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Article

Block-Level Climate Vulnerability Assessment of Aizawl District on Integrated Bio-Physical and Socio-Economic Sector

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Abstract: A climate change vulnerability assessment for the Indian Himalayan region, conducted by the Indian Himalayan Climate Adaptation Programme (IHCAP) in 2019, ranks Mizoram second in terms of climate change vulnerability. Mizoram has a fragile mountain ecosystem, and its people rely heavily on natural resources, making the state highly vulnerable to climate change. Studying climate change vulnerability is important to identify areas and communities most at risk, and this information helps develop strategies to reduce climate change impacts and build a stronger, more resilient community and environment. This study examines climate change vulnerability at the Rural Development (RD) Block level (Panchayati Samiti) in Aizawl district, focusing on both social and environmental factors. The results show that Darlawn Block is the most vulnerable, while Tlangnuam Block is the least vulnerable. The study also finds that the limited availability of clean drinking water and the large number of families working in agriculture are the main factors driving vulnerability in the area. This type of study assists planners and policymakers in identifying communities most at risk from climate change, enabling them to focus on mitigation and adaptation efforts for more informed policy decisions.

Keywords: climate change; vulnerability; socio-economic; bio-physical; mizoram; northeast india

1. Introduction

Climate change is characterized by a significant and lasting transformation in the mean climate state, which is driven by variations in the Earth's environmental factors (Abbass et al., 2022). A common example of this concept is the increase in global temperatures by almost 1 °C since the pre-industrial age (IPCC, 2014). The acceleration and increased frequency of extreme climate events due to global climate warming will increase the vulnerability of both human beings and regional economic systems. The ongoing effects of climate change are significantly influencing the agricultural sector, water resources, terrestrial ecosystems and biodiversity, coastal zones, and human health throughout Asia (Hitz and Smith, 2004). Rapid climate changes will disrupt the balance between humans and nature, particularly in vulnerable areas.

The poorest nations, reliant on climate-sensitive industries, are most at risk, emphasizing the need for adaptation (Nath and Behera, 2011). Climate change, vulnerability, and adaptive capacity have frequently been referenced in numerous studies examining societal impacts; nevertheless, there is a scarcity of research that specifically addresses the livelihood conditions of impoverished highland communities (Thong et al., 2023). The Intergovernmental Panel on Climate Change (IPCC) synthesis report confirms that human influence on the climate system is evident and increasing, with impacts observed across every continent and ocean (IPCC, 2014).

Vulnerability is characterized by the interplay of physical, social, economic, and environmental factors or processes that contribute to an increased risk of harm to individuals, communities, assets, or systems when confronted with hazards (Jaganathan, 2024). The hilly landscape of northeast India results in considerable variations in environmental and socio-economic conditions over relatively short distances. Assessing vulnerability to climate change is essential not only for understanding the risks it presents but also for identifying adaptation measures and efficiently allocating financial and other resources to the most vulnerable regions, populations, and sectors (Mizoram SCCC, 2020). Effective adaptation involves integrating climate change into existing development programs or establishing dedicated initiatives. Both approaches require understanding future climate changes and system vulnerabilities, which is assessed through vulnerability analysis, a critical first step in adaptation planning (Rama Rao et al., 2019).

This research is crucial for gaining a comprehensive understanding of climate-induced risks, enabling the development of effective resilience strategies, inclusive policies, and improved adaptation practices that better equip managers to address the challenges of a changing climate. The effects of climate change on rainfall patterns can be seen through the increasing occurrence and intensity of climate-related hazards and disasters in Mizoram, noticeable to the average person even without scientific evidence (Lalthanpuia et al., 2022). Another study was also conducted to understand the district-wise vulnerability of the forests and biodiversity (EF and CC, 2020). Based on all these factors, indicators are chosen from the entire set of potential indicators and systematically combined to show the levels of vulnerability (Kaly and Pratt, 2000; Cutter et al., 2003). By effectively summarizing and synthesizing information for policy purposes, vulnerability maps serve as powerful tools for guiding resource allocations and shaping policy decisions (Abson et al., 2012). A recent study on the climate vulnerability assessment of Mizoram incorporated four key dimensions of vulnerability: Village-wise study (Lalmalsawma et al., 2025), water (Lalthanpuia et al., 2022), shifting agriculture (Thong et al., 2022), and agroforestry (Thangjam et al., 2023) within its analytical framework. This study aims to address the existing research gap by integrating a diverse set of socio-economic and biophysical indicators to assess climate vulnerability. Additionally, it examines social and developmental disparities across various Blocks within Aizawl district, Mizoram, India providing a more comprehensive understanding of the localized impacts of climate change in the different Rural Development (RD) Blocks (Panchayat Samiti) of the district.

Study Area

Mizoram is in the southernmost part of Northeastern India, bordered by Myanmar to the east and Bangladesh to the west. It is positioned geographically between 21°57' and 24°30' N latitude and 92°15' and 93°29' E longitude, with Aizawl as its capital. The state features a forest cover of 18,430 sq.km, which constitutes 87.42% of its total land area. The topography of Mizoram is predominantly hilly, characterized by interconnected mountain ranges. The region's climate, along with its terrain and significant precipitation, fosters a diverse landscape rich in semi-evergreen forests. Based on the classification by Champion and Seth (1968), the forests of Mizoram can be categorized into Tropical Wet Evergreen, Tropical Semi-Evergreen, and Sub-Tropical Hill Forests.

Aizawl district spans approximately 3,576.31 sq.km and comprises 107 villages across four Rural Development (RD) Blocks. Phullen Block, which was once part of Aizawl district, has been incorporated into Saitual district since 2011. As per the 2011 census (Govt. of Mizoram), the population of the district is approximately 404,054, with a literacy rate of 89.40% with one municipality overseeing essential public services and urban infrastructure. The predominant demographic in Mizoram consists of tribal communities that are heavily reliant on natural resources and inhabit villages situated in the upper hill ranges. Consequently, Mizoram is particularly susceptible to the impacts of climate change, a challenge that is further compounded by insufficient infrastructure development (Mizoram SCCC, 2020).

2. Materials and Methods

Consistent with the risk management framework for climate change articulated by the Intergovernmental Panel on Climate Change (IPCC), Sharma et al., 2018 formulated a robust set of methodologies and guidelines for executing vulnerability assessments. The methodology employed to assess Block-level climate vulnerability in Aizawl district, Mizoram, India, involves a meticulous examination of both socio-economic and biophysical parameters, as outlined in the following sections (Figure 1).

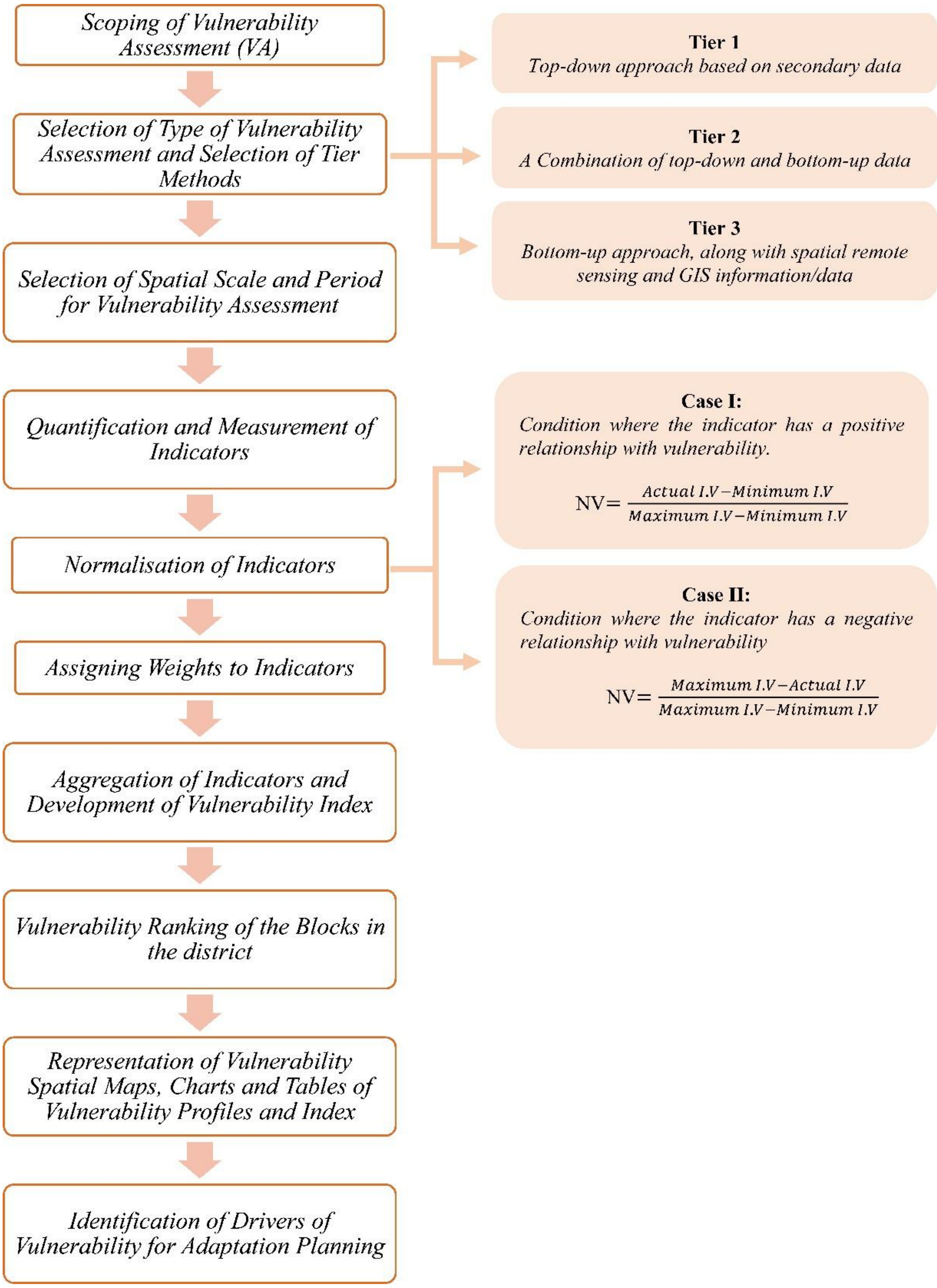

Figure 1. Flowchart of the steps involved in Climate Vulnerability Assessment.

2.1. Scoping of Vulnerability Assessment (VA)

Mizoram faces challenges from natural disasters, intensified by climate change and variability. To address this, a comprehensive assessment of the state's vulnerability is essential. By identifying the most at-risk areas and their contributing factors, policymakers can prioritize adaptation strategies and allocate limited resources effectively.

2.2. Selection of Type of Vulnerability Assessment and Selection of Tier Methods

This assessment evaluates the vulnerability of Mizoram at the Block-level using a bio-physical and socio-economic approach. A Tier-1 (top-down approach) methodology, which relies on secondary data is employed for the assessment.

2.3. Selection of Spatial Scale and Period for Vulnerability Assessment

The spatial scale of the study is the Block areas within Aizawl district. Vulnerability assessment indicators were identified through a literature review, as well as consultations with stakeholders and experts. Relevant indicators were selected based on their importance and applicability, following the same processes (Table 1).

Table 1. List of indicators selected relevant to Aizawl district, rationale for selection, indicator type, indicator type and their functional relationship with vulnerability.

Indicators	**Rationale for selection**	**Vulnerability type**	**Functional relationship with vulnerability**	**Source**
Percentage of BPL Families to the total household	Higher percentage of BPL household implies higher risk to the adverse impact of climate change.	Sensitivity	Positive	Statistical abstract of Mizoram 2011
% of female workforce	Contribution of woman to the household income signifies a more stable environment making them less susceptible.	Adaptive capacity	Negative	District Census Handbook. Dte of Census Operation, Mizoram (Census 2011)
Percentage of population employed in agriculture	A higher number indicates more people relying on a vulnerable income source, increasing their susceptibility to climate change	Sensitivity	Positive	District Census Handbook. Dte of Census Operation, Mizoram (Census 2011)
Total no of livestock per 1000 population	This reflects the diversity in agriculture and livelihoods, enhancing resilience to challenges	Adaptive Capacity	Negative	Statistical abstract of Mizoram 2011
Average person-days/household under Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)	Consistent fund support by the Government enhances their ability to adapt.	Adaptive Capacity	Negative	NREGA For 5 years 2015-16 to 2019-20 data average
Tap water from treated source	Access to tap water improves drinking water security with safety standards (Global water forum post-2015 agenda)	Adaptive Capacity	Negative	Public Health Engineering Department, Government of Mizoram (2019)
Percentage of rural population served by banks	This shows the economic stability of the region making them less vulnerable.	Adaptive Capacity	Negative	District Census Handbook. Dte of Census Operation,

				Mizoram (Census 2011)
Road density (Total road length divided by geographical area)	This demonstrates how easier access to markets during disasters enhances people's adaptive capacity.	Adaptive Capacity	Negative	Mizoram Remote Sensing Application Centre (MIRSAC)
Slope >70% (>35Deg)	Steeper slopes elevate landslide risk, reduce habitat quality, and increase forest vulnerability.	Sensitivity	Positive	Mizoram Remote Sensing Application Centre (MIRSAC)
Forest area in ha per 1000 rural population	Presence of large forest cover minimizes vulnerability during climate disasters	Adaptive capacity	Negative	Mizoram Remote Sensing Application Centre (MIRSAC)

2.4. Quantification and Measurement of Indicators

Numerical values for specific indicators are directly obtained from various sources as shown in Table 1 ensuring accuracy and consistency in the input for the assessment.

2.5. Normalisation of Indicators

The indicators had different units, such as percentages and relative values, making direct calculations impossible. To address this, values were normalized to a common scale ranging from 0 to 1 (Table 3). This unit-free scale helps with ranking and comparison, using different formulas based on whether the indicator has a positive (sensitivity indicators) or negative (adaptive capacity indicators) relationship with vulnerability (Sharma et al., 2018).

Case I: Condition where the indicator has a positive relationship with vulnerability

$$NV = \frac{Actual\ I.V - Minimum\ I.V}{Maximum\ \ I.V - Minimum\ \ I.V}$$

Case II: Condition where the indicator has a negative relationship with vulnerability

$$NV = \frac{Maximum\ I.V - Actual\ I.V}{Maximum\ \ I.V - Minimum\ \ I.V}$$

where,

I.V= Indicator value

NV=Normalised value

2.6. Assigning Weights to Indicators

Assigning weights to a total of 10 indicators was a complex process. Therefore, to simplify the process and to eliminate potential bias in the process, no weights were assigned to the indicators.

2.7. Aggregation of Indicators and Development of Vulnerability Index

The normalized value for each Block across all indicators was aggregated to calculate the Block's vulnerability index. This process was repeated for every Block, yielding the Composite Vulnerability Index (CVI) values.

2.8. Vulnerability Ranking of the Blocks in the District

After calculating the Vulnerability Indices (VI) for each Block, a comparative ranking was established based on these values. Blocks with higher VIs received higher vulnerability ranks, with rank 1 assigned to the most vulnerable Block. This helps prioritize interventions for at- risk areas.

2.9. Representation of Vulnerability Spatial Maps, Charts and Tables of Vulnerability Profiles and Index

The primary aim of representing vulnerability is to inform policymakers and stakeholders about vulnerability levels and associated risks. Spatial maps with colour gradients will illustrate varying vulnerability levels, supported by graphs, charts, and tables. Spatial units will be categorized based on their Vulnerability Index, with a scale from 1 (low vulnerability) to 4 (very high vulnerability).

2.10. Identification of Drivers of Vulnerability for Adaptation Planning

Average normalized values for each indicator were calculated across all Blocks to reflect their contributions to overall vulnerability. The percentage score of these averages, relative to the total, indicates each factor's significance. A higher percentage score signifies a greater impact on vulnerability, highlighting the key influencing factors.

3. Results and Discussions

The indicators for the Block-level climate vulnerability assessment on the integrated socio-economic and bio-physical sectors in Aizawl district were identified and selected through literature review, stakeholders and expert consultations. This led to the identification and selection of ten indicators relevant to the ground realities in Aizawl district for the climate vulnerability assessment. As shown in Table 1, the indicators in the present study falls under positive (sensitive) and negative (adaptive capacity) functional vulnerability type. Out of the ten indicators three indicators, namely, percentage of Below Poverty Line (BPL) families to the total household, percentage of population employed in agriculture and slope >70% (35°), are categorised under positive vulnerability, indicating the sensitivity or extent to which a system can be influenced by climate change, while the remaining indicators falling under negative vulnerability type are indicative of the system’s ability to adjust to climate change to lessen damage. For the positive type indicators, the vulnerability is said to increase as the normalised value increases, while for negative type, the vulnerability increases with decrease in the normalised value of the indicator (Table 3).

3.1. Socio-Economic & Livelihood Indicators

The analysis of socio-economic and livelihood indicators across the five regions reveals key differences in household poverty, workforce participation, agricultural employment, and livestock distribution, which reflect varying levels of socio-economic development and vulnerability (Table 2). The percentage of Below Poverty Line (BPL) families ranges from 12.02% in Tlangnuam to 22.61% in Darlawn, indicating that Darlawn has the highest poverty levels, which may contribute to greater socio-economic vulnerability. The percentage of the female workforce is relatively consistent across the regions, with values ranging from 42.07% in Thingsulthliah to 43.86% in Aibawk, reflecting a substantial and active female contribution to the labor force, which can help enhance community resilience. The percentage of the population employed in agriculture is highest in Phullen (43.82%) and Aibawk (43.29%), suggesting that these regions rely more heavily on agriculture as a livelihood, which could both offer stability and increase vulnerability to climate change impacts. Livestock ownership per 1000 population is notably high in Aibawk (322.34), indicating a strong reliance on livestock as a livelihood strategy, while Tlangnuam has the lowest livestock density (56.46), besides having the lowest agricultural employment (1.45%) suggesting less dependence on animal husbandry and possibly a more diversified income source. These indicators reflect different socio-economic profiles across the regions, with varying capacities to adapt to climate change and economic shocks

3.2. Institutional and infrastructure Indicators

The values for MGNREGA person-days per household are fairly consistent across the regions, ranging from 85.94 to 86.95 (Table 2). This consistency suggests that employment under the MGNREGA scheme is similarly utilized across the Blocks, yet this alone may not fully capture the socio-economic development or resilience of these areas. Access to treated tap water varies widely, with Tlangnuam providing the highest number of households (42,704) access to this vital resource. In contrast, Aibawk, Phullen, Thingsulthliah, and Darlawn have significantly fewer households with access, ranging from 185 to 3,187. This disparity indicates unequal access to essential infrastructure, which can directly impact public health and resilience to climate change, where reliable water sources are crucial for adaptive capacity.

Table 2. Name of the Blocks in Aizawl district showing their percentile contribution to the following indicators.

		Name of the Blocks in Aizawl district				
Indicators	**Unit**	**Tlangnuam**	**Aibawk**	**Phullen**	**Thingsulthiah**	**Darlawn**
Socio-economic and livelihood indicators						
Percentage of BPL Families to the total household	%	12.02	15.70	12.16	19.97	22.61
% of female workforce	%	42.45	43.86	42.34	42.07	43.61
Percentage of population employed in agriculture	%	1.45	43.29	43.82	22.33	36.92
Total no of livestock per 1000 population		56.46	322.34	144.03	111.88	158.63
Institutional and Infrastructure indicators						
Average person-days/household under MGNREGA		86.19	85.94	86.95	86.64	86.37
Tapwater from treated source	No.	42704	185	456	3187	741
Percentage of rural population served by banks	%	56.43	24.46	12.96	40.14	9.77
Road density (Total Road length divided by geographical area)	%	0.72	0.41	0.38	0.44	0.28
Bio-physical indicators						
Slope > 70% (>35Deg)	Sq.km	55.65	64.5	76.92	28.68	108.11
Forest area in ha per 1000 rural population		106.94	2445.88	2962.41	1578.96	2989.52

In terms of financial inclusion, Tlangnuam leads with 56.43% of the rural population served by banks, while Darlawn has the lowest at 9.77%. This disparity suggests that some regions with limited bank access struggle to obtain financial resources needed for adaptation during economic or climate-related shocks. Tlangnuam again stands out with the highest road density at 0.72%, while Darlawn has the lowest at 0.28%. Road infrastructure is essential for improving connectivity, which facilitates access to services such as healthcare and markets, crucial for resilience building. Lower road density in regions like Darlawn suggests limited access to these services, undermining their adaptive capacity to climate change.

3.3. Bio-Physical Indicators

The biophysical indicators analyzed across five regions (Table 2) show significant differences in slope and forest area, influencing environmental sustainability and climate change vulnerability. The slope data indicates areas with slopes exceeding 70% (or >35 degrees), with notable variations, especially in Darlawn, which has the largest area (108.11 sq. km), followed by Phullen (76.92 sq. km), Aibawk (64.5 sq. km), Tlangnuam (55.65 sq. km), and Thingsulthliah (28.68 sq. km). Steeper slopes increase erosion risk and limit land use, affecting agriculture and infrastructure development. Forest area per 1000 rural population varies significantly, with Darlawn having the highest forest area per capita at 2989.52 ha, followed by Phullen (2962.41 ha), Aibawk (2445.88 ha), Thingsulthliah (1578.96 ha), and Tlangnuam (106.94 ha). Larger forest areas indicate greater ecological resources, offering firewood, fodder, and non-timber forest products (NTFPs) for rural communities. These biophysical indicators suggest that Darlawn and Phullen, with steeper slopes and larger forest areas, face both opportunities and challenges in managing natural resources for climate change adaptation and economic improvement.

3.4. Vulnerability Index and the Drivers of Vulnerability

The data evaluates climate vulnerability across five Blocks in Aizawl district using various indicators, categorized into Actual Value (AV) and Normalised Value (NV) relationships with vulnerability. Tlangnuam Block has the lowest vulnerability index of 0.39, due to low values in sensitive indicators like BPL families and access to treated tap water, although road density and forest area slightly increase vulnerability (Table 4). Aibawk Block, with a vulnerability index of 0.54, ranks fourth, showing a mix of high vulnerability in the female workforce and livestock per 1,000 people, but lower vulnerability in rural population served by banks. Phullen Block, with an index of 0.57, ranks second, showing higher vulnerability in employment in agriculture and person-days per household under MGNREGA, compounded by low access to treated tap water. Thingsulthliah Block, with a vulnerability index of 0.56, ranks third, showing high vulnerability in BPL families and MGNREGA person-days. Darlawn Block, the most vulnerable with an index of 0.70, shows high vulnerability across multiple indicators like BPL families, forest area, and road density. Overall, Darlawn is the most vulnerable, and Tlangnuam is the least vulnerable, with employment in agriculture and BPL families playing significant roles.

Table 4. Vulnerability index values and corresponding ranks and categories of different Blocks in Aizawl district, Mizoram.

BLOCK	CVI Values	Vulnerability Ranking	Category
TLANGNUAM	0.39	5	Medium
AIBAWK	0.54	4	Medium
PHULLEN	0.57	2	Medium
THINGSULTHLIAH	0.56	3	Medium
DARLAWN	0.70	1	High

The analysis of vulnerability drivers highlights the various factors contributing to the region's overall vulnerability (Figure 2). The most significant factor is the limited availability of treated drinking water which accounts for 14.14% of the total vulnerability, emphasizing the critical role of clean water access in building resilience. Agriculture is another major driver, with a high number of families dependent on this sector contributing 12% to vulnerability, reflecting the sector's exposure to climate-related risks. Poor road connectivity contributes 11.32%, indicating that inadequate infrastructure limits access to essential services. Other contributing factors include lack of bank access (10.73%), gender disparity with low female workforce participation (10.05%), limited livestock options as alternative livelihoods (9.82%), and insufficient employment under NREGA (9.53%). Steep slopes (8.67%), high poverty rates (7.64%), and reduced forest cover (6.10%) also significantly impact the region's vulnerability.

These vulnerability drivers, with treated water access, agricultural dependence and road connectivity being the most significant contributors, collectively paint a picture of the region's overall vulnerability. Addressing these factors through improved infrastructure, economic diversification, financial inclusion, gender equality and sustainable natural resource management could significantly reduce the region's vulnerability to climate change and socio-economic shocks.

Table 3. Indicator actual values and normalised values for each of the indicators, for all the Blocks in Aizawl district.

Relationship with vulnerability	**Positive**		**Negative**		**Positive**		**Negative**		**Negative**		**Negative**		**Negative**		**Negative**		**Positive**		**Negative**		
Indicators	**Percentage of BPL Families to the total household**		**% of female workforce**		**Percentage of population employed in agriculture**		**Total no of livestock per 1000 population**		**Average person-days/household**		**Tapwater from treated source**		**Percentage of rural population served by banks**		**Road density (Total road length divided by geographical area)**		**Slope >70% (>35Deg)**		**Forest area in Ha per 1000 rural population**		**CVI Values**
BLOCK	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	AV	NV	
TLANGNUAM	12.02	0.00	42.45	0.79	1.45	0.00	56.46	1.00	86.19	0.75	42704	0.00	56.43	0.00	0.72	0.00	55.65	0.34	106.94	1.00	0.39
AIBAWK	15.70	0.35	43.86	0.00	43.29	0.99	322.34	0.00	85.94	1.00	185	1.00	24.46	0.69	0.41	0.71	64.5	0.45	2445.88	0.19	0.54
PHULLEN	12.16	0.01	42.34	0.85	43.82	1.00	144.03	0.55	86.95	0.00	456	0.99	12.96	0.93	0.38	0.77	76.92	0.61	2962.41	0.01	0.57
THINGSULTHLIAH	19.97	0.75	42.07	1.00	22.33	0.49	111.88	0.65	86.64	0.31	3187	0.93	40.14	0.35	0.44	0.64	28.68	0.00	1578.96	0.49	0.56
DARLAWN	22.61	1.00	43.61	0.14	36.92	0.84	158.63	0.51	86.37	0.57	741	0.99	9.77	1.00	0.28	1.00	108.11	1.00	2989.52	0.00	0.70

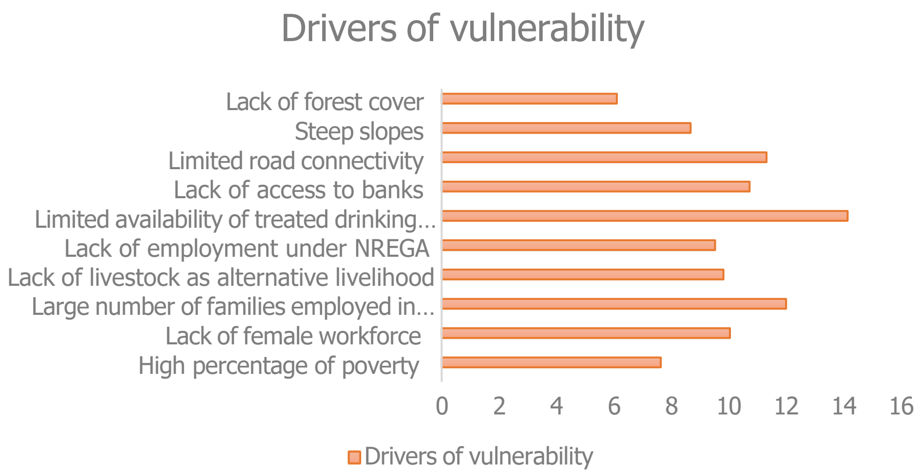

Figure 2. Bar diagram showing the overall drivers of vulnerability: indicators and their corresponding percentage contribution to the overall vulnerability assessment for Aizawl district.

4. Conclusion

The analysis of socio-economic, institutional, infrastructure, and biophysical indicators across the five Blocks in Aizawl district reveals significant disparities in development and vulnerability. The challenges faced vary between Blocks. For example, in Darlawn and Tlangnuam Blocks, biophysical factors like sloped terrain and forest cover appear to be linked to infrastructure availability, indirectly reflecting the region's socio-economic conditions. Strengthening infrastructure and transportation in remote areas can boost mobility and support sustainable development. Poverty levels are highest in Darlawn, making it the most vulnerable. Areas like Phullen and Aibawk, which rely heavily on agriculture, are more at risk from climate change.

Effective climate resilience strategies include women's empowerment, specialized training programs, livelihood diversification, improved water security, and expanded banking services, along with heightened climate change awareness. To avoid unintended consequences, it is crucial to design an equitable, research-based plan catering to the specific challenges of each region before implementation. Future research should focus on investigating the long-term effects of these vulnerabilities, particularly their impact on human health, food security, and water scarcity. This will contribute to bridging the gaps between adaptation and mitigation strategies, leading to more effective planning and management policies.

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