barriers," *The Hindu*, 02 August 2020.

[23] D. J. Borgohain, "Options to Placate the Tandava of the Mightly Son of Brahma (Part IV)," *North East Now*, 20 June 2019.

[24] Climate Research and Services, Indian Metrological Department, "Climate Summary Report," Ministry of Earth Sciences, Govt. of India, Pune, June 2022.

[25] M. K. Roxy, S. Ghosh, A. Pathak, R. Athulya, M. Mujumdar, R. Murtugudde, P. Terray and M. Rajeevan, "A threefold rise in widespread extreme rain events over central India," *Nature Communications*, vol. 8, 03 October 2017.

[26] Department of Science and Technology, Government of India , "Climate Vulnerabiity Asessment for Adaptation Planning in India: Using a Common Framework," 2020.

[27] V. Bhanumurthy, P. Manjusree and G. S. Rao, "Flood Disaster Management," in *Remote Sensing Applications*, National Remote Sensing Center (NRSC), 2010.

[28] H. S. Munawar, A. W. A. Hammad and S. T. Waller, "Remote Sensing Methods for Flood Prediction: A Review," *Sensors*, vol. 22, no. 3, 2022.

[29] "Flood Early Warning System - Best Practice," Assam State Disaster Management Authority (ASDMA).

[30] D. Barman, S. S. Kundu, J. Goswami, R. Das, N. Singh, A. Borgohain, R. B. Gogoi, V. Saikhom, S. B. Bora and S. Sudhakar, "Operational Flood Early Warning System (FLEWS) - A geospatial and hydro-met approach as developed by NESAC for Govt. of Assam," in *13th Esri India User Conference*, 2012.