Brahmaputra water conflict and vulnerability of the stakeholders in North- East

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Abstract

The Brahmaputra River is a vital source of economic, social, and environmental benefits; however, its transboundary nature has led to geopolitical tensions between India and China particularly over upstream dam construction increasing the vulnerability of the local population in the North-East. The effects of China's dam construction on the Brahmaputra raise concerns about the downstream water flows to the North-East of India and increased floods during the monsoon seasons. The problem of water scarcity and water shortage due to dam construction intensifies, due to the conflict hampering the livelihood of the people living in the lower riparian region of India, namely, the North-East states. Under the circumstances, this study looks at the vulnerability of the people along the Brahmaputra River in India, by dividing the region into three zones, namely the upper riparian consisting of the region of the state of Arunachal Pradesh near the Chinese border and middle and lower riparian, consisting of the regions in the State of Assam. A primary survey of the households of the three regions was conducted to assess the livelihood vulnerability of the people using Livelihood Vulnerability Index (LVI). A total of 450 households were surveyed randomly from 12 villages of 3 districts of upper, middle and lower riparian from the two states.

The LVI assessment includes ten major components, and each major component includes several indicators, which were developed based on the review of literature, expert advice and field analysis. The results showed that among all the indicators, the highest indexed value of the socio-economic component was 0.44 for the community living in the lower riparian region, and the lowest value was 0.27 in the upper riparian region. Similarly, the indexed value of the water resource component was the highest (0.52) of the community living in the lower riparian. Lastly, the study also calculates the risk of flood occurrence. The sensitivity, adaptive capacity, and exposure value were highest around (0.64) of the community living in the lower riparian. This indicates that the community living in the downstream area was the most vulnerable compared to the upstream region.

Keywords: Vulnerability, Adaptive Capacity, Exposure, Sensitivity, Flood

Introduction

The Brahmaputra River Basin is one of the largest river basins in South Asia, with an annual discharge of approximately 700 billion cubic meters (BCM) and a total drainage area of around 580,000 square kilometres. The river originates in the Tibet Autonomous Region of China shown in fig 1, where it is known as the Yarlung Zangbu, and flows for about 1,700 kilometers through Chinese territory. It then enters India, flowing for approximately 918 kilometers under the name Brahmaputra, before continuing into Bangladesh as the Jamuna (later merging with the Padma River) for around 337 kilometers (Barua et al., 2025). The Brahmaputra River serves as a vital lifeline for the Northeastern region of India, offering a range of economic, social, and environmental benefits, including hydropower generation, irrigation potential, and inland water navigation. However, emerging transboundary water conflicts, particularly between India and China, pose significant challenges to the sustainable management of this river system. The construction of dams by China on the upper reaches of the Brahmaputra (known as the Yarlung Tsangpo in Tibet) has raised serious concerns regarding the regulation of downstream water flows, especially in the context of increasing flood frequency and intensity during the monsoon season. These apprehensions are further exacerbated by the limited hydrological data sharing between China and India, which hampers timely flood forecasting and risk mitigation efforts. Additionally, dam-induced changes in river flow regimes contribute not only to seasonal water scarcity but also threaten the livelihoods of communities dependent on the river, particularly in the lower riparian zones. In this context, the present study investigates the livelihood vulnerability of populations residing along the Brahmaputra River in India. For analytical clarity, the region is categorised into three zones: the upper riparian zone, encompassing parts of Arunachal Pradesh adjacent to the Indo-China border; the midstream zone, comprising central Assam, i.e Lakhimpur; and the lower riparian zone, primarily consisting of western Assam districts such as Dhubri. This zonal framework allows for a comparative assessment of vulnerability patterns shaped by both environmental and geopolitical pressures. Communities residing in both hilly and lowland areas of Northeast India are increasingly affected by recurrent annual flooding. In particular, the Brahmaputra River, one of the largest transboundary rivers in South Asia induces frequent flash floods that severely impact the middle and lower regions of Assam during the monsoon season, typically from June to September. These natural flood events are further exacerbated by anthropogenic interventions, notably the construction of artificial dams in the seismically active zones near Arunachal Pradesh. The presence of such dams in earthquake-prone areas raises the risk of sudden water releases, contributing to intensified downstream flooding. This compounded flood risk results in widespread disruption and damage to the livelihoods and infrastructure of riparian communities, amplifying their vulnerability. This research paper examines the impacts of flooding and inundation on livelihoods across the upper, middle, and lower riparian zones of the Brahmaputra River, employing the Livelihood Vulnerability Index (LVI) as the primary analytical framework.

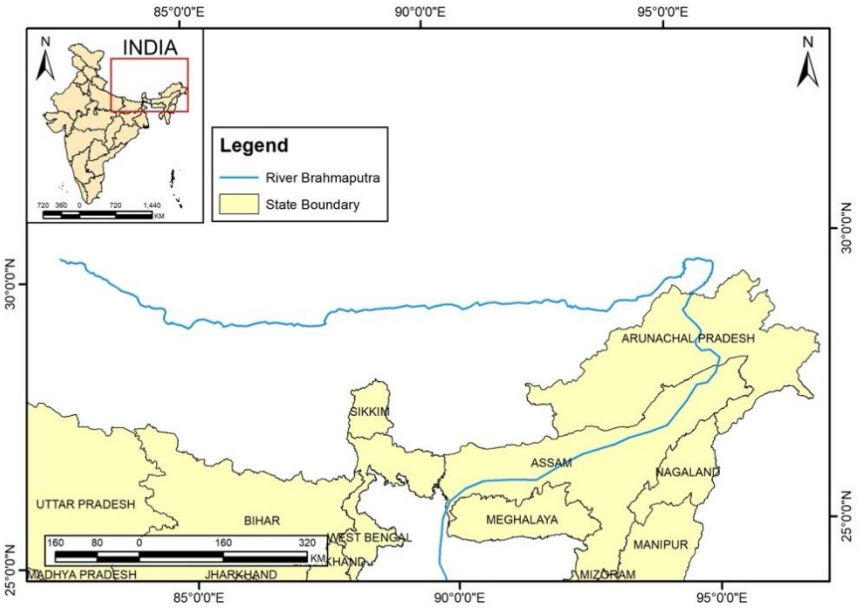


Fig 1- Flow of Brahmaputra River

Source- Author's own creation

Materials and Methods

Choice of States, District, Blocks and Villages

While conducting the study and field survey along the Brahmaputra River, the survey area was divided into three belts: Upper riparian, middle riparian, and lower riparian, as they are the most susceptible zones to flood. Based on purposive sampling, we chose the states and the districts. In our study, we have aimed to use both analytical and descriptive research. We have chosen three districts from the two states, Arunachal Pradesh and Assam; from 3 districts, one block has been taken which is nearest to the Brahmaputra River bank and more prone to floods using ASDMA and SDMA reports, 2023 and 2024. Arunachal Pradesh is an upper riparian, so we have chosen East Siang district; there is a total of 8 blocks in East Siang district and out of 8 blocks, we have taken the Namsing block. And from Assam, we have considered North Lakhimpur a middle riparian belt. In North Lakhimpur district, there are nine blocks, out of which one development block has been taken, which is very much affected as a riverine district, i.e., Telahi Block. Dhubri districts have been considered as lower riparian districts for the study. There are eight blocks in Dhubri district; out of 11 blocks, we have considered the Gauripur Block for the survey.

Table 1- Descriptive Statistics

S. N.	Characteristics	Upper Riparian (Arunachal Pradesh: Namsing Block)	Middle riparian (North Lakhimpur: Assam)	Lower Riparian (Dhubri: Assam)	Total
1	Total No. of households surveyed	150	150	150	450
2	Average age of household	41	49	57	
2	Average family size of household	5.3	5.2	5.69	
3	Average area of agricultural land	25	7.42	2.6	
4	Average Agricultural Income	50853.3	53808	23745.7	
5	Average Non-agricultural income	98482.55	168074.1867	157636.9	
6	Total average income	149335.8	221882.18	181382.6	
7	Average debt of household	2673	7560	10893.3	
8	Average no. of annual floods	5	5.95	6.2	

- Average age of household heads increases downstream. In upper riparian it was found 41years, 49 years in middle and 57 years in lower riparian. Average family size is fairly similar across regions, ranging from 5.2 to 5.69 members per household**.**
- The average area of agricultural land shows a sharp decline as one moves downstream: 25 units (possibly acres) in the Upper Riparian, 7.42 in the Middle Riparian, and just 2.6 in the Lower Riparian. This highlights the reduction of cultivable land in lower regions.
- A similar trend is reflected in agricultural income, which is highest in the Middle Riparian (₹53,808), slightly lower in the Upper Riparian (₹50,853.3), and significantly lower in the Lower Riparian (₹23,745.7). This decline correlates with the shrinking agricultural land area downstream.
- Non-agricultural income dominates household earnings in all three regions. The Middle Riparian households earn the most (₹168,074.19), followed by Lower Riparian (₹157,636.9), and then Upper Riparian (₹98,482.55). Because of the high flood occurrence in the lower and middle riparian of Brahmaputra river people generally tries to engage in non-agricultural income. From the primary survey[1] it was found that people was engaging in security guard's, hospitals, shops etc.
- Consequently, the total average income is highest in the Middle Riparian (₹221,882.18), followed by the Lower Riparian (₹181,382.6), and lowest in the Upper Riparian (₹149,335.8). This suggests that while agricultural opportunities shrink downstream, households rely increasingly on non-agricultural sources of income.
- The average debt per household increases from upstream to downstream: ₹2,673 in the Upper Riparian, ₹7,560 in the Middle Riparian, and a significant ₹10,893.3 in the Lower Riparian. This indicates that households in lower regions are more financially burdened, possibly due to higher vulnerability and reduced agricultural security.

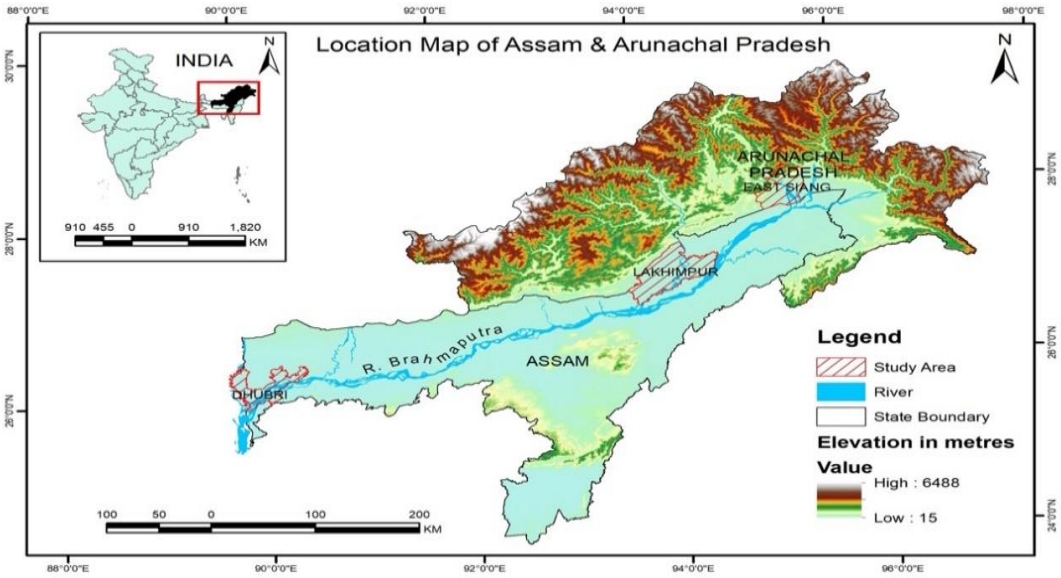


Fig 2- Study Area

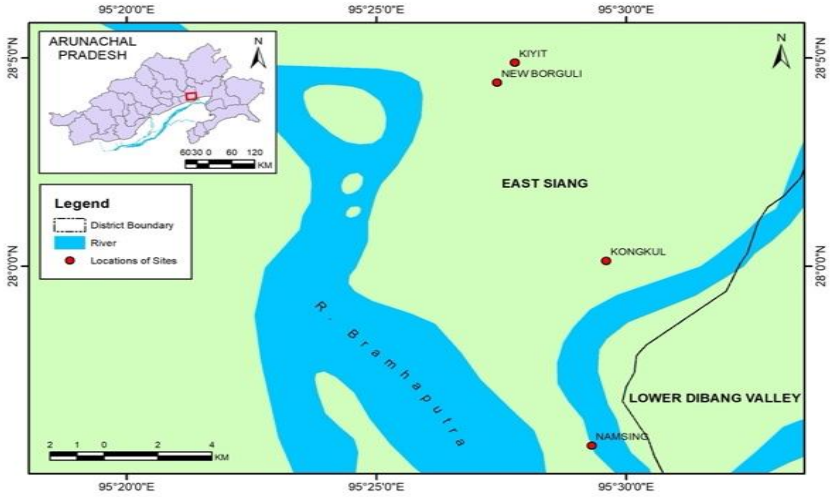


Fig.3- East Siang District of Arunachal Pradesh

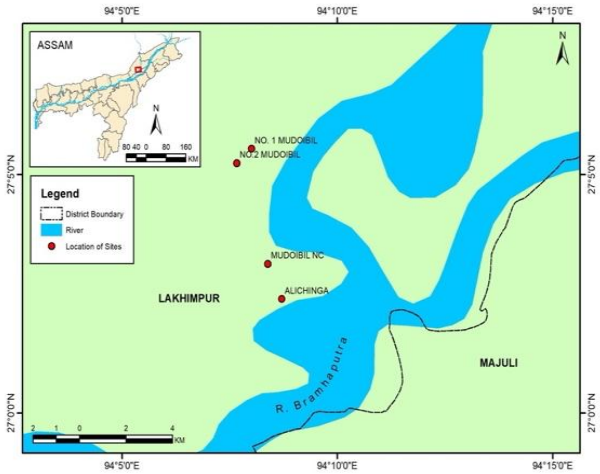


Fig.4- Lakhimpur District of Assam

The East Siang district, located in the state of Arunachal Pradesh, spans an area of approximately 4,005 square kilometers. Geographically, it lies between latitudes 27°03' and 29°42' North and longitudes 94°42' and 95°35' East. While the district is predominantly mountainous, it also includes flat lowland areas at the foothills, which merge into the Brahmaputra Valley of Assam. More than half of the households in the region rely primarily on agriculture, cultivating crops such as paddy, maize, millet, and mustard (Indiastat district agri). However, during mid-2024, severe flooding from the Siang River caused significant damage in areas like Mer, Namsing, and Borguli (Arunachal Observer, 2024). Over 200 hectares of paddy fields were inundated, leading to soil erosion and posing a serious risk of rice shortages in the area. Several settlements, including Naming, Kongkul, New Bornuli, and Kyit, are at potential risk of being submerged or displaced due to the planned dam construction (Times of India, 2025). Given their high exposure to potential submergence from proposed dams, these villages were selected as key sites for primary survey shown in fig 3. These communities not only face the threat of losing their land but also the erosion of traditional livelihoods and cultural heritage tied closely to the river ecosystem.

Lakhimpur district, situated in the Indian state of Assam, has its administrative centre at North Lakhimpur town. It is geographically positioned at approximately 27°95'N latitude and 80°78'E longitude. Lakhimpur is bounded on the north by Lower Subansiri and Papumpare districts of Arunachal Pradesh and on the east by Dhemaji district and the Subansiri River. The district comprises 2 subdivisions, namely Sadar and Dhakuakhana. And among them, 7 were Revenue circles and 9 development blocks. Among them, we have chosen the Telahi block (ASDMA report). Around 13.64% of the district's total land area is under forest cover. The primary languages spoken include Assamese, Mishing (Miri), and Bengali. The district's economy is predominantly agriculture-based, with nearly half of the population engaged in farming-related activities for their livelihood. The major crops cultivated in the region include rice, tea, mustard, and sugarcane. (extracted from Indiastat district agri). The Subansiri River, a significant tributary of the Brahmaputra, has triggered intense riverbank erosion in settlements such as No. 1 and No. 2 Mudoibil. In May 2025, authorities conducted an erosion assessment in the Pub Telahi Gaon Panchayat and raised concerns that approximately a dozen villages including those in Mudoibil, were at imminent risk of collapse unless urgent mitigation steps were implemented.

Dhubri district is bounded by interstate and international borders, primarily West Bengal and Bangladesh in the west, Goalpara & Bogaigaon in the east, Kokrajhar district in the north, and South Salmara Mankachar district and the state of Meghalaya in the south. The district lies between 89.42° to 90.12° east longitude and 25.28° to 26.22° north latitude, with an average elevation of approximately 30 meters above sea level. There are total of 8 revenue circles- Dhubri, Gauripur, Golakganj, Agomani, South Salmara Pt., Athani, Billasipara, Chapar (Government of Assam, 2024). Gauripur block has been chosen the study area among others. It suffers recurrent and severe flooding owing to swelling of rivers like the Gadadhar, Tipkai, and Brahmaputra. The socio-economic condition is seen as fragile over the years. Agriculture is the primary source of income, but frequent inundation and sand siltation have rendered formerly fertile fields uncultivable. In recent years, over 2,500 hectares of cropland, including winter (Sali) paddy and jute, were submerged, causing devastating damage to farmers' fields and yielding serious livelihood uncertainty (IndiaTodayNE, 2024). Mainly, farmers grow Sali rice, Boro rice, vegetables such as Brinjal, Luffa, Ridge Gourd, Yardlong beans and black-eyed peas during the flooded seasons.

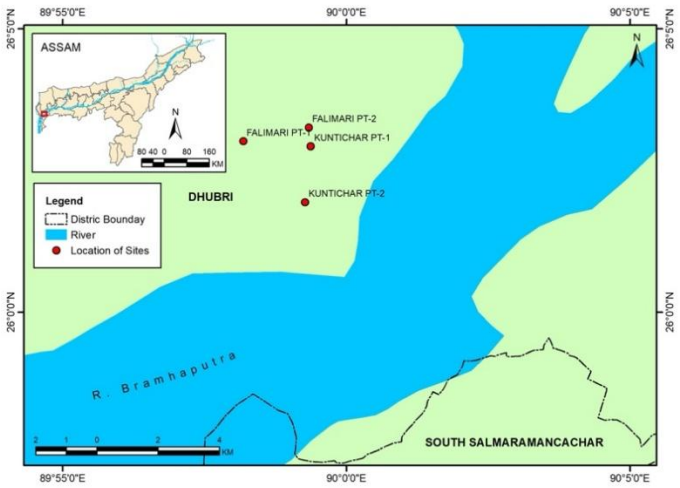


Fig.5- Dhubri District of Assam

Methodology

The field study was conducted in three stages: the pilot survey was conducted in May, i.e., pre-monsoon 2023, in the two districts of Assam and Arunachal Pradesh. Another survey was done post-monsoon in October 2023 in the two states to understand the community's vulnerability to floods and determine the indicators and the sub-components to compute the Livelihood Vulnerability Index (LVI). The final field survey was conducted from January to July 2024. The primary data were collected through household surveys, which were conducted based on random stratified sampling, for comparative analysis of the livelihood Vulnerability Index (LVI) of flood-prone zones near the river Brahmaputra's banks. A total of 450 households have been selected. From each village, 10% of households were selected for field data collection. A total of 12 villages from 3 districts and two states were taken. The information about the number of households in the randomly selected riverine villages is obtained from the officially allotted headman of the village (locally known as 'Gaon Burha') and from India Village Data. During the field study and survey, gender perspective and equal participation were kept in mind. The study area and the number of households are shown in Table 1.

Methods of measuring LVI

Among the various tools available for assessing vulnerability, the Livelihood Vulnerability Index (LVI) and the LVI-IPCC are among the most widely applied. In the riverine basin regions, researchers commonly utilize the LVI, LVI-IPCC, and the Climate Vulnerability Index (CVI) to evaluate the vulnerability of local communities (Saikia et al., 2024). Researchers commonly employ three primary indices to assess vulnerability: the Livelihood Vulnerability Index (LVI), the LVI-IPCC, and the Climate Vulnerability Index (CVI). Among these, the CVI is considered a more recent advancement or refinement of the original LVI framework. The above three indices are based on IPCC (2001) definition of vulnerability. According to the IPCC (2001), vulnerability is conceptualized as a function of three key elements: exposure, referring to the degree to which a system experiences climatic hazards; sensitivity, which denotes how significantly a system is impacted by those climatic stresses; and adaptive capacity, indicating the system's ability to adjust, mitigate potential damage, or manage the resulting impacts. However, the IPCC (2014) definition on vulnerability refers to the propensity or predisposition to be adversely affected. Here, Exposure is treated as a separate component of risk, along with hazard and vulnerability. The Livelihood Vulnerability Index (LVI) is structured to evaluate vulnerability by incorporating a range of dimensions, including demographic factors, health conditions, food and water security, access to natural resources, and the strength of social networks. This comprehensive framework enables it to effectively capture the multifaceted impacts of flooding on communities (Hahn et al., 2009). he Livelihood Vulnerability Index (LVI) is commonly applied in region-specific analyses to assess and compare vulnerability levels across different geographic zones, making it well-suited for evaluating variations among the upper, middle, and lower flood-prone areas of Assam (Saikia et al., 2024).

The Livelihood Vulnerability Index (LVI) was developed by Hahn et al., (2009) based on definition of IPCC (2001).

LVI- *f*(exposure, sensitivity, adaptive capacity).

Present study of IPCC (2021) considers LVI- *f*(sensitivity, adaptive capacity) to construct ALVI (Adjusted Livelihood Vulnerability Index).

Category of major components outlined below-

Exposure- Natural Hazards and Climate Variability

Adaptive Capacity- Socio-Demographic Profile, Livelihood Strategies, Social Networks, Financial Aspects, Physical Structure and Facilities.

Sensitivity- Health, Food, Water, Forest.

Adjusted Livelihood Vulnerability Index (ALVI) using added components and sub-components

The ALVI includes nine major components: Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Financial Aspects (FA), Physical Structure and Facilities (PSF), Health (H), Food (F), Water (W), Forest (F). Each of the components has several sub-components, which are developed based on the review of the literature and field analysis (Shreevastav et al., 2021). All the components were given equal weights. As all the components were measured on a different scale, it was first standardised for comparability as an index (Hahn et al., 2008). The equation for standardizing the numerical values was developed from the Human Development Index- HDI:

$$\text{Index S} = \frac{S - S_{min}}{S_{max} - S_{min}} \quad \text{-----(1)}$$

Where, S= Original sub-component, S_{max} & S_{min} = maximum and minimum values reflecting low and high vulnerability. The standardised sub-components were averaged to establish an index for each major component of vulnerability, i.e.

$$M_i = \frac{\sum_{i=1}^{n} indexS_i}{n} \quad \text{---------(2)}$$

Here, M_i = One of the ten major components. S_i = sub-components, indexed by i.n = number of subcomponents in each major component. Following the calculation of values for each of the ten primary vulnerability components for a site, an equation was used to average them.

$$ALVI = \frac{\sum_{i=1}^{n} W_{mi}\ M_i}{\sum_{i=1}^{10} W_{mi}} \quad \text{----------(3)}$$

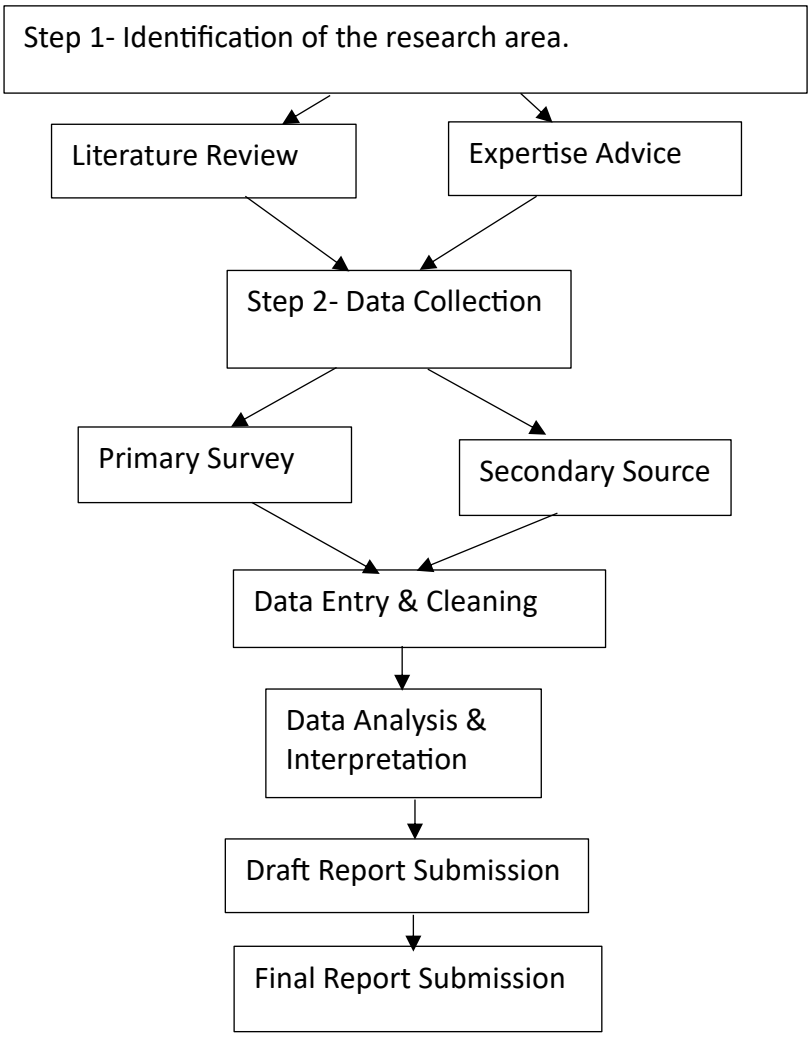
which can be expressed as

$$ALVI = \frac{W_{sdp}SDP + W_{LS}LS + W_{SN}SN + W_{FA}FA + W_{PSF}PSF + W_{H}H + W_{F}F + W_{w}W + W_{FR}FR + W_{NDCV}NDCV}{W_{SDP} + W_{LS} + W_{SN} + W_{FA} + W_{PSF} + W_{H} + W_{F} + W_{W} + W_{FR} + W_{NDCV}}$$

where, ALVI= Adjusted Livelihood Vulnerability Index, W_{mi} = Weights of each major components, Mi= Each major component.

To guarantee that every sub-component contributes equally to the total LVI, the weights of each significant component, Wmi, are established by the number of sub-components that comprise each significant component (Shreevastav et al., 2021). In this study, the LVI was scaled, ranged from 0 to 1. If it is near 0 (Least vulnerable) and 1 (most vulnerable). The whole study was done using primary data sources, except the temperature and the precipitation data (Indiastat).

Research flow chart-



Statistical Analysis

The data analysis was carried out after coding the questionnaire in an Excel sheet and Stata. In the analysis, the data were collected from two different states (Assam and Arunachal Pradesh) under which three different districts were taken from three different streams (Upper stream, Middle stream and Lower stream) based on 9 major components along with sub-components. The major components, namely- Socio-demographic Profile (SDP), Livelihood aspects (LA), Social Networks (SN), Financial Aspects (FA), Physical Structure & Facility (PSF), Health (H), Food (F), Water (W), Forest (FO).

Major components and sub-components developed

Major Component	Sub-component	Original Source
Socio-demographic profile (SDP)	Working age (<15 & >65 years)	Hahn et al, 2009
	% of female-headed households	Hahn et al, 2009
	% of households where head of HHs has not attended school	Hahn et al, 2009
	% of earnable members	Author's own, based on field survey
	% of earning members staying outside	Hahn et al, 2009
	Family size	Shreevastav et al, 2021
Livelihood Strategies (LS)	% of HHs dependent solely on Agri as a source of income	Hahn et al, 2009
	% of HHs dependent on non-farm income	Hahn et al, 2009
	% of HHs with no training to enhance livelihood	Shreevastav et al, 2021
	% of HHs who has not changed their cropping pattern (BORO, KHARIF, RABI)	Revised from, Shreevastav et al, 2021
	% of HHs reported loss of livestock (BORO)	Shreevastav et al, 2021
	% of HHs reported loss of livestock (KHARIF)	Shreevastav et al, 2021
	% of HHs reported loss of livestock (RABI)	Shreevastav et al, 2021
Social Network Component (SN)	% of HHs that haven't gone to their local government for assistance in past 12 months	Hahn et al, 2009; modified by Shah et al, 2013; Shreevastav et al, 2021
	% of HHs not receiving helps due to flood	Shreevastav et al, 2021
	% of HHs that have not been member of any organisation	Shreevastav et al, 2021
	% of HHs have no communicative devices	Shreevastav et al, 2021
Financial Aspects (FA)	Average Borrowings	Shreevastav et al, 2021
	% of HHs taken Debt from Banks	Modified from Shreevastav et al, 2021
	% of HHs taken Debt from Relatives	Modified from Shreevastav et al, 2021
	% of HHs taken Debt from Mahajan's	Modified from Shreevastav et al, 2021
	% of HHs taken Debt from SHG	Modified from Shreevastav et al, 2021
Physical Structure & Facility (PSF)	% of HHs having Katcha house 1	Modified from Shreevastav et al, 2021
	% of HHs having Pakka house 2	Modified from Shreevastav et al, 2021
	% of HHs having Katcha & Pakka house 1 & 2	Modified from Shreevastav et al, 2021
	% of HHs with house affected by floods	Shreevastav et al, 2021
	% of HHs whose land is damaged by flood	Shreevastav et al, 2021
	% of HHs with no access to road	Shreevastav et al, 2021
	% of HHs without property insurance	Shreevastav et al, 2021
Health (H)	% of HHs having Community Health Care in their area	Hahn et al, 2009
	Average time to the Health Center	Hahn et al, 2009
	% of HHs with family member with chronic illness	Hahn et al, 2009
	% of not receiving proper facilities for Child delivery & Immunization	Shreevastav et al, 2021
	% of households without Health Insurance	Shreevastav et al, 2021
	% of HHs without Sanitary facilities	Shreevastav et al, 2021
	% of HHs where a family member had to miss work in last 2 weeks due to illness	Hahn et al, 2009
Food (F)	% of HHs who are dependent on farm	Hahn et al, 2009
	Average fishing pattern range (1-3)	Author's own, based on field survey
	Average Crop Diversity Index range (>0-1)	Hahn et al, 2009
Forest (FO)	Average time to reach to forest	Shreevastav et al, 2021
	% of HHs not using forest- based energy for cooking purpose	Hahn et al, 2009
Water (W)	% of HHs not reporting water conflicts	Shreevastav et al, 2021
	% of HHs that utilize a natural water source	Hahn et al, 2009
	Average time need to reach the source of drinking water	Hahn et al, 2009
	% of HHs having Govt pumps	Author's own, based on field survey
	% of HHs having water filter	Shreevastav et al, 2021
	% of HHs that do not have a consistent water supply	Shreevastav et al, 2021
	Average number of liters of water stored per households	Hahn et al, 2009
	% of HHs using river water	Author's own, based on field survey

Results

Indexed value of Socio-demographic profile (SDP)- Downstream stakeholders had the highest average LVI value (0.44), while upstream stakeholders had the lowest (0.29). Several factors contribute to this disparity. Based on the sub-components outlined by Hahn et al. (2009) and Shreevastav et al. (2021), key contributors to higher vulnerability include larger family sizes and a higher percentage of household heads without formal education. The primary survey indicated that limited access to formal education in downstream areas is largely due to geographical remoteness, inadequate infrastructure, and the lack of basic educational resources. Additionally, students in these regions often face long commutes to school, which become particularly hazardous during the monsoon season when roads deteriorate significantly.

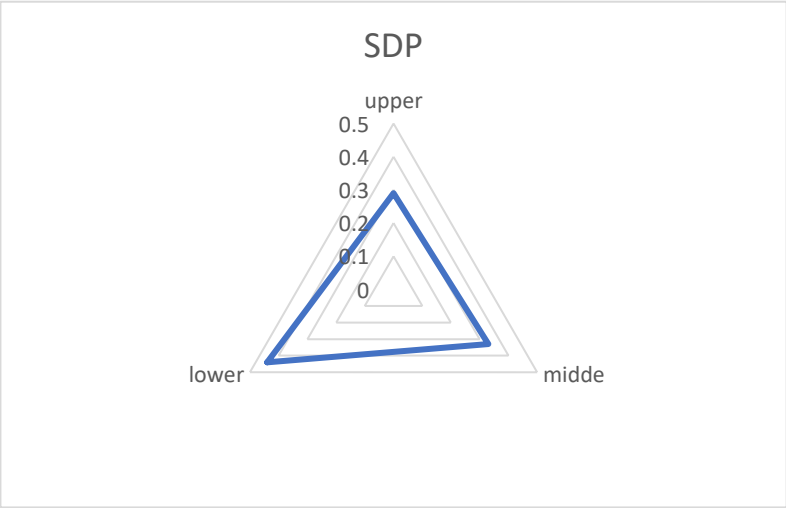


Table 2- Socio-demographic component (SDP)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Socio-Demographic Profile		Value	Index	Average	Value	Index	Average	Value	Index	Average
	Working age (<15 & >65 years)	37.70	0.38	0.29	44.40	0.44	0.33	40.00	0.40	0.44
	% of female-headed households	11.00	0.11		19.30	0.19		16.67	0.17	
	% of households where head of HHs has not attended school	16.00	0.16		48.00	0.48		60.67	0.61	
	% of earnable members	19.00	0.19		38.23	0.38		28.57	0.29	
	% of earning members staying outside	50.00	0.50		24.60	0.25		28.50	0.29	
	Family size	38.00	0.38		25.00	0.25		92.35	0.92	

Livelihood Strategies (LS)- The livelihood-indexed values varied in the communities living upstream, midstream and downstream regions. We have taken seven sub-components for the livelihood aspects, such as the percentage of households solely dependent on agriculture income and who are dependent on non-farm income, reported loss of livelihood in Boro, Kharif and Rabi seasons. The results came interestingly as the three streams have more or less the same amount of vulnerability, i.e. (0.68, 0.64 and 0.73). Here, the communities living in the three streams had limited awareness and livelihood opportunities. Both farm and non-farm income vulnerabilities were found to be primarily in the lower belt, as the lower stream stakeholders faced floods from June to September, resulting in a lower dependency on farming compared to the upper belt. Livestock and animal husbandry are essential components of rural livelihoods in East Siang, Lakhimpur and Dhubri districts. While East Siang is characterised by traditional livestock systems centred around Mithun and pigs, the districts of Assam show larger livestock populations and greater integration with agriculture and commercial production. Arunachal Pradesh hosts more than 90% of India's Mithun population, making it central to tribal livelihoods (ToI, 2025). In Lakhimpur, Cattle, poultry, sheep and goats are the dominant livestock with a basic integration of farming and mixed agriculture

livestock system. And in key characteristics of Dhubri district was found to be a large livestock population and backyard farming (Government of Assam, 2018).

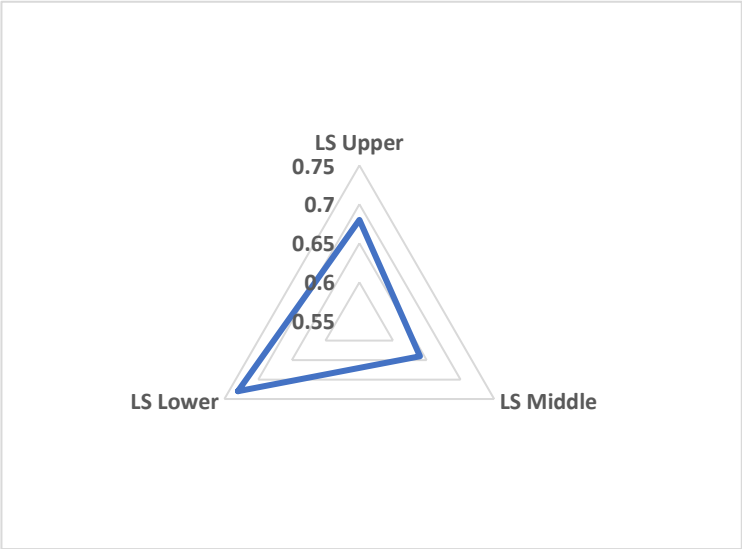
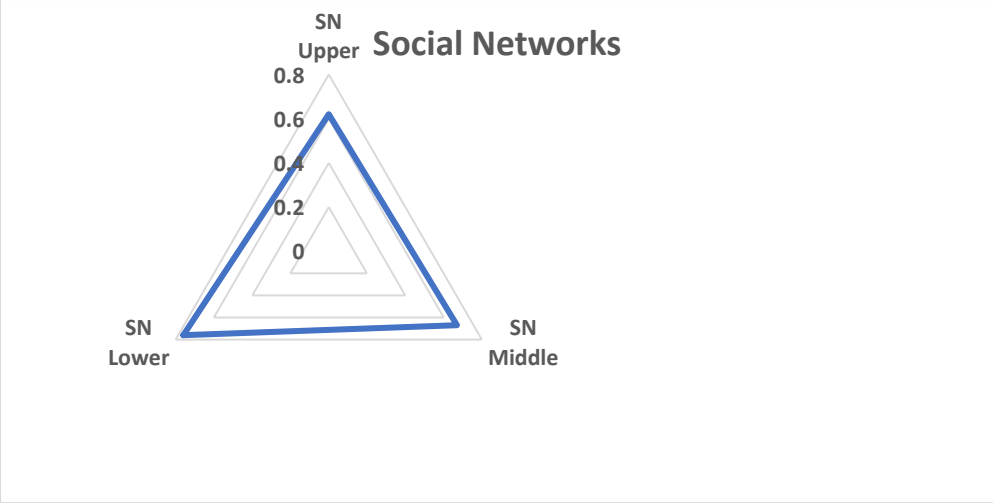


Table 3- Livelihood Strategies (LS)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Livelihood (LS)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs dependent solely on agri as a source of income	99.30	0.99	0.68	84.67	0.84	0.64	59.33	0.59	0.73
	% of HHs dependent on non-farm income	90.67	0.91		97.33	0.97		97.33	0.97	
	% of HHs with no training to enhance livelihood	0.00	0.00		69.00	0.69		100.00	1.00	
	% of HHs who has not changed their cropping pattern (Boro, Kharif, Rabi)	74.00	0.74		100.00	1.00		100.00	1.00	
	% of HHs reported loss of livelihood (Boro)	100.00	1.00		38.67	0.39		14.66	0.15	
	% of HHs reported loss of livelihood (Kharif)	13.00	0.13		24.67	0.25		56.67	0.73	
	% of HHs reported loss of livelihood (Rabi)	100.00	1.00		37.33	0.37		16.00	0.64	

Social Networks (SN)- The social network component also plays a critical role in influencing the Livelihood Vulnerability Index (LVI). This component comprises four key sub-components used to assess social vulnerability. Among these, the highest levels of vulnerability were observed in three specific areas: a significant proportion of individuals had not approached any government organization for assistance in the past 12 months, had not received any form of aid during flood events, and were not affiliated with any formal organization or group. The calculated index values reflect this trend, with downstream stakeholders exhibiting the highest vulnerability (0.76), followed by midstream (0.67), and upstream stakeholders (0.62). Notably, the relatively lower vulnerability among upstream stakeholders can be attributed to their engagement with local non-governmental organizations (NGOs), through which they receive various forms of support. This network-based assistance appears to mitigate their overall social vulnerability when compared to stakeholders in the downstream region.

Financial Aspects (FA)- The most critical component in the assessment comprises five sub-components, and its impact on vulnerability varies across the three river belts. Among them, the downstream region exhibited the highest level of vulnerability (0.12), followed by the midstream (0.10) and upstream regions (0.02). The midstream and downstream areas demonstrate relatively similar levels of vulnerability in this context. Self-Help Groups (SHGs) play a significant role in the lower riparian regions. Frequent and severe flooding in these areas has led to increased levels of indebtedness, making households more vulnerable compared to those in the upper riparian zone, where flood exposure and associated financial burdens are comparatively lower.



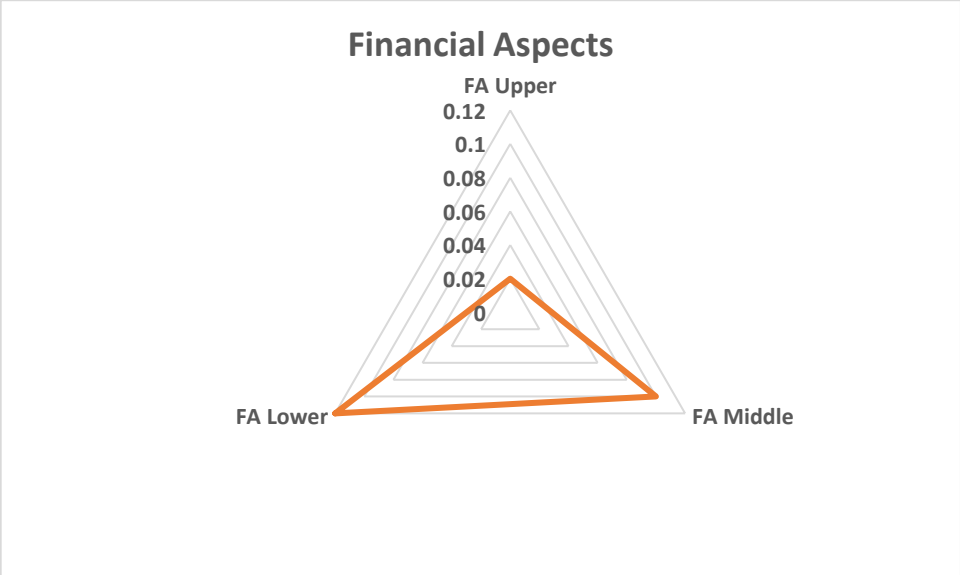


Table 4- Social Networks (SN)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Social Networks (SN)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs that haven't gone their local government for assistance in past 12 months	78.67	0.79	0.62	99.33	0.99	0.33	100.00	1.00	0.44
	% of HHs not receiving helps due to flood	91.33	0.91		99.33	0.99		100.00	1.00	
	% of HHs that haven't been member of any organisation	78.67	0.79		68.66	0.69		100.00	1.00	
	% of HHs have no communication devices	0.00	0.00		2.00	0.38		0.00	0.05	

Table 5- Financial Aspects (FA)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Financial Aspects		Value	Index	Average	Value	Index	Average	Value	Index	Average
	Average Borrowings	2673.33	0.03	0.02	7560.00	0.05	0.10	10893.33	0.07	0.12
	% of HHs taken debt from Banks	0.00	0.00		21.33	0.21		0.00	0.00	
	% of HHs taken Debt from Relatives	8.00	0.08		0.00	0.01		6.00	0.06	
	% of HHs taken Debt from Mahajan's	1.33	0.01		0.00	0.00		14.67	0.15	
	% of HHs taken Debt from SHG	0.00	0.00		21.00	0.21		32.67	0.33	

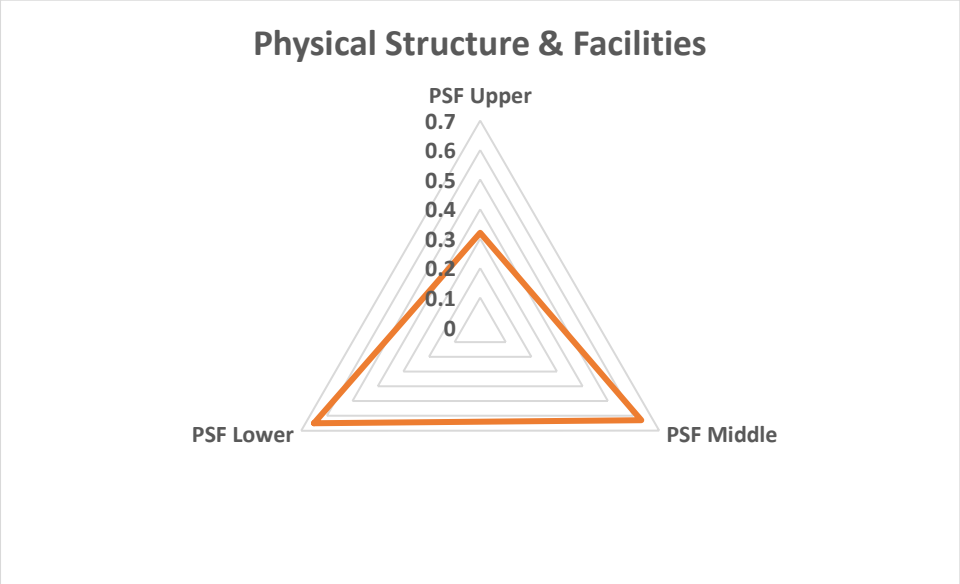


Table 6- Physical Structure & Facility (PSF)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Physical Structure & Facility (PSF)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs having Katcha house 1	34.00	0.34	0.32	86.00	0.86	0.63	96.00	0.96	0.65
	% of HHs having pakka house 2	12.00	0.12		8.00	0.08		4.00	0.04	
	% of HHs having both	54.00	0.54		6.00	0.06		0.00	0.00	
	of HHs with house affected by flood	14.00	0.14		93.33	0.93		95.33	0.95	
	% of HHs whose land is damaged by flood	12.00	0.12		52.67	0.53		56.67	0.57	
	% of HHs with no access to road	0.00	0.00		96.00	0.96		100.00	1.00	
	% of HHs without property insurance	95.33	0.95		100.00	1.00		100.00	1.00	

Physical Structure & Facility (PSF)- The physical structure component of the community was assessed using seven sub-components to calculate the average indexed value. The results indicated that the downstream communities exhibited the highest level of vulnerability in terms of physical infrastructure, with an average index value of 0.65, compared to 0.32 in the upstream region. One of the key contributing sub-components was the

higher percentage of households living in kutcha (non-permanent) houses in the downstream region. In the upstream riparian zone, particularly in the Upper riparian, houses are predominantly constructed using locally available materials such as bamboo, wood, cane, and Toko pata (a type of large leaf). In contrast, in the downstream areas, particularly in flood-prone regions, houses are generally built using sand, clay, and thatch, making them more susceptible to structural damage forcing residents to seek temporary shelter or migrate seasonally. Furthermore, the sloping terrain of the upstream region contributes to faster drainage and lower water retention, which results in relatively less damage to housing structures compared to the midstream and downstream regions, where water stagnation and prolonged inundation are more common (DDMA, 2024). Almost 90% of surveyed roads of lower belt were found to be either severly damaged due to prolonged flooding.

Health (H)- Access to health care services emerged as a significant component in the assessment of the Livelihood Vulnerability Index (LVI). This dimension was evaluated using seven sub-components, including average travel time to the nearest health facility, the presence of community health centers, availability of sanitation facilities, child care services, and immunization coverage, among others. The computed index values indicate that health-related vulnerability is relatively consistent across the three riparian zones, with the upper region recording a value of 0.34, the midstream region 0.36, and the downstream region 0.33. These marginal differences suggest that despite geographic and infrastructural variations, all three regions face comparable challenges in terms of healthcare access and related public health services. However, the slight elevation in the midstream zone may reflect disparities in service delivery or increased dependence on limited facilities under higher population pressure.

Table 7- Health (H)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Health		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs having community Health Care in their area	31	0.31	0.34	14	0.14	0.36	100	1	0.33
	Average time to the Health Centre	17.6	0.25		17.81	0.39		11.8	0.18	
	% of HHs with family member with chronic illness	23	0.23		37	0.37		23	0.23	
	% of not receiving proper facilities for child delivery & 8immunization	68	0.68		85	0.85		7	0.07	
	% of HHs without Health Insurance	4	0.04		8	0.08		2	0.02	
	% of HHs without sanitary facilities	3	0.03		71	0.71		81	0.81	
	% of HHs where a family member had to miss work in last 2 weeks due to illness	0	0		0	0		3	0.03	

Food (F)- Food security constitutes another critical component of the Livelihood Vulnerability Index (LVI), evaluated using three key sub-components: the percentage of household's dependent on farming as a primary livelihood source, the average fishing pattern range (on a scale of 1 to 3), and average crop density (ranging from >0 to 1). The computed index values reveal that the upstream region exhibits the highest level of vulnerability in this dimension (0.48), followed by the midstream (0.38) and downstream (0.35) regions. The heightened vulnerability in the upper riparian zone can be attributed to several interrelated factors. These include limited agricultural productivity due to terrain constraints, reduced crop diversity, and restricted access to aquatic food resources. Furthermore, the geographical and climatic conditions of the upper region, characterised by steep slopes, shallow soils, and limited irrigation infrastructure, pose significant challenges to intensive agriculture. The frequent occurrence of natural hazards such as landslides and earthquakes in the upper belt further exacerbates the fragility of food security by disrupting farming cycles, damaging infrastructure, and increasing dependence on subsistence-based agriculture.

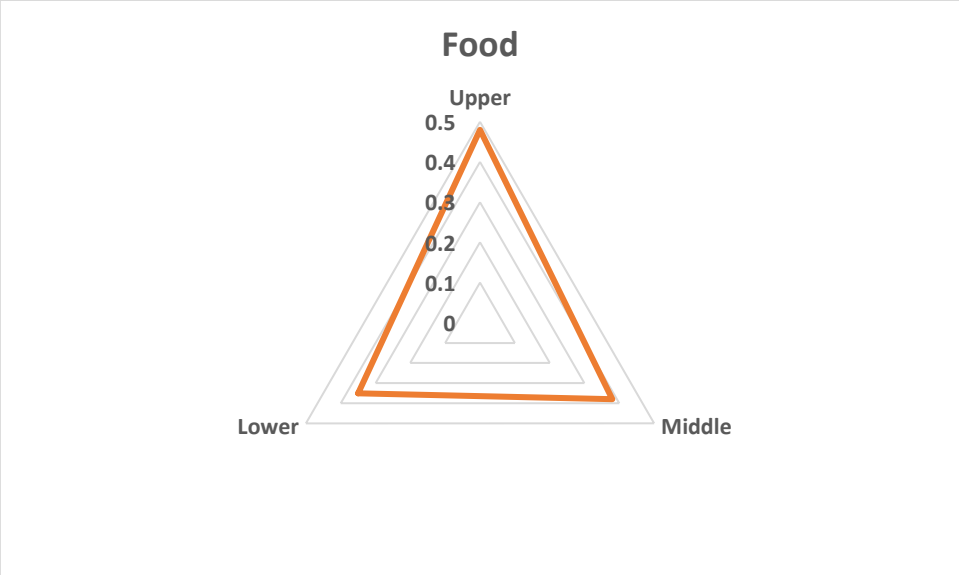


Table 8- Food (F)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Food (F)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs who are dependent on farm	96	0.96	0.48	78	0.78	0.38	59	0.59	0.35
	Average fishing pattern range (1-3)	15	0.13		16	0.16		14	0.14	
	Average Crop Diversity Index (>0-1)	33	0.33		16	0.16		33	0.33	

Water (W)- Water security forms a crucial dimension within the Livelihood Vulnerability Index (LVI) framework, assessed through eight sub-components, including access to consistent water supply, awareness of transboundary water conflicts, and the availability and functionality of public water infrastructure. The calculated vulnerability index values indicate that the downstream region experiences the highest water-related vulnerability (0.65), followed by the midstream (0.50) and upstream (0.49) regions. One of the most notable findings pertains to awareness of the Indo-China transboundary water conflict. While only about 10% of respondents in the upstream region reported any knowledge of this issue, the proportion was even lower in the downstream region, where the majority of households demonstrated no awareness. This lack of awareness potentially limits the community's preparedness and response to upstream water management issues that may affect downstream flows.

In the downstream belt, 100% of the surveyed households reported the absence of a reliable year-round water supply. This issue becomes especially severe during the flood season (June to September), when infrastructure is often damaged or submerged. Field observations further revealed that no government-installed water pumps were operational in the lower belt at the time of the survey. Although the Public Health Engineering (PHE) Department had initiated infrastructure development, many installations remained non-functional. In the midstream region, government water pump coverage was also inadequate, with an approximate ratio of 1 functioning pump for every 10 households, reflecting systemic deficiencies in public water provision across all belts, albeit most severe in the lower riparian zone.

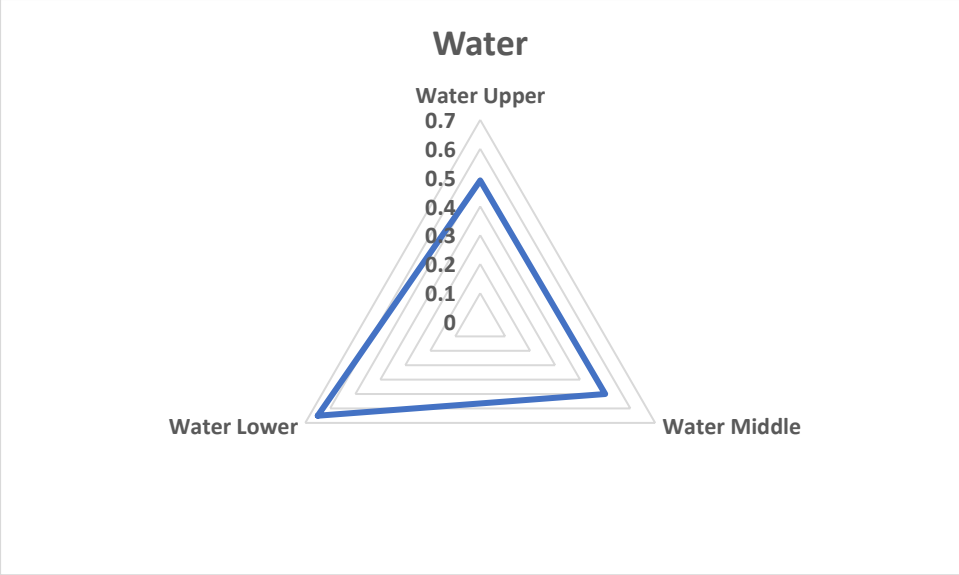


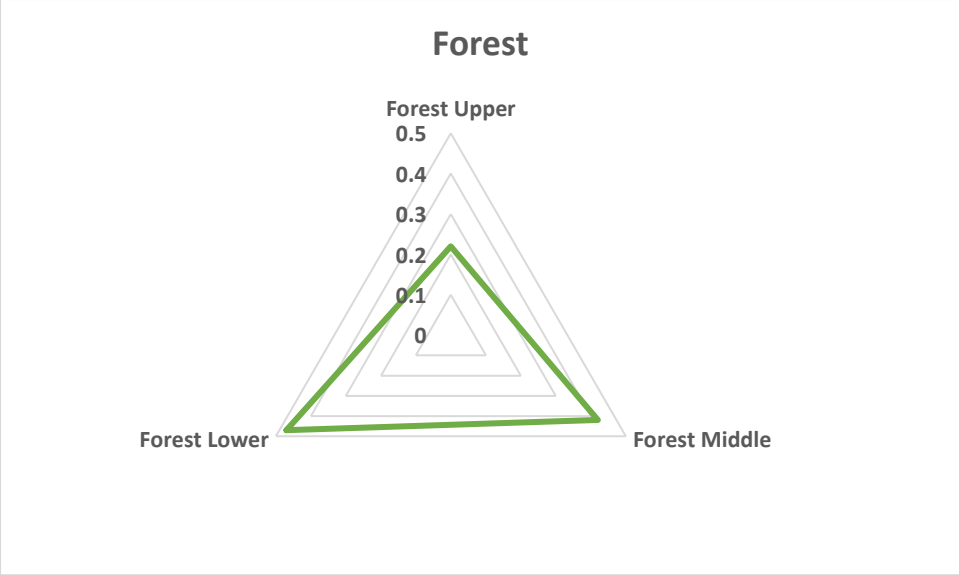
Table 9- Water (W)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Water (W)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	% of HHs not reporting water conflicts	10.00	0.10	0.39	100.00	1.00	0.50	100.00	1.00	0.65
	% of HHs that Utilize a natural water source	100.00	1.00		90.00	0.90		100.00	1.00	
	Average time need to reach the source of drinking water	37.90	0.38		53.33	0.53		40.00	0.40	
	% HHs having govt pumps	54.00	0.54		7.00	0.07		0.00	0.00	
	% of having water filter	86.00	0.86		18.70	0.19		94.00	0.94	
	% of HHs that don't have consistent water supply	0.00	0.00		97.00	0.97		100.00	1.00	
	Average litres of water stored per HHs	5.00	0.05		4.78	0.24		6.41	0.37	
	% of HHs using river water	19.00	0.19		13.00	0.13		45.00	0.45	

Forest (FO)- The final component assessed within the Livelihood Vulnerability Index (LVI) framework pertains to forest resource dependency. This dimension was evaluated using two sub-components: the average time required to access forest areas and the percentage of households not utilizing forest-based energy sources (such as fuelwood) for cooking purposes. The calculated index values reveal that vulnerability related to forest resources is lowest in the upstream region (0.22), while the midstream and downstream regions show comparatively higher vulnerability levels at 0.42 and 0.47, respectively. The elevated vulnerability in the lower riparian zone can be primarily attributed to limited forest cover, which significantly reduces community reliance on forest-based energy. Field data indicates that approximately 80% of households in the lower region lack access to forest-derived energy resources, leading to greater dependence on alternative and often less sustainable energy sources. In contrast, communities in the upper riparian zone benefit from closer proximity to forested areas, facilitating easier access to forest products and energy resources, and thereby demonstrating lower levels of vulnerability in this component.

Table 10- Forest (FO)

	Sub-components	Upper Riparian			Middle Riparian			Lower Riparian		
Forest (F)		Value	Index	Average	Value	Index	Average	Value	Index	Average
	Average time to reach to forest	2.05	0.4	0.22	1.66	0.12	0.42	2.36	0.14	0.47
	% of HHs not using forest-based energy for cooking purpose	16	0.03		72	0.72		80	0.8	



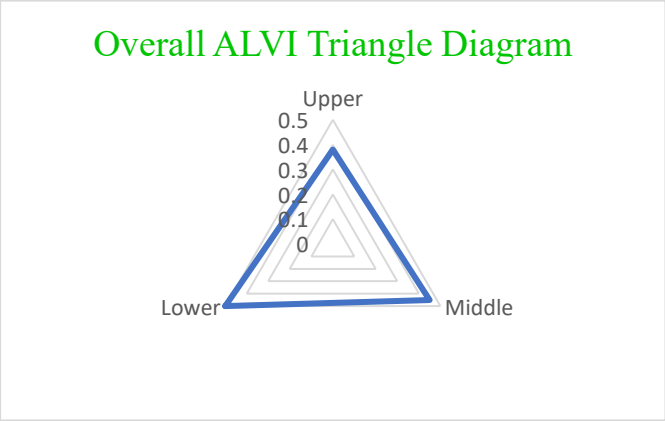


Fig 6- Extent of Vulnerability in all the belts.

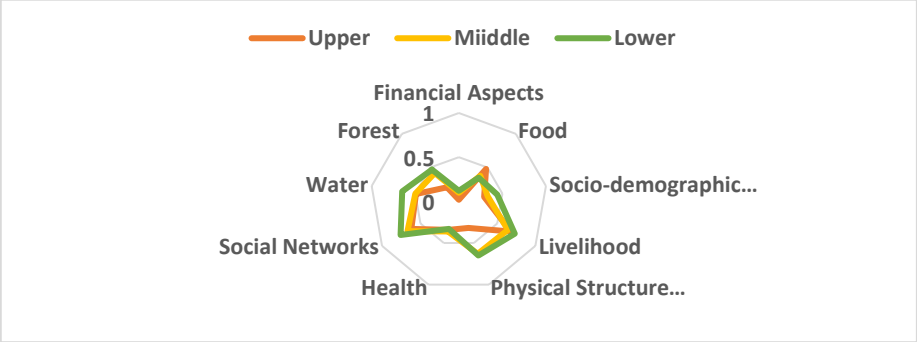


Fig 7- Comparative Vulnerability Spider Diagram

Comparative Livelihood vulnerability index values

The sum of all the components showed that community living in the lower belt was most vulnerable (0.5), followed by the middle belt with 0.45), but from the study, it was found that community living in the upper belt was least vulnerable to flood with an index value of 0.38. As a result, the vulnerability can be found more in the upper and middle riparian than the lower. The 7 major components, like socio-demographic profile, Livelihood strategies, Social Network, Financial Aspects, Physical Structure & Facility, Water and Forest, make the lower belt most vulnerable. But in the food component, the upper belt is seen as the most vulnerable compared to the other two. Interestingly, in the health component, it was found that all the belts were more or less same vulnerable due to a lack of proper health care services (Northeast Live, 2024). Currently, 15 Boat clinic units are operating across 13 districts, including Dhubri and Lakhimpur, where the primary survey was held (India Today NE, June

2025). The comparative vulnerability spider diagram of the major components of the ALVI for the three belts is shown in the fig7.

Conclusions

The highest indexed value for the socio-economic component was recorded among communities residing in the lower riparian zone, whereas the lowest was observed in the upper riparian region. Disaggregated analysis reveals that sub-components, including socio-demographic profile, livelihood strategies, social networks, financial resources, physical infrastructure, water access, and forest dependency, all exhibited higher vulnerability indices for the lower belt communities. Conversely, the food security component recorded the highest vulnerability in the upper riparian zone, while health-related vulnerability was most pronounced in the midstream region. These findings collectively suggest that communities in the lower riparian zone are significantly more vulnerable, particularly to flood-related impacts, than those in the upper belt, due to a convergence of socio-economic, infrastructural, and environmental stressors. In the lower riparian belt, heightened sensitivity is primarily driven by a combination of socio-economic and infrastructural limitations. These include high population density along vulnerable floodplains, prevalence of poorly constructed housing, inadequate access to safe drinking water and sanitation facilities, a significant proportion of informally educated or illiterate households, and limited access to early warning systems.

Recommendation

Based on findings from the field survey and supported by relevant literature (Hahn et al., 2009; Pandey & Jha, 2012; Shreevastav et al; 2021), several recommendations can be made to reduce vulnerability and strengthen adaptive capacity in the flood-prone regions of Assam, particularly the lower riparian areas. Promoting livelihood diversification through the development of small-scale enterprises, such as poultry farming, handicrafts, food processing, tailoring, and information technology, can significantly reduce dependence on climate-sensitive sectors like agriculture and fishing (IPCC, 2014; UNDP, 2020). The recently launched e-NAM market facility in Gauripur (June 2025) brings hope for better access to transparent marketing and income opportunities, though its benefits will hinge on sustained flood mitigation and support for farmers (The Sentinel, 2025). Additionally, enhancing access to crop insurance, expanding financial inclusion, and strengthening rural employment schemes like MGNREGA are critical to improving household resilience (MoRD, 2021). The extension of the Public Distribution System (PDS) to remote and vulnerable areas would further ensure food security during flood periods (Government of Assam, 2022). Infrastructure investments are equally vital, including the construction of rural roads, functional drainage systems, and flood-resilient shelters (World Bank, 2021). Ensuring the regular operation of government-installed water pumps, particularly during the monsoon season, would greatly enhance community preparedness and reduce water-related health and livelihood impacts. A majority of healthcare centres are inadequately equipped to handle medical emergencies effectively (CWC, 2020).

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Declaration of competing interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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