

# Micro Level Flood Vulnerability Assessment for Enhance Community Resilience in Lower Brahmaputra Valley Assam India

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**Abstract:** The flood vulnerability index (FVI) is a critical tool for assessing the susceptibility of areas to flooding, integrating various dimensions such as social, economic, and physical factors. Recent studies have developed diverse methodologies to create FVIs that reflect local conditions and enhance community resilience. These methodologies utilize advanced techniques, including artificial intelligence, geographic information systems (GIS) and participatory approaches, to generate comprehensive vulnerability assessments. This study aims to assess flood vulnerability in the lower Brahmaputra River Valley of Assam. Four vulnerability indices i.e. social, economic, environmental, and physical was calculated using twenty-one parameters and Analytic Hierarchy Process (AHP) was used for parameters weightage calculation. Farther these indices were combined to derive a final flood vulnerability index (FVI). The twenty-one parameters represent economic, social, environmental and physical aspects of the study area. The study finds that 58% of the villages in the study area are economically vulnerable, 57% are socially vulnerable, 56% are environmentally vulnerable, and 48% are physically vulnerable. It requires a holistic flood vulnerability planning and management approach for reducing vulnerability and increasing resilience.

**Key Words:** flood vulnerability, Brahmaputra River, physical vulnerability social vulnerability, environmental vulnerability, economic vulnerability.

## 1. Introduction:

Floods are the most common natural disaster, causing widespread damage, injuries, and loss of life globally [2]. They can happen in many forms, such as river, coastal, or urban floods, and occur when rivers overflow their banks, flooding nearby areas. This can disrupt transportation, agriculture, and everyday life [31]. Heavy rainfall, damaged riverbanks, dam failures, land-use changes, and deforestation are some of the reasons behind floods [12]. While



floods can sometimes benefit ecosystems, their overall impact is increasingly harmful due to climate change. To mitigate estuarine flood risk, strategies like increasing bed roughness to enhance hydraulic resistance are more effective than simply increasing flood storage capacity. Accurate flood risk assessments are crucial in developing regions. By mapping flood hazards, vulnerabilities, and risks, we can improve assessment reliability and global resilience [10]. Asia and Africa are the hardest-hit regions, accounting for most of the global flood damage and affected population [1]. Floods, the most devastating natural disaster, are responsible for a staggering 21% of all disaster-related deaths, 13.46% of injuries, 46.73% of the global disaster-affected population, and a staggering 24.38% of worldwide economic losses attributed to disasters [2]. Asia, particularly South Asia, bears the brunt of this devastation. A disproportionate 73% of the world's flood-risk population resides in Asia, with South Asia alone accounting for a staggering 39% of this figure; Southeast and East Asia follow closely with 30% and 20%, respectively [9]. River floods have claimed the lives of approximately 7 million people in the 20th century, and their annual economic toll is estimated at a staggering US\$104 billion. With a temperature increase of just 1.5°C, projections indicate that human lives lost to flooding could rise by a devastating 70-83%, while direct flood damage could increase by a catastrophic 160-240% compared to the 1976-2005 baseline, depending on socio-economic factors. [18]. Extensive and destructive floods occur annually. In the summer of 2010, Pakistan, India, and China experienced severe flooding. Similarly, in 2011, significant floods impacted Namibia, South Africa, Mozambique and Uganda in Africa; Colombia, Brazil, United States Mexico, in the Americas; and India, Cambodia, Korea, China, Philippines, Pakistan and Thailand in Asia. Each of these events resulted in over 50 average fatalities and substantial material loss [16]. Due to topographic and climatic diversity India is also immensely vulnerable to different types of flood; around 12 percent (>40 million hectares) of Indian landmasses are flood-vulnerable [39]. The Ganga-Brahmaputra floodplain, deltas and Krishna-Godavari delta region are some of the highly vulnerable regions to revering flooding. Among the different states of India, Uttar Pradesh, Bihar, West Bengal and Assam face the highest flood inundation and damage [17]. On average, 1650 people annually lost their lives between 1953 and 2016 due to floods in India, and India has the highest number of flood-related deaths among Asian nations [19]. Flooding and flood-related deaths predominantly occur during the monsoon season, accounting for 79% and 83%, respectively. States with extensive floodplains, such as Uttar Pradesh, Assam, West Bengal, and Bihar, are particularly vulnerable to frequent flooding. Simultaneously, hilly states like Uttarakhand and Himachal Pradesh experience catastrophic floods [29]. India has been repeatedly battered by catastrophic floods in recent years. Some of the most devastating include those in Bihar (2007, 2008), Mumbai (2005), Uttarakhand (2013), Assam (2012), Chennai (2015), Jammu & Kashmir (2014), and Kerala (2018) [19]. Among the Indian states 50% of the Assam geographical area are flood prone [17], Physiographically, Assam is mainly divided into two main drainage systems, i.e. Barak Valley and Brahmaputra valley. Because of the River Brahmaputra and its numerous tributaries The Brahmaputra valley is more susceptible to floods than the Barak valley [6]. Being the largest contributor of the

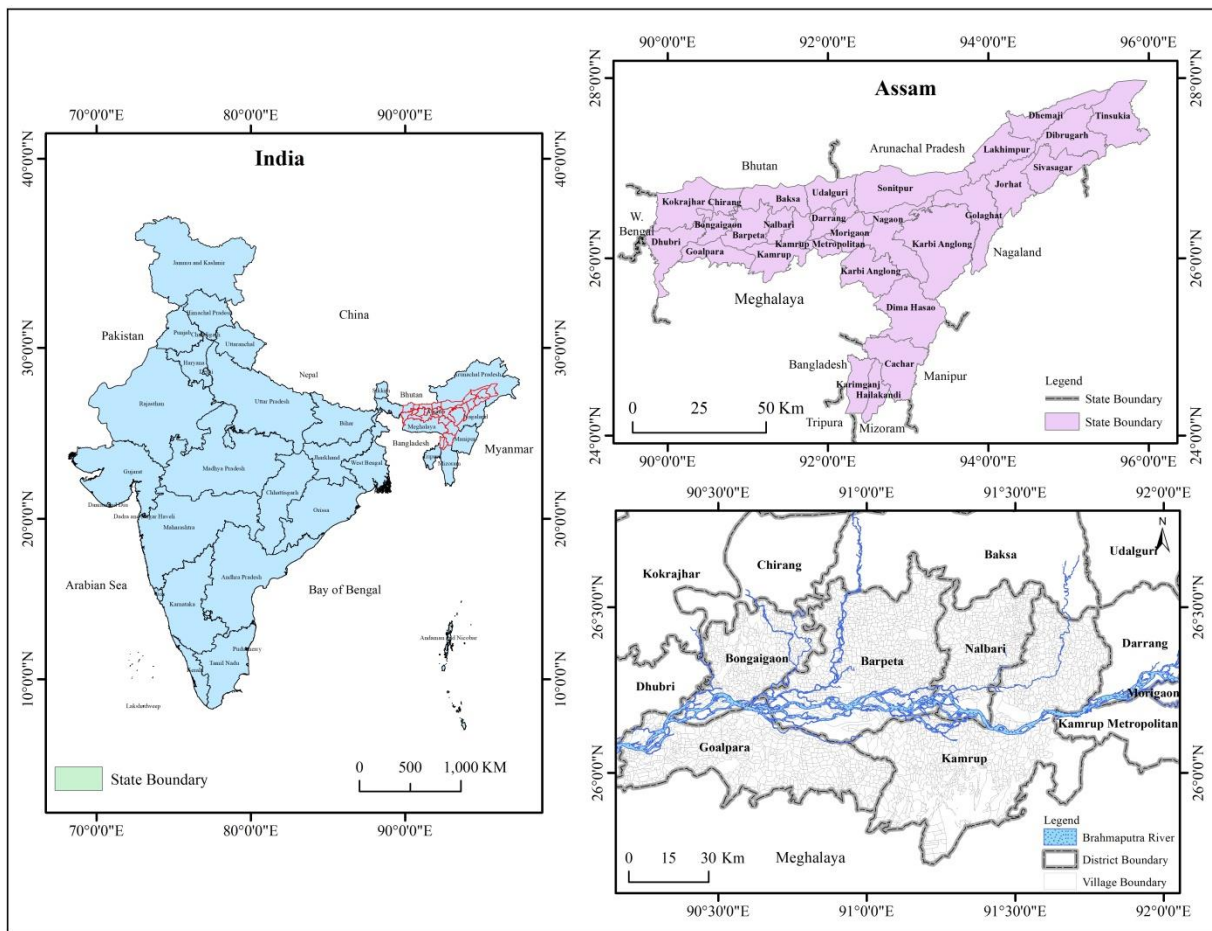
Ganga-Brahmaputra-Meghna river system the Brahmaputra River provides social, ecological, cultural and economic benefits to the millions of peoples of its riparian countries; at the same time causes damages and human sufferings by massive floods primarily in Assam and Bangladesh [25]. The lower and middle course of the Brahmaputra River are more vulnerable to floods than in upstream regions [33]. It experiences peak discharge during the monsoon season (July-September), primarily due to upstream heavy rainfall. This can lead to significant flooding and damage in the region [7]; occurrence of devastating floods in the Brahmaputra valley and its resultant damages have attracted the researcher's attention from different aspects like flood discharge [25], flood inundation mapping [8], flood hazard mapping [7, 35], early-warning system [15], river planform shifting [24], embankment breaching [11], climate change impacts [30] and many more; but there is lack of study focusing on micro-level vulnerability and impact assessment in the riparian settlements of the river. This study aimed at flood vulnerability assessment of the lower Brahmaputra valley villages. Administratively the lower Brahmaputra valley (Lower Assam) consists of twelve districts, the present study selects five severely flood affected district's i.e. Bongaigon, Barpeta, Kamrp, Nalbari and Golapara villages for flood vulnerability assessment from social, economic, physical and environmental aspect.

**Keywords:** Brahmaputra River, flood, Vulnerability assessment, flood vulnerability.

### **1.1. Flood Vulnerability Index (FVI):**

Vulnerability refers to the probability of individuals or groups to harm or the inability to cope with, overcome, or adapt to threats. It encompasses the likelihood of being affected by natural, man-made, or quasi-natural hazards, both physically and socioeconomically [5]. Vulnerability, as defined by the IPCC (2014) and UNESCO-IHE (2019), is not a measure of direct harm but rather a measure of susceptibility to potential harm. This susceptibility arises from a combination of exposure to hazards and sensitivity to their impacts, as well as a lack of adaptive capacity [23]. Growing populations and climate change are increasing the frequency and extent of flooding, affecting billions of people and causing substantial global damage. Effective flood risk management is therefore essential to mitigate these potential impacts. Vulnerability is a key component of flood risk assessment, encompassing various social, economic, physical, cultural, environmental, and institutional factors that determine the susceptibility of exposed elements to hazard impacts [20]. Recognizing the importance of understanding and assessing flood vulnerability, international initiatives such as the Sendai Framework for Disaster Risk Reduction (2015-2030) have emphasized this need. Vulnerability can be analyzed from social, economic, physical, and environmental perspectives [20]. Vulnerability assessment methods can be broadly classified into four categories: vulnerability indicators method, vulnerability curve method, disaster loss data method, and model method [21]. The Food Vulnerability Index (FVI) is a valuable tool for policymakers to identify vulnerable areas and prioritize investments. It aids in transparent decision-making and the development of effective strategies to combat food insecurity and adapt to flooding hazards [23].

**2. Study Area:** The Brahmaputra River Basin, a major river in India, lies between 23.9°N and 31.5°N latitude and 82.1°E and 97.7°E longitude. It flows through the states of Arunachal Pradesh and Assam. Originating in the Tibetan Himalayas, the river traverses the mountainous terrain of Arunachal Pradesh before flowing through the extensive alluvial plains of Assam, creating the fertile Brahmaputra Valley. Its extensive network of tributaries covers a significant portion of Northeast India, including parts of Arunachal Pradesh, Assam, Nagaland, Meghalaya, Sikkim, and West Bengal. [4]. The basin's territory is geopolitically distributed as follows: China (50.5%), India (33.6%), Bangladesh (8.1%), and Bhutan (7.8%) [8-7]. The administrative divisions of Assam is classified into five divisions, among them upper Assam, lower Assam, Northern Assam, and parts of central Assam comes under the Brahmaputra river valley. This study is focused on the micro level villages (figure 1) of the five districts i.e. Nalbari, Bongaigaon, Goalpara, Kamrup and Bongaigaon of lower Brahmaputra valley (Lower Assam).



**Figure 1:** Study area map of Lower Brahmaputra river valley (Assam)

### 3. Methodology:

#### 3.1. Data Used:

Table 1 summarizes the datasets used in this study. 30-meter resolution Digital Elevation Model (DEM) from Aster was employed, along with a Landsat 9 (OLI\_TIRS) satellite image. Village boundary shape files were sourced from the NASA Open Data Portal, while socio-economic data from the 2011 census and geological information from the Bhukosh portal were utilized.

**Table 1:** showing the utilized data sources of the study.

S.No.	Name	Source
1	Digital elevation Model (DEM)	Aster Dem ( <a href="#">Earthdata Search</a>   <a href="#">Earthdata Search</a> )
2	Landsat-9 (OLI_TIRS)	USGS Earth Explorer ( <a href="#">EarthExplorer</a> )
3	Village Boundary	NASA Open data
4	Socio Economic Data	Census of India ( <a href="#">Home</a>   <a href="#">Government of India</a> )
5	Road Network Data	<a href="https://geosadak-pmgsy.nic.in/OpenData">https://geosadak-pmgsy.nic.in/OpenData</a>
6	Geology	Bhukosh ( <a href="#">Bhukosh</a> )

#### 3.2. Preparation of Input Parameters:

The vulnerability assessment was conducted based on Twenty one social, economic, physical and environmental parameters (table 2). All the input parameters were extracted from the given data sources in table 1. The drainage parameters i.e. drainage density, drainage frequency and topographic parameters like elevation, relief, slope were derived from DEM. The socio-economic parameters i.e. household density, population density, literacy rate, female population, child population, dependency ratio, non-working population, marginal worker, agricultural labor was derived from the census of India data. Landsat 9 satellite image was used to derive the NDVI and NDWI of the study area and finally the geology map was derived from Bhukosh geology shape file.

**Table 2:** Showing the vulnerability indices and the analyzed parameters.

S. No.	Vulnerability Index	Parameters
1	Social Vulnerability Index (SVI)	Household Density
		Population Density
		Child Population
		Female Population
		Literacy Rate
2	Economic Vulnerability Index (EVI)	Agricultural Labor (%)
		Non-Worker (%)
		Marginal Worker (0 to 3 Months)
		Marginal Worker (3 to 6 Months)
		Dependency Ratio (%)
3	Environmental Vulnerability Index (EVI)	NDWI
		NDVI
		Confluence density
		Road Density
		Distance from River (meters)
4	Physical Vulnerability Index (PVI)	Elevation (meters)
		Slope (degree)

		Relief (meters)
		Geology
		Drainage density
		Drainage Frequency

### 3.3. Analytic Hierarchy Process (AHP):

Analytic Hierarchy Process (AHP) is one of the Multi Criteria Decision Making (MCDM) techniques which is a very powerful technique it has various application in field of science, social science, economics, politics [40], mostly used in planning work, developmental works, ranking, business analysis, cost benefit analysis, decision making [26], hazard, disaster risk and vulnerability assessment etc. [38, 32]. It's a widely acceptable technique because of its very simple and easily understandable nature. It has been used by researchers to divide the problem in separate hierarchical order and by applying expert knowledge; weightages can be assigned to the controlling factors for decision making and solving the problem, this concept allows group decision making. The concept was given by [27], to calculate factor weighting with the help of preference matrix, where all the criteria are compared with each other for decision making [13]. The final flood hazard map was generated using the parameter weightage and the factors and sub-class weightages were calculated using the following procedures and formulas.

#### Step: 1

$$A = \begin{matrix} & C_{11} & C_{12} & C_{13} \\ C_{21} & C_{21} & C_{22} & C_{23} \\ C_{31} & C_{31} & C_{32} & C_{33} \end{matrix} \quad (1)$$

In this comparison matrix, C<sub>11</sub> represents the value at the intersection of the first row (ith) and first column (jth). The AHP comparison matrix is square matrixes where, the diagonal elements are all 1, indicating that each criterion is equally important to itself. The off-diagonal elements represent pairwise comparisons between criteria, with scores indicating the relative importance of one criterion over another.

Pairwise comparison matrices were constructed by rating each criterion against every other criterion. This was done using a relative dominance scale of 1 to 9, as defined by [28]. (Table 1).

**Table: 3** Description of scales for pairwise comparison Matrix [Source: 28].

Scales	Degree of preferences	Descriptions
1	Equal importance	Two attributes with equally contribution to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong Importance	Experience and judgment strongly favor one activity over another
7	Very strong and Demonstrated Importance	An activity is favor very strongly favored over another, its dominance demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over another is the highest possible order of affirmation.



2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed.
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**Step: 2**

For each pairwise matrix, the values within each column were added together. The sum of each column was then represented by the following equation.

$$C_{ij} = \sum_{i=1}^n C_{ij} \quad (2)$$

**Step: 3**

The normalization of each column value, subsequent to the second equation, can be represented by the following equations.

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^n C_{ij}} = \begin{matrix} X11 & X12 & X13 \\ X21 & X22 & X23 \\ X31 & X32 & X33 \end{matrix} \quad (3)$$

**Step: 4**

A priority vector was calculated by normalizing the criterion values and then dividing each normalized value by the sum of normalized values in its row.

$$W_{ij} = \frac{\sum_{j=1}^n X_{ij}}{n} = \begin{matrix} W11 \\ W12 \\ W13 \end{matrix} \quad (4)$$

**Step: 5**

The principal eigenvector, denoted as  $\lambda_{max}$ , was determined by calculating the average value of each consistency vector. This eigenvalue plays a crucial role in the Analytic Hierarchy Process (AHP) as it is used to calculate the consistency ratio (CR), a measure of the consistency of the pairwise comparison matrix. The following formula was employed to determine  $\lambda_{max}$ .

$$\lambda_{max} = \sum_i^n CV_{ij} \quad (5)$$

**Step: 6**

To evaluate the consistency of the pairwise comparison matrix, the Consistency Index (CI) was calculated. This calculation required determining the matrix's maximum eigenvalue ( $\lambda_{max}$ ).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

**Step: 7**

The Random Index (RI) is used to assess the consistency of a pairwise comparison matrix. Table 4 presents the RI values used for calculating the CI.

**Table: 4** Random index value [Source: 28]

N	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

**Step: 8**

The consistency of judgments is evaluated using the consistency ratio (CR). A CR below 0.1 generally indicates sufficient consistency for decision-making. However, the acceptable CR threshold varies depending on the matrix size: 0.05 for 3x3 matrices, 0.08 for 4x4 matrices, and 0.10 for larger matrices ( $n > 5$ ). The CR values presented in the following tables demonstrate acceptable consistency within the pairwise comparison matrices, confirming the reliability of the judgments for further analysis. Conversely, a CR exceeding the relevant threshold suggests inconsistencies in the pairwise comparisons.

$$CR = \frac{CI}{RI} \quad (7)$$

**3.4. Derivation of the Vulnerability Index:**

The present study addresses the lower Brahmaputra river Flood vulnerability of from four different aspects (figure 2). The social vulnerability index (SVI) studies flood vulnerability of communities from social aspects. Economic Vulnerability Index (EVI) studies the community's exposure and resilience from the external events like floods. The Environmental and Physical Vulnerability addresses the FVI as the extent of environmental resilience, exposure to the flood events and how the physical topographic, hydrological characteristics is controlling the flood vulnerability respectively. The AHP method was used as primary method to calculate the parameter and parameter sub-class weightages; by combining the calculated parameter and sub-parameter weightage village level social, economic, physical and environmental vulnerability index were derived. At the last stage the vulnerability indices were combined together (Eq. 8) to derive the overall Flood Vulnerability Index (FVI).

$$FVI_{Total} = FVI_{Physical} + FVI_{Environmental} + FVI_{Social} + FVI_{Economic} \quad (8)$$

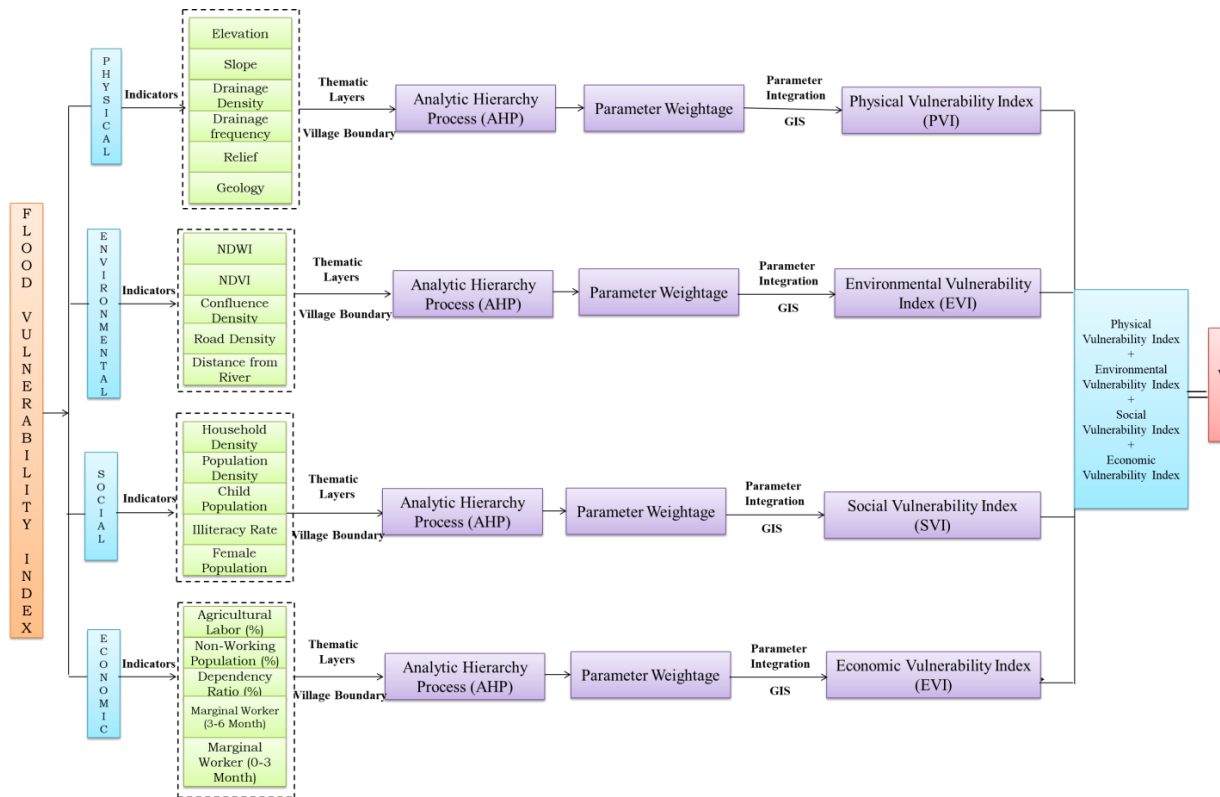


Figure 3: Showing the methodological flowchart of the study.

#### 4. Results & Discussion:

##### 4.1.1. Social Vulnerability Index (SVI):

Social vulnerability quantifies human susceptibility to disaster impacts, due to the variability in the social aspects [34]. This study combines the village wise census parameters to assess the social vulnerability from flood inundation. The Social vulnerability parameters are household density, population density, child population, literacy rate and female population of the village level. Densely populated areas are more flood-vulnerable due to increased exposure and strained infrastructure. Higher literacy reduces vulnerability through better understanding and preparedness. Large child and, often, female populations are highly vulnerable due to dependency, social roles, and economic factors. These intersecting factors require targeted protection strategies. The parameter's Weightages (table 5) were assigned based on their relative significance; it unveils villages featured with high population density, household density, child population, female population and less literacy rate are highly susceptible to flood social

vulnerability. Among the 3600 studied villages 1735 and 343 are very highly and highly socially vulnerable, these villages are distributed throughout the study area, together they represents 57.72 % of the total villages.

**Table 5:** showing the Flood Social vulnerability (SVI) criteria and sub-criteria weightage.

Parameters	Normalized AHP Weightage (%)	Sub-Classes	Sub-Parameter Weightage	CR	Sub-Class Rank
Household Density	42	<40	0.062319155	0.014074	1
		40-80	0.098461869		2
		80-120	0.160834987		3
		120-160	0.261920601		4
		>160	0.416463387		5
Population Density	26	<100	0.062319155	0.014074	1
		100-200	0.098461869		2
		200-300	0.160834987		3
		300-400	0.261920601		4
		>400	0.416463387		5
Child Population	16	<50	0.062371320	0.037386	1
		50-100	0.114978279		2
		100-150	0.147815175		3
		150-200	0.261221584		4
		>200	0.413613642		5
Literacy Rate	10	<20	0.401483857	0.040503	5
		20-40	0.269941238		4
		40-60	0.164269584		3
		60-80	0.109131162		2
		>80	0.055174160		1
Female Population	6	<100	0.052953101	0.06184	1
		100-200	0.110358913		2
		200-300	0.181630087		3
		300-400	0.251447308		4
		>400	0.403610591		5

#### 4.1.2. Economic Vulnerability Index (EVI):

Economic vulnerability defined as any country's exposure to outer shocks, such as natural disasters, due to its inherent economic characteristics. Index method is one of the widely used methods for natural hazard vulnerability assessment which aim to capture the multifaceted nature of vulnerability and resilience, including their economic dimensions [22]. The present study incorporates five economic variables i.e. agricultural labors (%), Non-Working Population (%), dependency ratio (%), marginal worker (0 to 3 months) and marginal worker (3 to 6 months) at village level to assess flood economic vulnerability. Floods economically harm communities with many agricultural laborers (due to income loss), a large non-working population (increasing dependency), a high dependency ratio (burdening workers), and many marginal workers (vulnerable to job loss). Parameters and sub-parameter weightage (table 6) reveals areas with high agricultural labors, marginal workers, non-working population and more dependency ratio are economically backward and they have highly exposed to the hazard, disaster events. The derived EVI map

(figure 4) infers 1475 and 614 villages are very highly and highly economically vulnerable from floods and they are randomly distributed throughout the study area, 808 villages are moderately, 385 and 315 villages with relatively stable economy having low economically vulnerability.

**Table 6:** showing the Flood Economic vulnerability (EVI) criteria and sub-criteria weightage.

Parameters	Normalized AHP Weightage (%)	Sub-Classes	Sub-Class Weightage	CR	Sub-Class Rank
Agricultural Labor (%)	41	< 2	0.056104767	0.043682198	1
		2_4	0.119318602		2
		4_6	0.157058257		3
		6_8	0.257039820		4
		>8	0.410478554		5
Non-Working Pop (%)	26	<40	0.066423369	0.039860531	1
		40-60	0.102444103		2
		60-80	0.151619004		3
		80-100	0.264745705		4
		>100	0.414767819		5
Dependency Ratio (%)	16	<30	0.062319155	0.014074273	1
		30-40	0.098461869		2
		40-50	0.160834987		3
		50-60	0.261920601		4
		>60	0.416463387		5
Marginal Worker (3-6)	10	<25	0.055360033	0.031498708	1
		25-50	0.107576312		2
		50-75	0.168867794		3
		75-100	0.257280592		4
		>100	0.410915269		5
Marginal Worker (0-3)	8	< 5	0.062319155	0.014074273	1
		5_10	0.098461869		2
		10_15	0.160834987		3
		15-20	0.261920601		4
		>20	0.416463387		5

#### 4.1.3. Environmental Vulnerability Index (EVI):

Vulnerability is the potential for a system (natural or human) to be negatively impacted by events. These events, both natural and human-made, can harm ecosystems by reducing their diversity, size, health, and ability to support life. A country's vulnerability depends on its characteristics, natural forces, and human activities. By analyzing the present condition and risk level the EVI predicts future environmental response to the events (UNEP). Five parameters i.e. NDWI, NDVI, river confluence density, road density and distance from river channels were considered which represent the general hydrology, vegetation cover and built environment To assess the flood induced environmental vulnerability of the study area. Sparse vegetation (low NDVI) increases flood risk due to reduced interception and increased runoff. High water presence (high NDWI) indicates saturated soils and surface water, also increasing risk. River confluences are highly vulnerable due to increased water volume and complex

flow. High road density reduces infiltration and increases runoff due to impervious surfaces and altered drainage, simultaneously Areas located closer proximity to rivers are more vulnerable due to overbank flooding and higher water velocity. These factors combine to influence flood environmental vulnerability. The EVI map shows villages situated in areas with high NDWI, low vegetation cover, close proximity from rivers and high confluence density are highly environmentally vulnerable. Figure 4 shows 1249 and 786 are having very high and high EVI. Simultaneously 742 villages are moderate, 479, 344 villages are located less EVI prone areas.

**Table 7:** showing the Flood Environmental vulnerability (EVI) criteria and sub-criteria weightage.

Parameters	Normalized AHP Weightage (%)	Sub-Classes	Sub-Class Weightage	CR	Sub-Class Rank
NDWI	42	< 2	0.062376387	0.01377	1
		2_4	0.098572773		2
		4_6	0.161050407		3
		6_8	0.261787988		4
		>8	0.416212445		5
NDVI	26	<40	0.416212445	0.01377	5
		40-60	0.261787988		4
		60-80	0.161050407		3
		80-100	0.098572773		2
		>100	0.062376387		1
Confluence density	16	<30	0.072581652	0.05593	1
		30-40	0.123950898		2
		40-50	0.193866865		3
		50-60	0.225599888		4
		>60	0.384000697		5
Road Density	10	<25	0.058553735	0.02799	1
		25-50	0.090742227		2
		50-75	0.186240536		3
		75-100	0.255708619		4
		>100	0.408754882		5
Distance from River	6	< 5	0.412655596	0.06682	5
		5_10	0.252667291		4
		10_15	0.169121811		3
		15-20	0.095107012		2
		>20	0.070448290		1

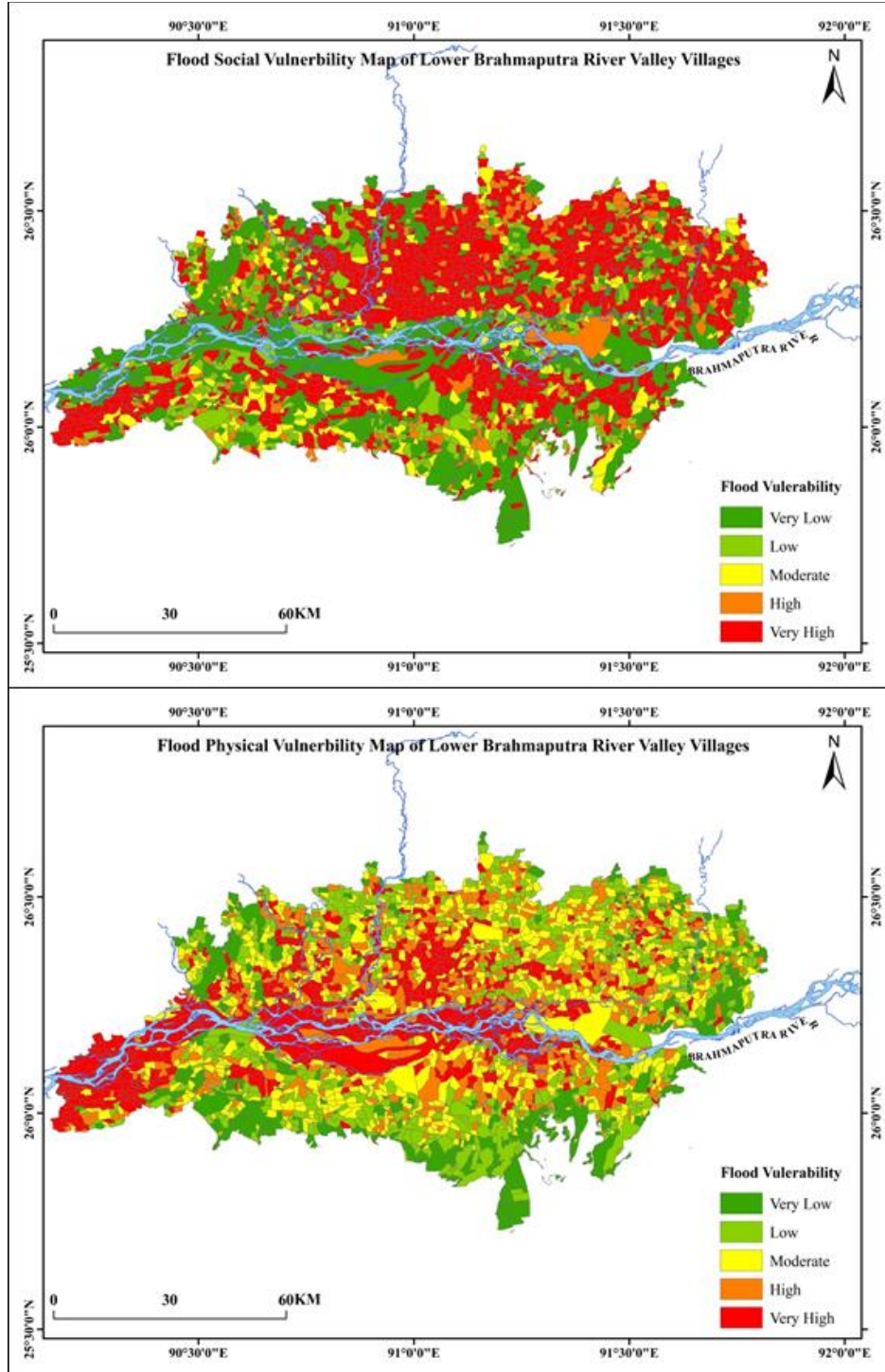
#### 4.1.4. Physical Vulnerability Index (PVI):

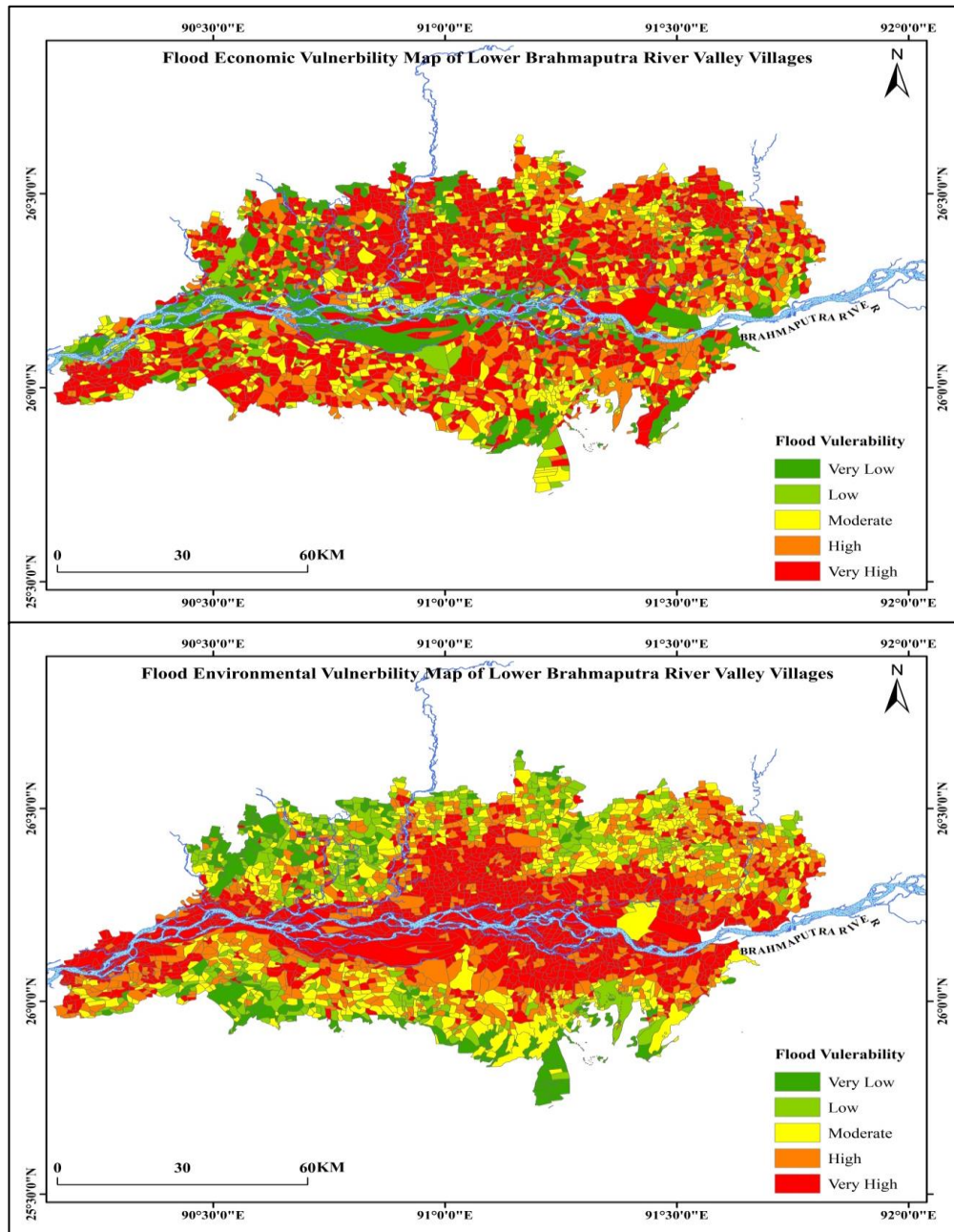
Physical Vulnerability Index (PVI) measures how likely an area is to be physically damaged by natural disasters like floods, earthquakes, and climate change. The more exposed an area is to these hazards, the more vulnerable it is [36]. Physically study area belongs to Lower Brahmaputra river floodplain, with flat terrain, less relief, gentle slope and frequent flood inundation. Parameters like study area Elevation, slope, relief, drainage density, drainage frequency, geology were assigned weightage for physical exposure (PVI) analysis. Lower elevation increases flood vulnerability as water flows downhill. Steep slopes reduce inundation but increase runoff speed and erosion, while gentle slopes are more prone to inundation. High drainage density and frequency indicate efficient water collection

and more stream pathways, increasing flood potential. High relief (elevation difference) leads to varied vulnerability, with steep slopes causing rapid runoff and low-lying plains experiencing widespread inundation. These topographic and drainage factors interact to determine physical flood vulnerability. The PVI map (figure 4) shows villages with high physically vulnerable are situated mostly along the low elevated, gentle slope, river banks. As shown in figure 4 among the villages 1739 (48%) village are located in high physical vulnerability zone, 782 villages are moderately vulnerable and 1079 villages are located physically less vulnerable zones.

**Table 8:** showing the Flood Physical vulnerability (PVI) criteria and sub-criteria weightage.

Parameters	Normalized AHP Weightage (%)	Sub-Classes	Sub-Parameter Weightage	CR	Sub-Class Rank
Elevation	38	<30	0.3801130	0.0561	5
		30-40	0.2548416		4
		40-50	0.1672059		3
		50-60	0.1136995		2
		>60	0.0841397		1
Slope	25	< 2	0.4175091	0.0025	5
		2-2.5	0.2627569		4
		2.5-3	0.1616916		3
		3-3.5	0.0988933		2
		>3.5	0.0591488		1
Drainage Density	16	<0.25	0.1050568	0.00377	1
		0.25-0.5	0.1033230		2
		0.5-0.75	0.1423420		3
		0.75-1.0	0.2426709		4
		>1.0	0.4066072		5
Drainage Frequency	10	>1.0	0.0623192	0.01407	1
		0.75-1.0	0.0984619		2
		0.5-0.75	0.1608350		3
		0.25-0.5	0.2619206		4
		<0.25	0.4164634		5
Relief	7	<15	0.4164634	0.01407	5
		15-20	0.2619206		4
		20-25	0.1608350		3
		25-30	0.0984619		2
		>30	0.0623192		1
Geology	7	Assam-Meghalaya Gneissic Complex	0.5392922	0.00477	3
		Kyrdem, nongpoh, Myllem Ranite, S. Khasi, Batholiths & Equivalent Granites	0.2974238		2
		Undiff. Fluvial/ Aeolian/ Fluvial/ Glacial & Coastal sediments	0.1632838		1





**Figure 4:** showing the (a) social Vulnerability Index (PVI), (b) physical vulnerability index (PVI) (c) economic vulnerability index (EVI) (d) environmental vulnerability index (EVI), of lower Brahmaputra river valley

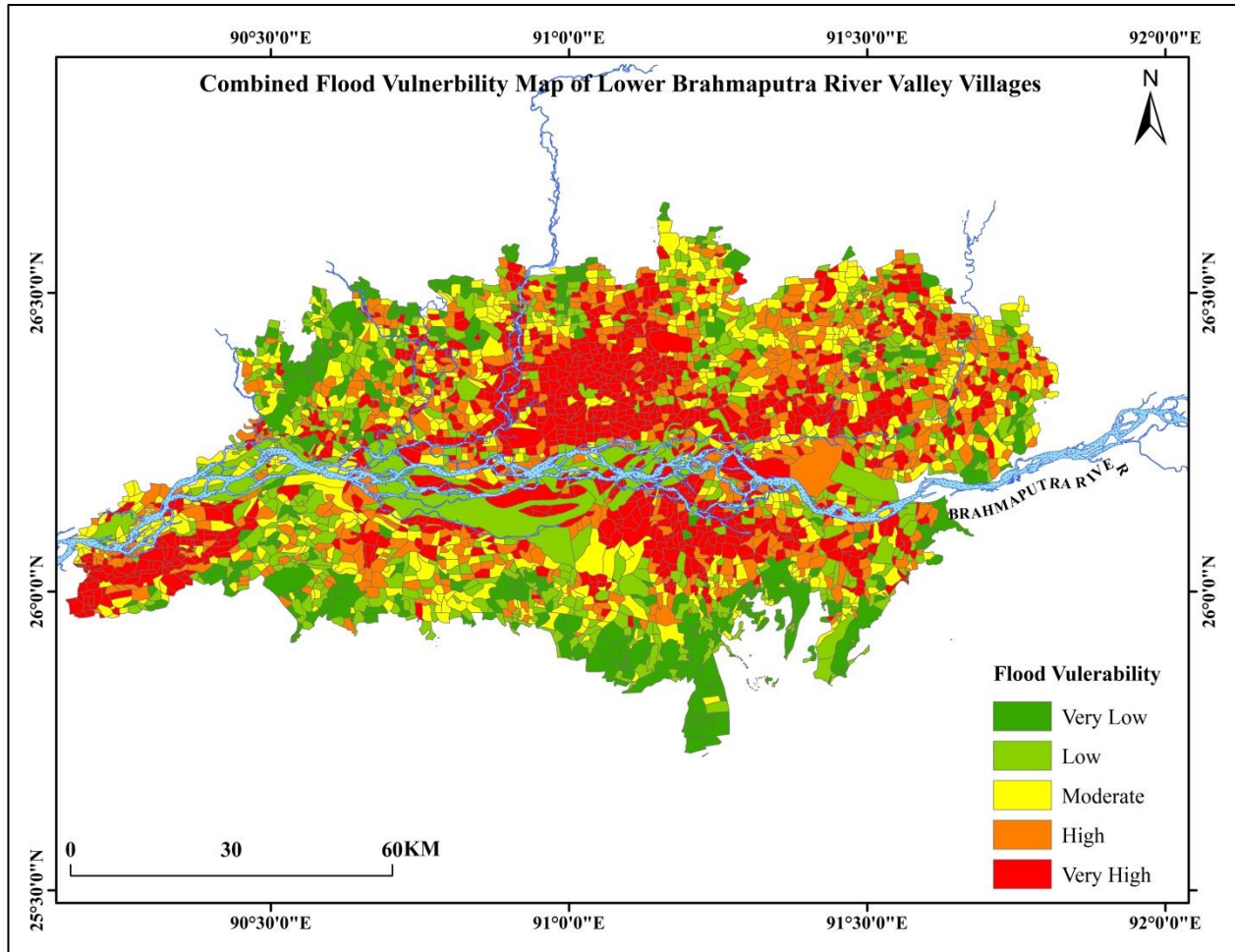
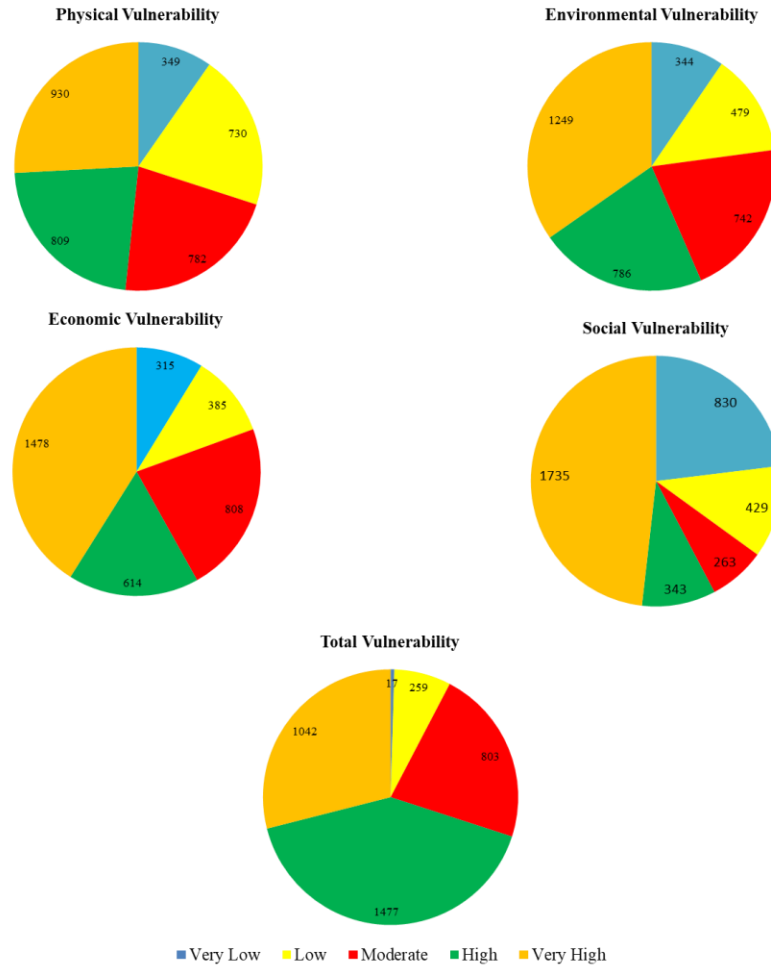


Figure 5: showing the final flood vulnerability index (FVI) of the lower Brahmaputra river valley.



**Figure 6:** pie-diagram showing village wise FVI distribution of lower Brahmaputra river valley.

Figure 5 showing the FVI map of the study area. The FVI is the combination of all the analyzed vulnerability indices. It represents all aspects of vulnerability i.e. social, economic, physical and environmental of the study area from floods. Villages with very high and high FVI are mostly located along the river banks and a low elevated zone, these villages represents all aspects vulnerability i.e. physical, environmental, economic and social from floods. The FVI reveals among the studies villages 1042, 1477 villages are very highly and highly vulnerable, 803 villages are moderately vulnerable and 259, 17 villages are low and very lowly vulnerable respectively.

**4.2. Discussion:**

The study represents overall vulnerability of the lower Brahmaputra valley at micro level village scale. The vulnerability was analyzed from social, economic, environmental and physical aspect. All the analyzed vulnerability



indices represent different aspects. The vulnerability assessment infers fifty percentages of the analyzed villages are vulnerable from all aspects like economically, socially, environmentally and physically. Among the villages 58% are economically vulnerable, 57% socially vulnerable, 56% and 48% are environmentally and physically vulnerable; final FVI delineates 70 percentages of the villages as highly and very highly vulnerable from floods. Physical and Environmental vulnerability of the study area are controlled by the natural setup of the region like low elevation, low slope, near proximity from rivers, high topographic and soil moisture and local geology which increases natural exposure of the villages. It requires scientific and engineering measures like structural measures, early warning systems, and evacuation process. On the other hand the social and economic vulnerability index reveals more than fifty percentage villages are vulnerable from social and economic aspects like high population, household density, low literacy rate, high dependency ratio, higher number of marginal and agriculture workers who are highly vulnerable. The social and economic vulnerability of the region can be addressed mainly by the non-structural and institutional measures like public awareness, community engagement and resilient economy etc. which can decrease vulnerability and increase community resilience.

#### **6. Conclusion:**

The present work carries out a micro-level flood vulnerability study of the lower Brahmaputra valley villages in Assam. Here the flood vulnerability index (FVI) was derived by combination of four different vulnerability indices i.e. economic vulnerability, social vulnerability, physical vulnerability & environmental vulnerability; which represents different aspects of flood vulnerability like social, economic, environment and physical topography; it helps in identifying actual vulnerability of the concerned area or community and to implement appropriate flood mitigation measures which can enhance community resilience. The study infers 58% of the villages are economically vulnerable, 57% are socially vulnerable, 56% are vulnerable from environmental perspective and 48% are vulnerable from physical topographic characteristics and relative position. The spatial Variation in distribution of the vulnerability indices were observed as, both physical and environmental vulnerable villages are located along the bank surrounding areas of main Brahmaputra River and its tributaries due to their topographic and environmental factors; on the other hand the economic and socially vulnerable villages are randomly distributed throughout the study area. Overall the region is vulnerable from all the aspects of vulnerability on average more than 50% villages are shown under all types of vulnerability. Based on the derived results the study suggests structural measures and advanced early warning system for reduction of environmental-physical vulnerability simultaneously non-structural, institutional, public awareness, community engagement measures to reduce social-economic vulnerability; which can increase community resilience.

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