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Climate Change and Farmer Livelihoods in Wayanad, India: A Livelihood Vulnerability Index Assessment

Nikhil Kumbrottil Sundaran[1], Aparna Radhakrishnan[1], Dileepkumar Ravindran[2], Binoo Palackal Bonny[3], Navitha Vijayan Nandini[4]

[1]Department of Agricultural Extension Education, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, 695 522, India.

[2] Department of Mathematics, KSMDB College, Sasthamcotta, Kollam, Kerala, 690 521, India.

[3] Communication Centre, Directorate of Extension, Kerala Agricultural University, Mannuthy, Thrissur, Kerala, 680 651, India.

[4] [1]Department of Agricultural Extension Education, College of Agriculture, Vellanikkara, Thrissur, Kerala, 680 656, India

Correspondence to: Nikhil K. S. (nikhilks7428@gmail.com)

Abstract. This study investigates the intricate relationship between climate change and livelihood vulnerability in the Wayanad district of Kerala, employing a Livelihood Vulnerability Index (LVI) to assess the household-level vulnerability of local farmers. A total of 41 indicators were used to construct the vulnerability index for the farmers of the Western Ghat region, with 16 indicators related to sensitivity, 7 to exposure, and 18 to adaptive capacity, and the index is administered to the farmers of Wayanad, Kerala. The results indicate a high level of vulnerability among most farmers, with exposure and sensitivity to climate risks, such as floods and droughts, significantly outweighing their adaptive capacity. The findings reveal that a substantial proportion of rural households are highly exposed to adverse climate change risks and lack the social, physical, and financial capital to effectively mitigate these challenges. The region's geographic and climatic conditions further exacerbate these vulnerabilities. Given the heavy reliance on agriculture for livelihoods in Wayanad, these results underscore the urgent need for targeted policy interventions to enhance the resilience of these communities.

Key words – Flood, adaptive capacity, households, livelihood, sensitivity, exposure

1. Introduction

Climate change is a severe global threat (Birkmann et al., 2022) with significant detrimental effects on agriculture (Liaqat et al., 2022). It particularly impacts impoverished rural communities that lack the resources and capacity to adapt to changing environmental conditions and access alternative methods of production (Wilk et al., 2013; Mugiya and Hofisi, 2017; Shisanya and Mafongoya, 2017). The consequences of climate change and extreme weather events can vary among farmers in the same area due to factors such as socio-demographic and economic differences within households (Kabir and Serrao-Neumann, 2020; Ofori-Kyereh et al., 2023). These consequences include decreased productivity of crops and livestock, heightened vulnerability to diseases and pests, and alterations in water resources and soil characteristics (Jbawi, 2020; Kołoszycz, 2020). Such shifts can

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lead to immediate crop failures and prolonged declines in production, posing significant threats to food security (Leichenko and O'Brien, 2002). Therefore, regional studies on adaptive capacity and vulnerability to climate change in areas prone to natural hazards are crucial for comprehensively understanding and effectively addressing the impacts of climate change (Malone and Engle, 2011).

Central to the discourse on climate change adaptation and mitigation strategies is the concept of livelihood vulnerability (Cannon and Muller-Mahn, 2010), defined as the susceptibility of a community's means of living to risks from ecological, financial, natural, and human-made sources, which can compromise its ability to sustain itself (Sarker et al., 2019). One effective way to conceptualize livelihood vulnerability to climate change is as a result of both biophysical and social factors (Cutter et al., 2000). It is characterized as a function of three components: adaptive capacity, sensitivity, and exposure (Jamshidi et al., 2019). Adaptive capacity represents the system's ability to respond effectively to changing environmental conditions, considering factors such as technological innovation, institutional capacity, access to resources, and social capital (IPCC, 2007). This includes four forms of capital leading to sustainable livelihoods: human, physical, social, and financial capital (Pandey and Jha, 2012). Exposure encompasses a thorough examination of the degree to which a system or community is directly impacted by climate-related hazards, considering factors such as the frequency, intensity, and spatial distribution of these hazards (Parry, 2007). Sensitivity focuses on the inherent characteristics and attributes of a system that render it susceptible to the effects of climate change, including socioeconomic conditions, demographic characteristics, infrastructure quality, and ecosystem health (IPCC, 2007). Each dimension of vulnerability is measured based on associated socio-environment specific indicators for assessing vulnerability at the community level (Jamshidi et al., 2019). These indicators are site-specific and are identified for different livelihood sectors (Leichenko and O'Brien, 2002). This approach is valuable for monitoring trends and capturing the multidimensionality of vulnerability and adaptation, providing a comprehensive framework for understanding and addressing the impacts of climate change on rural livelihoods.

According to the Kerala State Action Plan on Climate Change 2023-2030, several districts including Wayanad, Kozhikode, Kasaragod, Palakkad, Alappuzha, Idukki, Kannur, Malappuram, and Kollam are identified as highly vulnerable to the impacts of global warming and climate change due to factors such as high disease prevalence, a significant vulnerable population, and inadequate healthcare and relief infrastructure. Focusing on Wayanad, a high-altitude valley in Northern Kerala with a tropical monsoon climate due to its location in the Western Ghats (Gaetaniello et al., 2014), heavy rainfall occurs during the southwest monsoon season (June to September) and relatively less rainfall during the northeast monsoon season (October to December) (DES, 2005). Consequently, the region faces increased vulnerability to climate change impacts such as floods, landslides and droughts (Mathew, 2019). With agriculture being the primary occupation for most of Wayanad's population, livelihoods are directly influenced by climatic conditions, making them highly susceptible to climate variability (DES, 2005). Therefore, recognizing and addressing climate change vulnerability is crucial for developing effective policies and strategies to mitigate its impacts and build resilience within these communities. As highlighted by Huong et al. (2019), the initial step in this process involves conducting a comprehensive vulnerability assessment, which entails evaluating the interactions between human populations and their physical, social, and economic environments (Sarjana et al., 2009; Pachauri et al., 2014).

The study underscores the urgent need for targeted interventions that address the specific vulnerabilities of Wayanad households, which are deeply intertwined with the natural environment. It helps to equip these households with the tools they need to build resilience in the face of a changing climate. The findings enable the stakeholders to identify priority areas for intervention, allocate resources effectively, and develop adaptation strategies that enhance resilience and promote sustainable development in the face of climate change challenges (Pandey et al., 2017).

2. Materials and methods

2.1. Study Area

Kerala, particularly Wayanad, is highly vulnerable to climate change impacts such as floods, landslides, and droughts due to its geographic location, monsoon climate, and the influence of the Western Ghats (Varughese and Purushothaman, 2021). The Western Ghats, a biodiversity hotspot in India, is home to diverse land-use patterns including large-scale plantations and smallholder farms (Myers et al., 2000). Its geographical location significantly influences the state's climatic conditions (Nair et al., 2021) and the region experience recurring climate risks related to devastating landslides, floods (Raj and Sofi, 2021) and drought (Gopinath et al., 2020).

Wayanad district, located between 11°68′54” N and 76°13’20” E (Figure 1), covers an area of 2131 square kilometres. It is located at the southern edge of the Deccan Plateau and the Western Ghats, characterized by dense forest cover (Silja et al., 2008; Arumugam et al., 2023) and it is highly vulnerable to landslides (Abraham et al., 2023). The district situated in the high ranges of Kerala, is marked by agricultural challenges related to natural disasters such as floods and droughts, leading to agrarian distress (Tomson et al., 2023). Agriculture forms the primary economic activity of the district, and it is renowned for its cultivation of rice and pepper, along with crops such as coffee, tea, coconut, plantain, and cardamom (John et al., 2020).

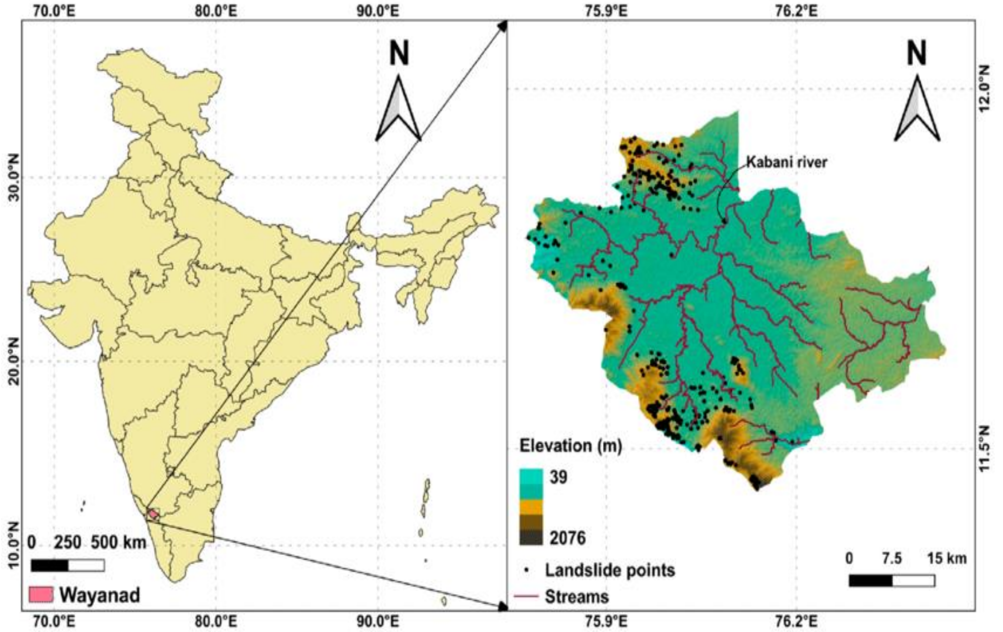

Figure 1: Geographic location of Wayanad district

2.2. Data collection

Data was collected through surveys, field inspections, and focus group discussions. A semi-structured questionnaire was used to assess farmer vulnerability based on exposure, sensitivity, and adaptive capacity. Exposure data was obtained from farmer surveys and secondary NCEP-NCAR reanalysis data on weather parameters for 10 years (2013-2023). Sensitivity and adaptive capacity data were collected through farmer surveys, focusing on demographics, social groups, land use, agricultural practices, human, physical, social, and financial capital.

2.3. Sampling technique

Wayanad district was purposefully sampled for the study due to its high incidence of agrarian distress caused by natural calamities such as floods and droughts (Tomson et al., 2023). The district comprises 23 villages: Ambalavayal, Edavaka, Kaniyambetta, Kottathara, Meenangadi, Meppadi, Mullankolly, Muppainad, Muttil, Nenmeni, Noolpuzha, Padinharathara, Panamaram, Poothadi, Pozhuthana, Pulppalli, Thariode, Thavinhal, Thirunelly, Thondernadu, Vellamunda, Vengappalli, and Vythiri. Data were collected from all the panchayats within these villages to ensure a comprehensive analysis of the district's vulnerability to climate change. The data were collected from a total of 115 respondents of the 23 grama panchayats, five from each panchayath by employing simple random sampling technique.

2.4. Selection of respondents

Before collecting individual respondent data, the study villages were visited, and a focus group discussion was conducted to gain insights into the conditions of the local people, the characteristics of the area, and the farming practices (Raihan and Hossain, 2021).

2.5. Livelihood vulnerability index for the farmers of Western Ghat region

An indicator-based methodology was employed to frame the Livelihood Vulnerability Index (LVI), a valuable tool for assessing how vulnerable households is to climate change and other external pressures. The LVI focuses on three key aspects: exposure (the threats households face), sensitivity (how susceptible they are to those threats), and adaptive capacity (their ability to cope). Each of these aspects is further broken down into sub-components and indicators, providing a comprehensive picture of vulnerability. The indicators under each dimension were selected through an extensive review of the literature and expert judgment. A total of 55 indicators were initially considered for the study, out of which 41 were included in the final construction of the LVI. The exposure dimension consists of 7 indicators, while sensitivity and adaptive capacity comprise 16 and 18 indicators, respectively. The list of indicators is given in the table 1. The LVI assigns weights to these indicators to create a single score, often using a balanced weighted average. In this study, Principal Component Analysis (PCA) was employed to determine the weights, ensuring they reflect the importance of each indicator within the LVI framework for understanding the vulnerability of farmers in the Western Ghats to climate change.

Step 1. Transforming measurement units. The first step entails converting the raw data from each indicator, acquired through a questionnaire survey, into suitable standardized measurement units.

Step 2. Normalization of indicators. As the indicators originally varied in units or scales, they underwent normalization (Pandey et al., 2017) so that each indicator value falls between 0 and 1 by using the equation (Equation (1)).

$$X_{ni} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where, Xni is the normalized indicator value, X is the actual indicator value, X is the maximum value of indicator and and X_{min} is the minimum value of the indicator.

Step 3. Assigning weightage to the indicator and construction of livelihood vulnerability index. Weightage for indicators under each dimension were given by using Principal Component Analysis (PCA). Based on the presumption that there are common elements that explain the variance in the vulnerability, it assisted in the assigning of the weightage. To calculate weights for constructing indexes, the loadings of each variable on the retained principal components are utilized. To maximize the variation explained by the first component, the PCA results were rotated using the varimax method. The analysis only includes components with eigenvalues greater than 1.

After getting weightage, the livelihood vulnerability index of each respondent under three functions was calculated by using the following equation (Equation (2)).

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$$LVI = \frac{\sum_{i=1}^{n} X_{ni} W_i}{\sum_{i=1}^{n} W_i} \qquad (2)$$

Where, LVI^{R} is the livelihood vulnerability index of a respondent, Xni was the normalized value of indicator and W_I is the weightage of the indicator. After that, the average livelihood index value is constructed by using the equation (Equation (3)).

$$LVI^{RA} = \frac{LVI^{R}}{n} \qquad (3)$$

Where LVI^{RA} is the average livelihood vulnerability index of a respondent and n is number of indicators

Step 4. Construction of average livelihood vulnerability index under three functions.

The average LVI of a respondent under exposure function, its subcomponents are climatic variables and extreme events is developed using two equations and they are known as LVI^{CV} and $LVI^{EE.}$

$$LVI^{E} = \frac{LVI^{CV} + LVI^{EE}}{2} \qquad (4)$$

Where LVI^{E} is the Livelihood vulnerability index under exposure dimension, LVI^{CV} and LVI^{EE} are the Livelihood vulnerability index values under climatic and extreme events subcomponents respectively. The average LVI of a respondent under sensitivity function for which the sub-components are demographic, vulnerable social group, land and agricultural activity is developed using four equation (Equation (5)), and they are knowns LVI^{D}, LVI^{VSG}, LVI^{L}, and LVI^{AA} respectively.

$$LVI^{S} = \frac{LVI^{D} + LVI^{VSG} + LVI^{L} + LVI^{AA}}{4} \qquad (5)$$

The average livelihood vulnerability index of a respondent under adaptive capacity for which the sub-components are human capital, physical capital, social capital and financial capital is constructed by using equation 3 and they are recognized as LVI^{HC}, LVI^{PC}, LVI^{SC}, LVI^{FC} respectively. It is calculated by using the equation (Equation (6)).

$$LVI^{AC} = \frac{LVI^{HC} + LVI^{PC} + LVI^{SC} + LVI^{FC}}{4} \qquad (6)$$

Step 5. Construction of overall livelihood vulnerability index. The overall livelihood vulnerability index of a particular respondent is constructed by using the equation (Equation (7)).

$$LVI = LVI^{E} + LVI^{S} - LVI^{AC} \qquad (7)$$

Step 6. Categorization of Livelihood Vulnerability Index Values. The obtained index values are categorized into four quartiles, recognized as very high, high, medium, and low vulnerable households. This categorization is done using quartiles, as outlined by Sujakhu et al., (2018).

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Table 1. Indicators for the various determinants of vulnerability and functional relationship with vulnerability

Components of vulnerability	Subcomponents	Indicators	Data collection	Functional relationship
Exposure	Climatic variables	Variance in annual rainfall	Secondary data	+
		Temperature variance	Secondary data	+
		Number of rainy days	Secondary data	+
		Change in mean temperature	Secondary data	+
	Extreme event	Frequency of flood	Secondary data	+
		Frequency of drought	Secondary data	+
		Frequency of heavy rainfall	Secondary data	+
Sensitivity	Demographic	Unemployment in the family	Field survey	+
		Family member involved in agriculture	Field survey	+
		Geographic location (Urban, rural, sub-urban)	Field survey	+
		Housing type (renter, homeowner)	Field survey	-
		Number of children under malnutrition	Field survey	+
	Vulnerable to social group	Children under 5 years old	Field survey	+
		Adults above 65 years old	Field survey	+
		Number of disabled persons	Field survey	+
	Land	Average land size	Field survey	-
		Uncultivated area due to water shortage	Field survey	+
		Sloppy farm land	Field survey	+
		Farm land size to each family member	Field survey	-
	Agricultural activity	Crop diversity ratio	Field survey	-
		Type of farming	Field survey	-
		Chemical fertilizer consumption	Field survey	+

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		Land cultivated by drought resistance variety	Field survey	-
Adaptive capacity	Human capital	Gender of the respondent	Field survey	-
		Experience in agriculture	Field survey	-
		Family annual income in rupees	Field survey	-
		Training received	Field survey	-
		Educational qualification of the respondents	Field survey	-
	Physical capital	Herd size	Field survey	-
		Farm equipment	Field survey	-
		Land Holding	Field survey	-
		Radio listening behaviour	Field survey	-
		TV watching behaviour	Field survey	-
		Newspaper reading habit	Field survey	-
	Social capital	Personal contact	Field survey	-
		Group contact	Field survey	-
		Mass media contact	Field survey	-
		Information evaluation behaviour	Field survey	-
	Financial capital	Availability of financial sources and credit	Field survey	-
		Milk production, consumption and sale	Field survey	-
		Form of savings and debt	Field survey	-

3. Result and discussion

3.1 Socio-economic profile of respondents

The socio-economic characteristics of farmers in Wayanad reveal a dependence on agriculture and allied activities as their primary source of income. The majority of the respondents in the study owned land holdings ranging from 0.3 to 2.4 acres and reported an annual income between Rs. 15,000 and 75,000. This limited land ownership and low income underscore the economic vulnerability of the farming community in the district. The data also indicate that most farmers belong to nuclear families, while a smaller portion resides in joint family setups (Prasad et al., 2017). The prevalent family structure can influence labour availability and the distribution of resources within households, impacting agricultural productivity and resilience to climate change. The detailed socio-economic profile of the respondents is given in the table 2.

The major crops cultivated by farmers in Wayanad include rice, coffee, black pepper, ginger, tapioca, fruits, and vegetables (Prathapachandran and Devadas, 2023). These crops form the backbone of the local economy and are integral to the livelihoods of the farming community. However, the cultivation of these crops is highly susceptible to climate variability, with floods and droughts posing significant risks. The choice of crops reflects the region's agro-climatic conditions and the traditional agricultural practices of the farmers. The reliance on these crops, coupled with the economic constraints, highlights the need for diversification and the adoption of sustainable agricultural practices to enhance resilience and ensure food security in the face of climate change.

Table 2. Socio-economic profile characteristic of respondents

Profile characteristics	Category	Percentage
Age	Young (<35)	6.96
	Middle (35-55)	58.26
	Old (>55)	34.78
Gender	Male	91.30
	Female	08.70
Educational status	Primary	27.83
	Upper primary	60.00
	High school	8.7
	Higher secondary	3.4
Farming experience	Low (<22)	18.26
	Med (22-48)	66.08
	high (>48)	15.66
Family annual income	Low (< Rs. 15,000)	16.52
	Medium (Rs. 15,000-75,000)	69.57
	High (> Rs. 75,000)	13.91
Land holding	Low (<0.3 acre)	13.91
	Med (0.3-2.4 acre)	66.09
	High (>2.4 acre)	20.00
Family structure	3 membered	6.09
	4 membered	51.30
	5 membered	16.52
	More than 6 membered	26.09

3.2. Exposure assessment

Wayanad district, nestled in Kerala's highlands (700-2100 meters above sea level), experiences a diverse climate with an average annual rainfall of 2322 mm (Madhu et al., 2021). Assessing exposure, a crucial aspect of vulnerability, this study focused on climatic factors. We analysed four key indicators: drought occurrences, flood incidents, heavy rainfall events, and rainy days. Wayanad farmers grapple with agricultural challenges due to frequent floods and droughts, highlighting their increased exposure and vulnerability to climate change (Tomson et al., 2023). Figure 2 presents a ridge plot illustrating the 90th percentile rainfall characteristics in Wayanad district from 1979 to 2023. Analysis of the plot reveals a notable increase in extreme rainfall events, with an increment of 1.06 mm over the last decade (2013 to 2023). Furthermore, a linear trend analysis of the data spanning from 1979 to 2023 indicates a total increase of 4.68 mm in intensity of extreme rainfall events. For the particular study period from 2014 to 2023, it is remarkable to note that the amount of rainfall has shown a drastic increase, especially in the years 2018, 2019, and 2021 with daily amounts reaching up to 14 mm, 19 mm, and 22 mm, respectively. This indicates an increasing trend in the extreme rainfall characteristics for Wayanad district. For instance, heavy rainfall events triggered consecutive flooding in 2018 and 2019 (Parthasarathy et al., 2021; Mehrishi et al., 2022), leading to land subsidence, fatalities (Madhu et al., 2021), and disruptions in agriculture and transportation. Floods also cause a decline in agricultural output, financial losses, and the emergence of waterborne diseases (Khan et al., 2022).

A study conducted by Tomson (2020) in Wayanad district reported that 41.4 percent of coffee farmers, 32.7 percent of black pepper growers, and 30 percent of coconut farmers experienced production losses ranging from 20 to 50 percent, 30 to 50 percent, and 20 to 50 percent, respectively, due to the flood in 2019–2020. In addition to this, Wayanad has battled droughts over the past decade. The 2016 drought exemplifies a broader trend of climate-induced water scarcity and reduced precipitation in South India, severely impacting agricultural development (Khan et al., 2022; Dhanya and Geethalakshmi, 2023), as shown in the ridge plot depicted in Figure 2. Figure 3(a) depicts the characteristics of maximum temperature distribution from 2013 to 2023 for Wayanad district. The data show an increase in extreme temperatures during the study period. Upon close observation, it is evident that in the years 2014, 2016, 2017, 2019, 2020, and 2023, the extreme temperature exceeded 35 degrees Celsius. Likewise, the minimum temperature distribution is depicted in Figure 3(b). It is also clear from Figure 3(b) that the minimum temperature is showing an increasing trend similar to the maximum temperature. Over the past 10 years, the minimum temperature has consistently exceeded 22.5 degrees Celsius. Notably, in 2016, the minimum temperature exceeded 23.75 degrees Celsius, and in 2019 and 2020, it nearly reached 23.75 degrees Celsius. These figures clearly indicate a significant difference between the minimum and maximum temperatures, a disparity that has been increasing over the past decade. Dileepkumar et al. (2018) observed a 0.7-degree Celsius increase in the 2-meter surface temperature along the west coast of India. This temperature rise is attributed to anthropogenic factors such as greenhouse gas emissions, aerosol forcings, and alterations in land use and land cover, as further supported by Krishnan and Ramanathan (2002). Hence, these fluctuating temperature parameters underscore the relevance of changing climatic factors and the current study of Wayanad district.

Over the past decade, the Wayanad district in Kerala has experienced notable shifts in its agricultural patterns due to extreme temperature variations. Rising temperatures have led to increased incidents of heat stress on crops such as coffee and spices, which are pivotal to the local economy. This temperature stress not only reduces crop yields but also affects their quality, posing significant risks to the livelihoods dependent on agriculture. Additionally, such temperature extremes exacerbate water stress conditions, further challenging the irrigation practices and water management strategies crucial for sustainable agriculture in the region.

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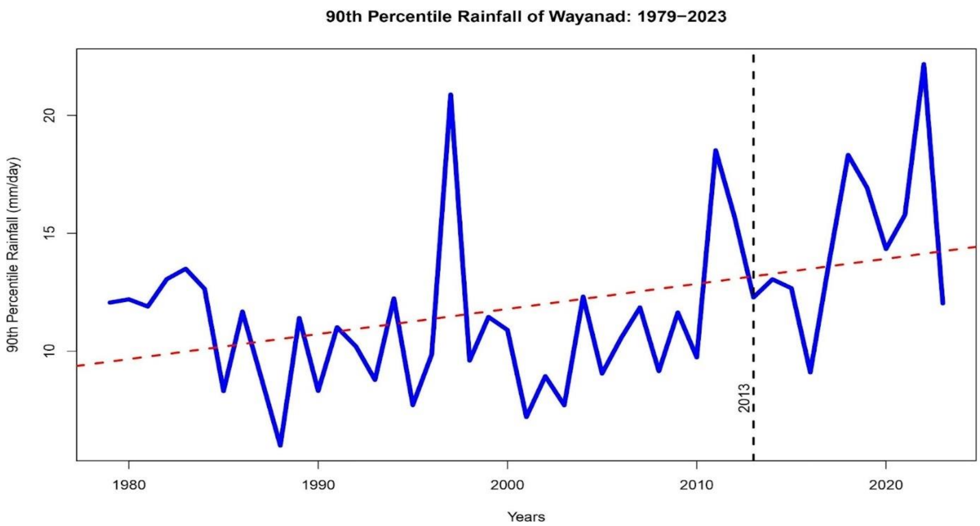
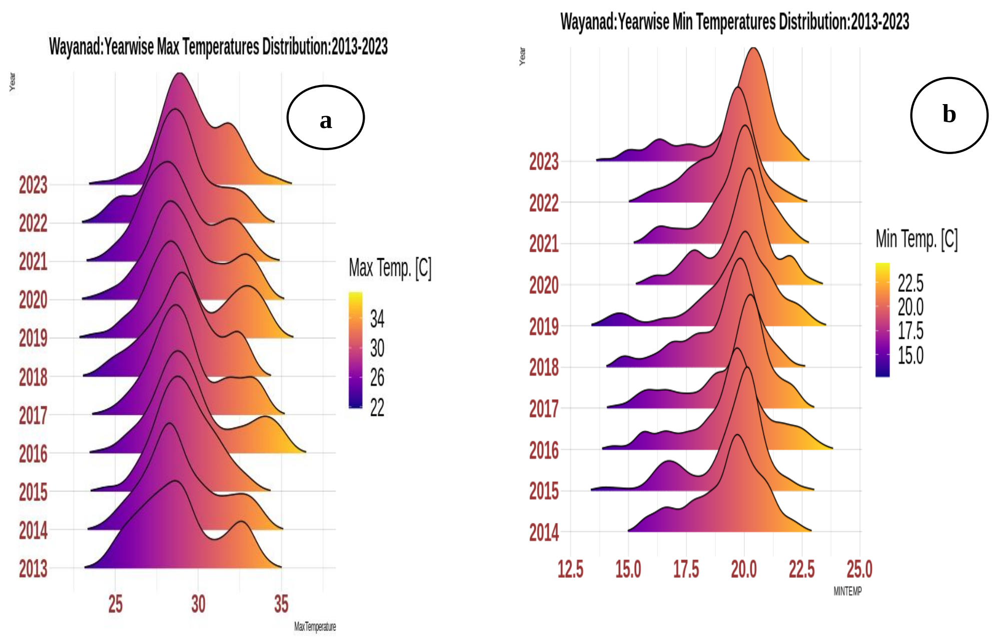


Figure 2: 90th percentile rainfall characteristics of Wayanad district for 1979-2023



Figures 3 (a-b): Yearwise maximum temperature distribution and Year wise minimum temperature distribution in Wayanad district for 2013-2023

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3.3. Sensitivity

In crafting the Livelihood Vulnerability Index, a comprehensive approach was adopted, focusing on four key sensitivity subcomponents viz; demographic factors, vulnerability within social groups, land characteristics and agricultural activities. Initially, the demographic domain was examined, with five indicators selected for assessment, namely, unemployment in the family, family members involved in agriculture, geographic location, housing type and number of children. Following an analysis using principal component analysis, three indicators viz; unemployment in the family, family members involved in agriculture and the number of children emerged as pivotal in delineating demographic vulnerability.

The weights assigned to each indicator within their respective principal components are, unemployment in the family (0.69), family members involved in agriculture (0.57) and number of children (0.59). Vulnerability to climate change can be greatly increased when there is unemployment in the family, especially in low income and rural households (Mendoza et al., 2014; Ncube et al., 2016). The majority of households have more than two members who are unemployed in the family, due to the scarcity of resources for efforts at mitigation and adaptation. Reduced crop yields and increased livelihood vulnerability are just a few of the negative effects that climate change may have on these vulnerable households (Amos, 2014). Consequently, lowering these households' unemployment is essential to lessening their susceptibility to climate change. Agrarian households face heightened susceptibility to the effects of climate change, with indicators such as education, income and resource availability significantly shaping their vulnerability (Ado et al., 2018), which can be witnessed in the study locale. Climate related shifts can impact economic uncertainty for these families, especially impacting those with limited educational qualifications (Yang et al., 2022). Additionally, the vulnerability of Wayand agrarian households to climate change is influenced by their geographical location and developmental status, with more advanced regions exhibiting lower vulnerability levels. These observations underscore the imperative for tailored strategies and measures aimed at bolstering support for agrarian communities confronting the challenges of climate change in Wayanad district.

In addressing vulnerability within social groups, a total of three indicators were initially identified for the analysis. The result of Principal component analysis shows that the two indicators, 'children under 5 years old' and 'adults above 65 years old' significantly contribute to climate change vulnerability. The vulnerability assessment assigns significant weight to the presence of vulnerable demographics, particularly adults above 65 years old (0.97). This reflects the disproportionate impact climate change has on these populations, as highlighted by Sripada (2021). Vulnerability in older adults stems from a combination of physiological decline and socioeconomic limitations. Factors like health, financial standing, and social networks play a crucial role, as external elements such as emergency preparedness and access to transportation (Gamble et al., 2013; Rhoades et al., 2018). Oven et al. (2012) emphasizes the importance of integrating health and social support systems to enhance their coping capacity. The high weighting and existing research underscore the urgent need for expanded research efforts and coordinated adaptation strategies specifically aimed at mitigating the vulnerability of elderly citizens in the face of climate change (Rhoades et al., 2018).

In the assessment of the land sub component, four initial indicators were selected for evaluation. Only two indicators surfaced as significant contributors to understand land related vulnerabilities and the indicators are 'average land size' and 'uncultivated area due to water shortage'. The weights assigned to each indicator within their respective principal components are, average land size (0.89) and uncultivated area due to water shortage (0.12). In Wayanad district, the average land holding size ranged from 1.35 hectares for small farms to 2.94 hectares for large farms. Among small farmers, 0.08 hectares were irrigated land and 1.27 hectares were dry land. In contrast, large farms had 0.25 hectares of irrigated land and 2.69 hectares of dry land (Mathew et al., 2018). The smaller size of land holding, lower educational status and lesser adaptive capacity make the farm households highly vulnerable to changing climate (Tripathi and Mishra, 2017). The reduced water availability may cause crop yields to suffer, which may lead to food poverty and land degradation (Fitton et al., 2019). These results highlight the urgent need to put strong adaptation plans in place to mitigate the effects of water shortages on agricultural productivity in the context of climate change.

In addressing the agricultural activity sub-component, an initial selection of four indicators were made for comprehensive evaluation. Out of these four, crop diversity ratio and type of farming emerged as salient contributors to vulnerability. The weights assigned to each indicator within their respective principal components are as follows: crop diversity ratio (0.90) and type of farming (0.79). Crop diversification can lead to positive livelihood benefits including increased resilience, improved nutrition and reduced poverty (Vernooy, 2022) and thereby less vulnerable to climate change. The chief agricultural crops in the district are coffee, tea, cocoa, pepper, banana, vanilla, rice, coconut, cardamom, tea, ginger, etc. This diversification directly points towards intercropping, which has the advantages of increased yield security and soil conservation. It has been recognized as a viable climate change adaptation technique (Himanen et al., 2016).

3.3. Adaptive capacity

The development of the Livelihood Vulnerability Index (LVI) involved a systematic selection of ten indicators under the human capital component. These indicators were carefully chosen to reflect various aspects of vulnerability among the farming community in Wayanad. To refine the selection and ensure the relevance of the indicators, Principal Component Analysis (PCA) was employed. Through this statistical method, four key indicators were extracted: gender, education, experience, and annual income. These indicators were found to have the most significant influence on livelihood vulnerability.

The extracted indicators were then weighted based on the rotated component matrix obtained from the PCA. This weighting process ensured that each indicator's contribution to the overall vulnerability index was proportional to its significance. The use of PCA and the subsequent weighting provided a robust and nuanced measure of vulnerability, capturing the complex interplay of socio-economic factors that affect farmers' resilience to climate change. The resulting LVI offers a comprehensive tool for assessing the human capital dimension of vulnerability, guiding targeted interventions to enhance the adaptive capacity of the farming community in Wayanad.

The weights presented indicate the relative importance of each indicator within the principal components derived from the analysis. Gender carries a weight of 0.331, education holds a weight of 0.670, experience is assigned a weight of 0.321, and annual income weighted 0.813. These weights reflect the contributions of each indicator to the overall assessment of human capital within the livelihood vulnerability index framework. Education and

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experience in agriculture are pivotal in influencing how farmers perceive and address climate change. These factors notably impact farmers' recognition of climate change and their strategies for adaptation (Hasan and Kumar, 2019). Specifically, education and experience correlate with a deeper comprehension of climate change and the adoption of measures for adaptation. The low level of education of farmers in the locale has made them unaware about the scientific mitigation practices and adaptive capacity. Hence, there is a necessity for enhanced education and institutional support to enhance farmers' capacity to adapt to climate change (Abid et al., 2015). This emphasizes the significance of education, which can empower farmers to more effectively mitigate the effects of climate change (George et al., 2007). Another crucial indicator in determining adaptive capacity and susceptibility to climate change is the family's annual income (Reidsma et al., 2009). The low income of households in the Wayanad made them less adaptive and more vulnerable to adverse climatic conditions. Particularly in flood prone regions, income inequality and variations in agricultural income play a substantial role in determining vulnerability (Alamgir et al., 2021). Also, wealthier farmers with higher socioeconomic status tend to perceive climate risks differently and possess greater capacity to adapt as a result (Cooper and Wheeler, 2017).

For the physical capital component, seven indicators were initially considered. Out of these, four key indicators named, average milch animal, milking machine, farm equipment and irrigation were extracted by using PCA. The vulnerability assessment emphasizes the importance of physical capital, encompassing essential infrastructure and resources needed for sustainable livelihoods (Pandey et al., 2017). Indicators like average milch animals (weight: 0.860), milking machines (0.877), farm equipment (0.787), and irrigated land ownership (0.793) received high weightage within the physical capital component, highlighting their significance. Livestock ownership is widespread, providing income, food security, and resilience for many households (Pandey et al., 2017). Farm machinery, particularly precision agriculture technologies like drip irrigation, can significantly bolster farm resilience against climate change impacts (Mohapatra et al., 2022). Unfortunately, the lack of these crucial assets renders most farmers highly vulnerable. This underscores the need for interventions that enhance access to essential physical capital resources, allowing farmers to strengthen their livelihoods and adapt to a changing climate.

Seven indicators were initially selected under the social capital component. They are the social resources by which local communities' pursuit their livelihood objectives (Pandey et al., 2017). After conducting Principal Component Analysis (PCA), four key indicators were extracted, they are possession of radio and television and the listening and watching behaviour. Subsequently, weights were calculated for each indicator based on their relationship with the components identified in the rotated component matrix. The weights assigned to each indicator within their respective principal components are, possess radio (0.954), radio listening behaviour (0.943), possess television (TV) (0.888), and TV watching behaviour (0.848). These weights indicate the relative importance of each indicator in assessing the social capital component within the framework of the analysis. The role of radio and television in communicating climate change is crucial, especially in reaching vulnerable communities (Mannar, 2014), with the news media being a primary source of information. Therefore, media communication, including radio and television, significantly shapes public awareness and knowledge about climate change and mitigation practices in Wayanad district.

In the development of the Livelihood Vulnerability Index (LVI), seven indicators were initially assessed for the financial capital aspect. Financial capital refers to the monetary assets individuals typically utilize to manage extreme events (Pandey et al., 2017). Three key indicators viz; source of credit, type of credit and amount they received emerged significantly in PCA. The weights assigned to each indicator within their respective principal components are, source of credit (0.926), type of credit (0.90) and amount (0.609). These weights signify the relative importance of each indicator in assessing the financial capital component within the framework of the analysis. Farming in Wayanad region is very fragile because it is prone to frequent damage by landslides, heavy rain, cloudburst and drought. Once farming land is damaged, households are unable to cultivate the soil for the next few months and have to invest a large proportion of their savings in restoration of the land (Pandey et al., 2017). Therefore, financial capital has a crucial role in their vulnerability to climate change (Yang et al., 2022). Credit institutions and concessional loans play a vital role in enabling farmers to build resilience to climate change impacts (Odhong et al., 2019). However, the accessibility of credit facilities for mitigating climate change in agriculture poses a significant challenge, especially for smallholder farmers.

The classification of respondents into different vulnerability levels was done based on Quartile deviation thresholds. (Table 3).

Table 3. Classification of Respondents into Vulnerability Levels Based on Quartile Deviation Thresholds

Sl No:	Vulnerability level	Quartile deviation threshold	Number of respondents	Percentage
1	Low Vulnerable	<0.011	25	21.74
2	Moderately vulnerable	0.011- 0.128	27	23.47
3	Highly vulnerable	0.128-0.188	29	25.21
4	Very highly vulnerable	>0.188	34	29.57

The classification of respondents into vulnerability levels based on quartile deviation thresholds reveals a diverse distribution across the sample. Notably, 25 respondents, comprising 21.74% of the total, fall under the category of low vulnerable with vulnerability index levels below 0.011. Moderately Vulnerable respondents, totalling 27 individuals or 23.47% of the sample, exhibit vulnerability levels ranging from 0.011 to 0.128. Meanwhile, 29 respondents, representing 25.21% of the total, are classified as highly vulnerable, with vulnerability levels spanning 0.128 to 0.188. Lastly, 34 respondents, accounting for 26.57 % of the sample, are categorized as very highly vulnerable, indicating vulnerability levels surpassing 0.188. From statistical analysis it is clear that, for the majority of the households, the combined effect of exposure and sensitivity outreach their adaptive capacity which made them vulnerable to climate change. Also, only for a few households having a negative livelihood vulnerability index value, which indicates their high adaptive capacity and very less vulnerability to climate change. This classification underscores the nuanced susceptibility among respondents to various factors under scrutiny, offering valuable insights into the distribution of vulnerability within the Wayanad region. The spider diagram illustrating the climate change vulnerability of households, which includes exposure, adaptive capacity, and sensitivity, is presented in figure 5 below. The figure does not show a symmetrical triangle due to the disparity among the components.

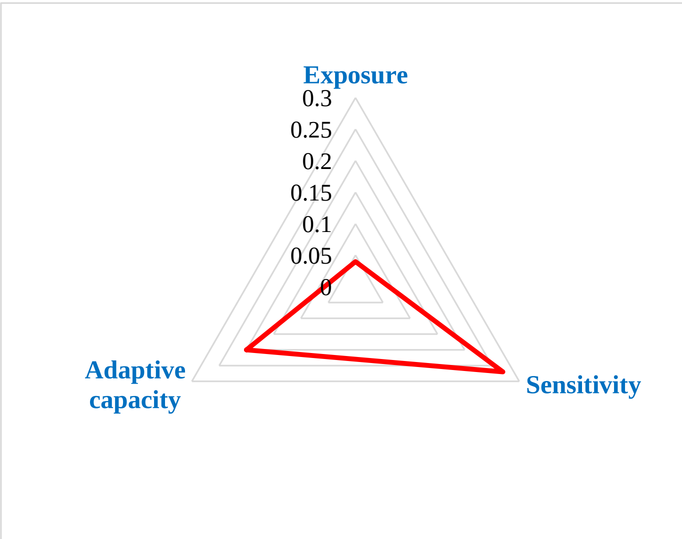

Figure 5: Spider diagram of climate change vulnerability components

4. Conclusion

In the present, the livelihood vulnerability index developed for farmers in Western Ghat region and administered to the Wayanad districts provides a comprehensive framework for assessment of vulnerability through the measurement of exposure, sensitivity and adaptive capacity. Through the examination of various indicators under these functions, it becomes evident that households in the Wayanad region faces significant challenges due to climate change, particularly in terms of exposure to extreme events like floods and drought. Sensitivity assessment reveals demographic factors, vulnerability within social groups, land characteristics and agricultural activities as crucial components contributing to vulnerability. The indicators such as unemployment in the family, family members involved in agriculture, and the number of children emerged as significant contributors to demographic vulnerability, while factors like children under 5 years old and adults above 65 years old highlighted vulnerability within social groups. The assessment of adaptive capacity emphasizes human and physical capital, social capital, and financial capital. Indicators such as education, experience, annual income, possession of radios and TVs, and access to credit play pivotal roles in determining adaptive capacity. The classification of households into vulnerability levels based on quartile deviation thresholds underscores the diverse distribution of vulnerability within the sample population. The results indicated that the Wayanad region is highly vulnerable to climate change, necessitating urgent and tailored interventions to address the specific challenges faced by its farmers.

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Author Contribution

Nikhil Kumbrottil Sundaran.: Primary data collection and preparation of manuscript

Aparna Radhakrishnan: Preparation of manuscript

Dileepkumar Ravindran.: Secondary data collection and Statistical analysis

Binoo Palackal Bonny: Proof reading of manuscript

Navitha Vijayan Nandini: Statistical analysis of the primary and secondary data

Competing interests

The authors declare that they have no conflict of interest.

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