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Assessment of District Level Climate Vulnerability of Mizoram, India: Water Resources Approach

Lalthanpuia[1,2]*, H. Laldinpuii[2], Samuel Lalmalsawma[2] and James Lalnunzira Hrahsel[2]

[1]Department of Environmental Science, Mizoram University, Tanhril – 796009, Mizoram
[2]Mizoram State Climate Change Cell, Mizoram Science Technology & Innovation Council (MISTIC), Directorate of Science & Technology, Govt. of Mizoram, Mizoram New Capital Complex, Khatla, Aizawl – 796001, Mizoram
✉ lalthanpuia24@gmail.com

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Abstract: Mizoram, one of the north-eastern states in India, predominantly consists of hilly terrain with tribal populations living in villages scattered along the upper reaches. The high dependency of people on natural resources and rainfed agricultural practices relying wholly on the southwest monsoon make the region highly vulnerable to climate change exacerbated by poor development infrastructure, land use and land cover change, forest loss and degradation. The vulnerability of the state needs to be addressed to assist in developing practical and reliable plans to increase resilience against long term climate change. The intrinsic properties corresponding to sensitivity and adaptive capacity of the state in terms of domestic water resources availability are focused here to assess inherent vulnerability to unprecedented changes than can be caused by climate stress. The assessment follows an analytical framework by selecting indicators that define vulnerability criteria across all the districts in the state. Indicators were given weights per the best reflection to ground reality by means of stakeholder consultations. Composite Vulnerability Index (CVI) was calculated for each district across all indicators. Districts were ranked and categorised into high, medium, and low vulnerability based on their CVI values. Drivers of vulnerability were determined by calculating the contributions of each individual indicator to overall vulnerability. The calculated CVI was highest for Champhai making it the most vulnerable district. CVI was lowest for Mamit making it the least vulnerable district. Across all districts, limited availability of perennial springs per household, less forest cover and limited availability of ground water resources were the top drivers of overall vulnerability.

Keywords: Vulnerability; Sensitivity; Adaptive capacity; Climate change; Stakeholders.

Introduction

Ever since the pre-industrial era, the concentration of greenhouse gases like carbon dioxide, methane and nitrous oxide has increased significantly in the earth's atmosphere largely due to emissions from anthropogenic activities. The effects of such increases in greenhouse gases have been detected throughout the climate system and are strongly believed to have been the dominant cause of the observed global warming since the mid-20th century (IPCC AR5, 2014).

The risks of climate change impact over different timescales can be reduced through mitigation and adaptation which are complementary approaches for risk reduction of climate change impacts over different time periods. The "first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability" (IPCC AR5, 2014). Thus,

*Corresponding Author

there is a pressing need to assess the vulnerability of natural ecosystems and or socio-economic systems to current climate risks and long-term climate change as it is a vital preceding step to developing adaptation policies, strategies and practices.

Vulnerability is linked to the intrinsic conditions of a society or system. Vulnerable systems may or may not face climate change risks depending on their exposure to hazards. Vulnerability is defined as the propensity or predisposition to be adversely affected It is an endogenous characteristic of a system and is determined by its sensitivity (degree to which a system is affected by or responsive to climate stimuli) and adaptive capacity (potential or capability of a system to adapt to climatic stimuli or their effects or impacts) (IPCC AR5, 2014).

Reports from the project on Climate Change Adaptation in Rural Areas of India (CCA RAI) published in 2014 by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH explain that vulnerability information enables practitioners and decision-makers to identify the most vulnerable areas, sectors and social groups. In turn, climate change adaptation options can be targeted at specified contexts which then can be developed and implemented. Assessing vulnerability to climate change also provide a starting point for identifying measures to adapt to climate change impacts and to efficiently allocate financial and other resources to the most vulnerable regions, people and sectors. Furthermore, climate change vulnerability assessments can be used to monitor and evaluate the success of adaptation measures as well.

Simultaneously, the CCA RAI project also came up with frameworks for different approaches to Climate ChangeVulnerability Assessments which also provide various tools and practical methods using indicator-based assessment at various level of measurements and sectors (GIZ, 2014). The report on Vulnerability Assessment of Madhya Pradesh towards Climate Change published in 2014 by State Knowledge Management Centre on Climate Change, Environmental Planning and Coordination Organization (EPCO), Bhopal, India gave a detailed application of the framework in different case studies of indicator-based climate vulnerability assessment conducted under the CCA RAI project. However, the concept of climate change vulnerability followed by the framework was adapted from Allen Consulting (2005) which explains vulnerability as a function of exposure, sensitivity and adaptive capacity of a system to climate stress. This concept of vulnerability was in line with the IPCC AR4 technical summary 2007 (Parry et al., 2007).

Subsequently, Sharma et al. (2018) have prepared and formulated frameworks, methods and guidelines for the assessment of vulnerability and risk due to climate change following the risk assessment framework proposed in the Working Group II of the IPCC AR5 2014 report. The concept followed by this framework removes exposure by explaining vulnerability as the intrinsic property of a system which can be determined by the sensitivity and adaptive capacity of a system. This definition of climate change vulnerability remains unchanged in the IPCC AR6 (2022) (Portner et al., 2022). Sharma et al. (2018) provided step by step explanation of vulnerability and the process and assessment and its application. The study explains climate change and climate variability, the reason for the assessment, target groups and utility of assessment, evolution of IPCC vulnerability frameworks, necessity of vulnerability assessment for adaptation planning, the vulnerability and risk assessment frameworks developed and tiers of assessments, step by step methodology and integrating vulnerability and risk assessment with climate change adaptation planning.

Detailed applications of the study by Sharma et al. (2018) have been published in the Department of Science & Technology, Govt. of India and two project reports in 2019 and 2020 where selected indicators were used to determine current climate vulnerability rankings and drivers of vulnerabilities of states and districts of India.

With the above background, this paper attempts to construct the vulnerability index of different districts of Mizoram by employing the indicator method of quantifying vulnerability to determine the ranking of districts and their respective drivers of vulnerability. Some indicators from the whole set of potential indicators will be selected and then systematically combining them to indicate the levels of vulnerability (Cutter et al., 2003; Kaly and Pratt, 2000). The analysis was carried out for a comparative representation of vulnerability at the district level in terms of domestic water resources availability.

Study Area

The whole state of Mizoram, located in the adjoining areas of the southern foothills of the Indian eastern Himalayas has been experiencing changes in climate including rising temperature and changes in the temporal and spatial distribution of rainfall. The effects of such changes have been evident in the increased events and intensity of climate-related hazards and disasters in the state of Mizoram which can be perceived by a common man even without the support of scientific data.

The whole state of Mizoram is characterised by a series of hill ranges, rough terrain with steep slopes and deep valleys. The region has diverse climate regimes which are highly dependent on the Indian southwest monsoon. The majority of the crops in the state are under rain fed agriculture. The natural resources in the region are subjected to degradation and loss due to deforestation, unsustainable shifting cultivation practices, fragmentation and degradation. Due to the hilly terrain and the cultivation of crops along the slopes, the soil resources are also subjected to erosion and loss (Rabindranath et al., 2011). The majority of the population in Mizoram are tribal communities highly dependent on natural resources and living in villages scattered along the upper reaches of hill ranges. Many areas face severe water scarcity during the summer months. As such, the state of Mizoram is highly vulnerable to climate change and climate variability exacerbated by poor infrastructure development in the region (Mizoram SCCC, 2020).

Materials and Methods

Based on the conceptualizations of climate change-related risk from the risk management and assessment framework published in the IPCC (2014), step-by-step methods and guidelines for assessing vulnerability developed by Sharma et al. (2018) following the IPCC AR4 (2014) risk assessment framework was followed and adopted for this study. The following points show the approach adopted in this study for assessing the district-level climate vulnerability of Mizoram from domestic water resources perspective.

Scoping of Vulnerability Assessment (VA)

The whole state of Mizoram is vulnerable to natural disasters, coupled with the impact of climate change and climate variability. This calls for a scientific and robust assessment of the vulnerability of the state at different levels to identify the most vulnerable areas and their drivers of vulnerability for policy makers and planners so that they can prioritise areas for adaptation plans and investment with limited resources.

Selection of Type of Vulnerability Assessment

This assessment will be a vulnerability assessment of Mizoram at the district level: Water resources approach.

Selection of Tier Methods

This assessment was conducted using Tier 1 approach which utilises mainly secondary data from various sources and geo-spatial data.

Selection of Spatial Scale and Period for Vulnerability Assessment

The spatial scale for this assessment is the political boundary of the pre-existing eight districts of Mizoram. This assessment will be an inherent vulnerability under current climate conditions. Therefore, data were collected one time during variable years for each unit of measurement to represent the current scenario.

Identification, definition and selection of indicators for vulnerability assessment: Identification of indicators was done through literature review, stakeholders and expert consultations. The screening and selection of such identified indicators based on their importance and relevancy to indicate vulnerability were determined through the same processes (Table 1).

Quantification and Measurement of Indicators

All indicators were expressed in terms of numerical numbers that quantify the values for each district so that mathematical operations can be applied to them. Numerical numbers for certain indicators are input directly from the source of data. For other indicators, further calculations from the data sources were required which utilises a simple mathematical formula to complex Geo-spatial techniques using GIS software.

Normalisation of Indicators

The measurement units were not the same for all indicators, some were expressed in percentage while some were relative values. Therefore, they cannot be directly used for calculations. To address these issues, indicator values were normalised across all units of measurement (Table 2). Normalized values are unit free, and they all lie between 0 and 1 (0 implies the least vulnerability and 1 implies the highest vulnerability) and can be used for ranking and comparison. The following formulae were used for the calculation of normalisation, which depends on whether the indicator has a positive (sensitivity indicators) or negative relationship (adaptive capacity indicators) with vulnerability.

Case I: The indicator has a positive relationship with vulnerability

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

Table 1: List of indicators selected relevant to districts, rationale for selection, indicator type, sources of data and weights assigned to them

Indicators	*Rationale for selection*	*Indicator type*	*Source of data*	*Weights assigned*
Available ground water resource in (million cum) w.r.t total geographical area	Ground water is a source of high-quality fresh water and plays a central part in sustaining ecosystems and enabling human adaptation to climate variability and change (Taylor et al., 2013).	Adaptive Capacity	Public Health Engineering Department, Government of Mizoram (2019)	25
% household piped water connection	Piped water supply can improve drinking water security when coupled with safety norms to reduce water contamination (Global water forum post-2015 agenda)	Adaptive Capacity	Public Health Engineering Department, Government of Mizoram (2019)	13
No. of perennial springs available per household	The mountain people depend largely on spring water for their sustenance. The mountain springs are also the natural discharges of groundwater from various aquifers (Tambe et al., 2012)	Adaptive Capacity	Public Health Engineering Department, Government of Mizoram (2019)	20
% Forest cover	Forest cover dynamics are an important indicator of climate change and can have a substantial impact on local water resources (Sahin and Hall, 1996; Arnold et al., 2020)	Adaptive Capacity	India State of Forest report 2019	30
Regional Water Stress Index (RWSI) $\text{RWSI} = 1-\left(\frac{ET}{ETwet}\right)$ *(ET = Evapotranspiration ETwet = Potential Evapotranspiration)*	The regional water stress index (RWSI) is a part of the drought assessment index. Its index is an indicator of the regional water deficit (Sahoo et al., 2019; Gao et al., 2011)	Sensitivity	NOAH land surface model predicted data in Global Land Data Assimilation System (2019)	12

Case II: The indicator has a negative relationship with vulnerability

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

Where NV is Normalised value and I.V. is Indicator value

Assigning Weights to Indicators

Unequal weights were assigned to each indicator in such a way that the total weight of the 5 selected indicators sums up to 100 (Table 1). This was done by a process of consulting with stakeholders and experts which would best reflect the ground reality and relevance for the state of Mizoram.

Aggregation of Indicators and Development of Vulnerability Index

The normalised values of each indicator were multiplied by their respective weights which produce weighted values for all indicators across all units of measurements. The vulnerability index of each district was determined by aggregating their respective weighted values across all indicators.

Vulnerability Ranking of the Districts in the State

Once Vulnerability Indices (VI) are calculated for all the districts, a comparative ranking was carried out based on the index value. The higher the value of VI of a district, the higher will be its rank in vulnerability where rank 1 was allocated to the most vulnerable district.

Table 2: Indicator actual values and normalised values for each of the indicators, for all the districts in Mizoram

Districts	*Available ground water resource in (million cum) w.r.t total geographical area*		*% household piped water connection*		*No of perennial springs available per household*		*% Forest cover*		*Regional Water Stress Index (WSI)*	
	AV	*NV*	*AV*	*NV*	*AV*	*NV*	*AV*	*NV*	*AV*	*NV*
Aizawl	0.39	1.00	4.52	1.00	0.00	0.94	86.52	0.35	0.99999983	0.17
Champhai	0.43	0.96	13.10	0.00	0.01	0.66	81.73	0.97	0.99999986	0.53
Kolasib	1.29	0.11	10.39	0.32	0.00	0.97	85.53	0.48	0.99999982	0.00
Lawngtlai	1.40	0.00	8.54	0.53	0.01	0.74	86.90	0.30	0.99999990	1.00
Lunglei	1.14	0.26	5.68	0.86	0.03	0.00	88.67	0.08	0.99999988	0.75
Mamit	1.40	0.00	12.72	0.04	0.01	0.74	89.26	0.00	0.99999985	0.35
Serchhip	0.53	0.87	5.79	0.85	0.00	1.00	86.13	0.40	0.99999990	1.00
Siaha	0.63	0.77	5.96	0.83	0.01	0.80	81.49	1.00	0.99999988	0.76

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

The basic idea behind representation of vulnerability is to convey the information about the state of vulnerability and the associated risks to the policy making bodies and other stakeholders. Spatial maps with the gradient of colours indicating the level of vulnerability will be used along with graphs, charts and tables. The different spatial units measured were also represented below categorically based on their Vulnerability Index relative value between 1 to 4; with 1 being low to 4 being very high vulnerability.

Identification of Drivers of Vulnerability for Adaptation Planning

Most vulnerability studies are conducted as a prerequisite to making policies to prevent further degradation of environmental assets. To develop an efficient adaptation planning technique, identifying the main drivers behind vulnerability is crucial. Vulnerability assessment helps in selecting adaptation measures based on the assessment of the drivers of vulnerability. Drivers of vulnerability are indicators used for vulnerability assessment which are expressed as sensitivity or lack of adaptive capacity. Their respective contributions to composite vulnerability Indices are quantified and represented by their magnitude. For determining the drivers of vulnerability for the whole state of Mizoram, the weighted values across all districts were averaged for each indicator thereby resulting in every indicator having its own weighted values. The percentage score of the weighted value of an indicator from the sum of weighted values of all indicators was then considered as the percent contribution of that indicator to the overall vulnerability (drivers of vulnerability); a higher percentage score indicates a higher contribution to vulnerability. The drivers of vulnerability for each district were also calculated separately by taking the percentage score of their respective weighted values in each indicator from the sum of their respective weighted values across all indicators.

Results and Discussion

Vulnerability Profile and Ranking of Districts

Table 3 and Figure 1 show that the Champhai district has the highest vulnerability index value (0.782) compared to the other seven districts in the state of Mizoram which place it in vulnerability rank 1 indicating it to be the most vulnerable district against climate variability and climate change in terms of domestic water resource availability. Similarly, the Siaha district scored the vulnerability index value of 0.777 and was placed in rank 2 followed by Serchhip in rank 3 (0.751) and so on. Mamit district scored the least number vulnerability index values (0.205) making it the least vulnerable district.

Table 3: Vulnerability index values and corresponding ranks and categories of districts in the state

Districts	*Vulnerability index value*	*Rank*	*Category*
Champhai	0.782	1	HIGH
Siaha	0.777	2	HIGH
Serchhip	0.751	3	HIGH
Aizawl	0.700	4	HIGH
Lawngtlai	0.430	5	MEDIUM
Kolasib	0.426	6	MEDIUM
Lunglei	0.306	7	LOW
Mamit	0.205	8	LOW

The ranking of districts based on the vulnerability index values is relative and comparative in nature (DST, 2019; DST, 2020; Sharma et al., 2018). In other words, the Mamit district is the only one, which is least vulnerable to climate change as compared to other districts, and it does not mean that it is at all not vulnerable. It is also important to note that the comparative analysis is also based on a set of selected indicators to determine the vulnerability index values for different districts (Mohanty & Shreya, 2021; DST 2019, 2020).

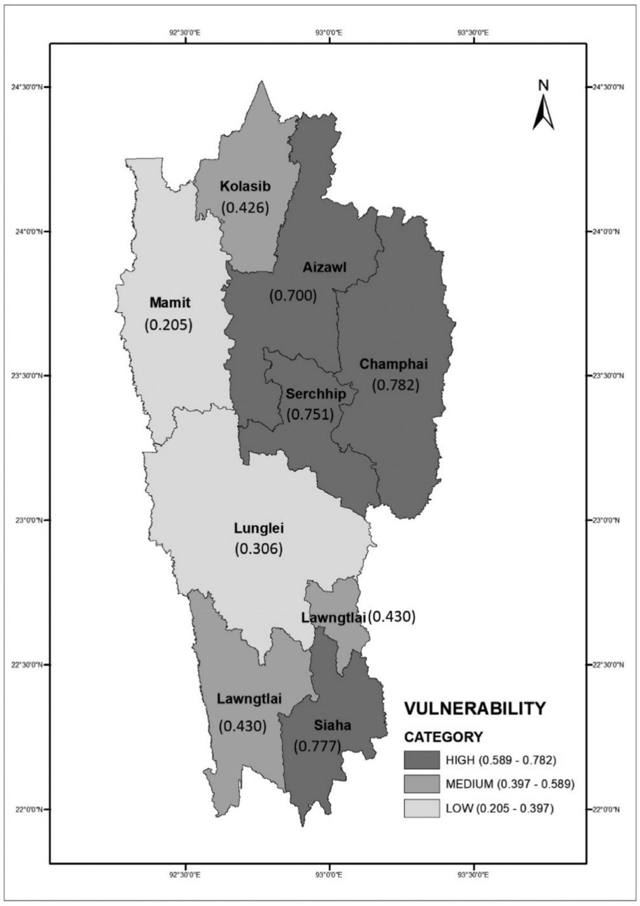

Figure 1: Map showing vulnerability index values and corresponding vulnerability ranks and categories of districts in the state of Mizoram against climate change and climate variability to water resources.

Each district will have its own specific problems and an extent of its own level of vulnerability. Therefore, when looking at the result such as this study, it is advisable to consider the determinants (indicators used) of vulnerability index values, weights given and disparities in the value of indicators across districts which are the key factors of differences in the vulnerability index values across the districts.

Based on the three categorical divisions of vulnerability mentioned earlier in the methodology, Siaha, Serchhip Champhai and Aizawl districts were placed in the high vulnerability category, Lawngtlai district in medium category, while the other three districts; Kolasib, Lunglei and Mamit districts were all placed under low category. It is important to note that the vulnerability category is a division based on the mathematical class interval of the vulnerability index values and is relative in nature.

Drivers of Vulnerability

Overall Vulnerability

Based on the percent contribution of each indicator across all districts to aggregated vulnerability index value of all indicators averaged across all districts, limited availability of perennial springs per household contributes highest (26.76%) to overall vulnerability followed by less forest cover (23.36%), lack of ground water resources (22.65%), water stress index (14.05%) and limited piped-water connection for household (13.18%) (Figure 2).

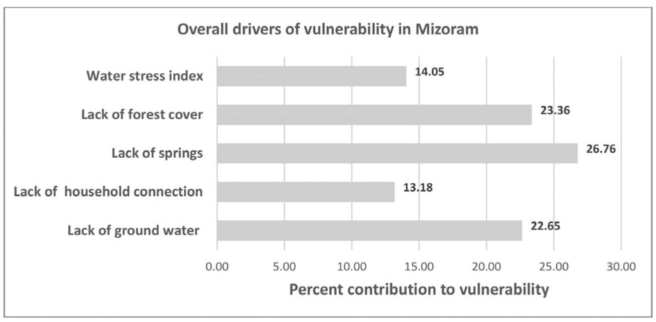

Figure 2: Bar diagram showing overall drivers of vulnerability: indicators and their corresponding percent contribution to an overall vulnerability against climate change and climate variability to water resources for the state of Mizoram.

District Wise Drivers of Vulnerability

Similarly, drivers of vulnerability and their respective percent contribution for each district were shown in Figure 3 (a to h) below in order of vulnerability ranking from 1 to 8. These figures highlight differences in drivers of vulnerability from district to district in contrast to the overall picture for the whole state of Mizoram shown in Figure 2. For instance, limited availability of perennial springs per household is the top contributor to vulnerability in the Champhai district whereas limited availability of ground water resources is the top contributor to vulnerability in the Champhai district. Likewise, the top contributors and their relative comparison can be seen in Figure 3 (a-h).

Conclusion

The result of vulnerability assessment can be highly subjective without careful examination of ground reality; especially, when assigning weights to indicators which is the major determinant apart from the actual data as seen in Table 2. Champhai district, which is the most vulnerable district of this study, as per the actual data has the most vulnerable score in none of the indicators used for the measurement but scores very high in two indicators and relatively high in one indicator having the highest weights. Similarly, the Mamit district, which is the most vulnerable for this study, as per the actual data has the least vulnerable score in two of the highest weighted indicators. Therefore, having relatively higher sensitivity or less adaptive capacity among different districts for most weighted indicators determines their higher vulnerability in the composite vulnerability index values and vice versa. Hence, while measuring vulnerability using selected indicators, one should note that there can be various inherent characteristics that can be used as indicators to measure the vulnerability of the same study area other than currently employed indicators. Therefore, it is important to carefully examine the most suitable indicators. Prior to the assessment, selection of indicators and assigning of weights are advised to be done with careful review by experts and stakeholder consultations.

The overall drivers of vulnerability are determined when the scores against the indicators are averaged across all the districts, they correspond with the weights assigned to the indicators as shown in Figure 2 (drivers of vulnerability are indicators expressed in lack of adaptive capacity to climate stress). However, it is evident that indicators contributing to the top drivers of vulnerability are not homogeneous when they are

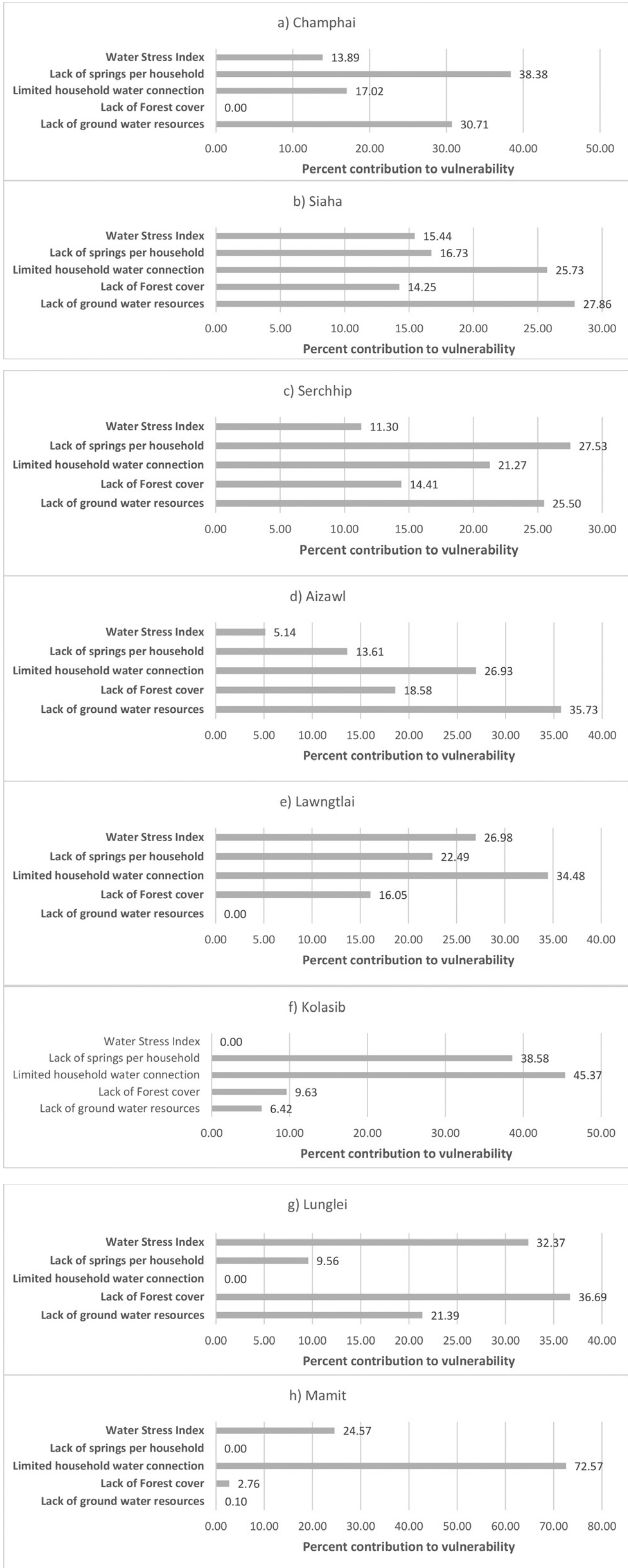

Figure 3 (a-h): Bar diagram showing drivers of vulnerability: indicators and their corresponding percent contribution to overall vulnerability for all districts in the state of Mizoram against climate change and climate variability to water resources.

considered separately for each district. This shows that districts are having specific problem or characteristics that need to be addressed separately. Therefore, planners and policy makers when investing their resources in reducing vulnerability can prioritise according to the result of the assessment carried out for their respective area of interest.

Nevertheless, vulnerability assessment does not end at Tier 1 approach such as this study, it is advisable that assessment of vulnerability should be repeated at finer resolution at block/village level/community level using primary data of location specific indicators.

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