

A Multidimensional Climate Vulnerability Index for Rural Households: Empirical Evidence from Togo 2019¹

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Abstract. This paper develops a multidimensional climate vulnerability index for rural households in Togo using 2019 household survey and satellite-based data. The index combines exposure, sensitivity, and adaptive incapacity indicators within a deprivation-based framework and applies transparent cut-offs and weights. Results show that climate vulnerability is widespread, with the highest concentration in rural areas and in the northern regions, especially Savanes and Kara. Exposure accounts for nearly half of total vulnerability, with drought and soil moisture deficit as major drivers. The index provides a replicable tool for territorial targeting of adaptation policies and for monitoring climate-related household risks.

1. Introduction

Climate change poses a major threat to agricultural systems and rural livelihoods, particularly in low-income countries where rising temperatures, erratic rainfall, droughts, and extreme weather events undermine food security and economic stability [1–6]. In Sub-Saharan Africa, where agriculture is largely rain-fed, rural households are especially vulnerable because their livelihoods depend heavily on natural resources [4–8]. Following the IPCC framework, climate vulnerability is understood as the interaction of exposure, sensitivity, and adaptive capacity [1,9–11]. Togo provides a relevant case study because of its marked climatic contrasts, strong dependence on small-scale agriculture, and persistent structural constraints such as limited irrigation, weak access to improved inputs, and low social protection coverage [29–32]. Despite important advances in the literature, empirical measurement of climate vulnerability remains limited by fragmented approaches that often separate environmental exposure from socioeconomic conditions and rarely test robustness systematically [12–21,33]. This paper addresses these gaps by developing a Multidimensional Climate Vulnerability Index for rural households in Togo using 2019 survey and geospatial data. The index combines environmental exposure, sensitivity, and adaptive incapacity within a deprivation-based framework inspired by multidimensional poverty measurement [22,23]. By integrating satellite-based and household-level indicators and assessing robustness through leave-k-out procedures, the study provides a transparent, reproducible, and policy-relevant tool for measuring the incidence, intensity, and territorial distribution of household climate vulnerability [20,24–28,34–36].

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2. Literature Review and Conceptual Framework

Climate vulnerability is now widely understood as a socio-environmental construct shaped by the interaction of exposure, sensitivity, and adaptive capacity rather than by climatic hazards alone [1,7,9,10,12,13]. While early assessments focused mainly on biophysical exposure, later work showed that similar climatic shocks can produce very different welfare outcomes depending on household and community conditions [7,8,10]. In empirical research, this creates an important measurement challenge because vulnerability is a latent concept that must be approximated through observable environmental and socioeconomic indicators. Existing approaches generally follow either an outcome-based perspective, which estimates projected damages under specific climate scenarios, or a contextual perspective, which evaluates the structural conditions that influence current susceptibility and capacity to respond [8]. This study adopts the contextual approach because it allows vulnerability to be measured directly from observed geospatial and household data without relying on forward-looking assumptions. Within this perspective, a multidimensional index is appropriate because climate vulnerability is inherently multidimensional and only partly compensatory: low exposure does not eliminate socioeconomic fragility, and greater adaptive capacity does not remove climatic risk. Composite indicator theory suggests that such an index requires clear choices regarding indicator selection, transformation, weighting, aggregation, and validation [19–21]. Following the multidimensional poverty literature, this paper uses a deprivation-based framework in which indicators are converted into binary shortfalls relative to defined thresholds [22,23]. This improves interpretability, limits sensitivity to extreme values, and supports transparent policy use. Equal weighting is applied within dimensions to preserve simplicity, comparability, and conceptual clarity, while aggregation is structured to allow partial substitutability within dimensions but not across the core components of vulnerability. This design is consistent with the IPCC framework and yields a decomposable measure that can be broken down by dimension and population subgroup, making it suitable for policy analysis and territorial targeting.

3. Design of the Multidimensional Climate Vulnerability Index

Following Alkire and Foster, the construction of the multidimensional index is guided by a set of explicit design principles. The index aims to measure household vulnerability to climate change as the combined effect of exposure to climatic risks and limited capacity to respond, adapt, and recover. It is also intended as a decision-support tool for targeting interventions, prioritizing public investment, monitoring progress, and strengthening coordination across sectors and regions. While the application focuses on Togo, the methodology is potentially replicable in other countries. The household is the unit of identification, whereas the individual is the unit of analysis. The empirical framework draws on two complementary data sources: the 2019 Enquête Harmonisée sur les Conditions de Vie des Ménages for socioeconomic information and satellite-based datasets processed in Google Earth Engine for environmental indicators. The index is structured around three dimensions, namely environmental exposure, sensitivity, and adaptive incapacity, in order to capture both external climate-related pressures and household response constraints. The complete set of dimensions, indicators, weights, and cut-offs is reported in Table 1.

Table 1. List of indicators by dimension

Dimension	Indicator	Definition (cut-offs)
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Sensitivity (25%)	Small scale food producer	Household is classified as a small-scale food producer when it falls below the 40th percentile threshold of cumulative land size, livestock (TLUs), and economic size (LCUs).
	Agricultural household	Household is engaged in any agricultural activity (crop, livestock, fishery or forestry production)
	Inadequate housing quality	Household dwelling lacks adequate structural quality, defined as having a dirt floor or non-brick external walls, or lacking a solid roof.
	Lack of electricity access	Household does not have access to electricity.
	Lack of improved sanitation	Household does not have access to improved sanitation facilities, defined as facilities ensuring hygienic separation of human excreta from human contact.
	Lack of safe drinking water	Household does not have access to a safe drinking water source (e.g., piped water, protected well, communal tap).
	Female household head	Head of household is female.
	High dependency ratio	Household demographic dependency ratio (population aged 0–14 and 65+ relative to working-age population 15–64) is equal to or greater than 2.
	Household head elderly or very young	Head of household is younger than 18 years old or older than 60 years old.
	Household in severe food insecurity	Household is considered vulnerable if its food insecurity score reflects severe food insecurity (FIES scale)
	Bottom 40% income	Household is considered vulnerable if its total income places it in the bottom 40 percent of the national income distribution.
	High non-employment ratio	More than 50% of working-age members of the household are not employed
	Youth NEET (Not in Education, Employment, Training)	At least one youth member of the household is not in education, employment, or training (NEET).
Poor household	Household per capita consumption falls below the national poverty line. ¹	
Adaptive Capacity (25%)	Low adult educational attainment	Household average years of education among adults (15+) is below seven years.
	Adult illiteracy	At least one adult member of the household is illiterate (unable to read and write a simple statement).
	Lack of mobile phone ownership	Household does not own a mobile phone.

	Low asset ownership	Household owns fewer than two of the following durable assets: television, radio, refrigerator, gas/electric stove, microwave, fan, washing machine/dryer, vacuum cleaner, air conditioner, generator, or improved stove.
	Lack of transport ownership	Household does not own any motorized vehicle, bicycle, or boat.
	No use of agricultural mechanization	Household does not use mechanized equipment in farming activities.
	No access to private transfers	Household does not receive domestic or international remittances or other private transfers.
	Lack of social protection coverage	No member of the household receives social insurance or social assistance benefits.
	Lack of fertilizer use	Household does not use inorganic fertilizers.
	Lack of improved seeds	Household does not use improved seed varieties.
	Lack of pesticide or herbicide	Household does not use pesticides, herbicides, or other agricultural chemicals.
	Lack of irrigation	Household does not use irrigation in crop production.
	Lack of agricultural machinery	Household does not own mechanized farming equipment.
	Lack of agricultural land ownership	Household does not own agricultural land.
Exposure (50%)	Drought exposure (SPI-based)	A household is considered exposed to drought conditions if it resides in a prefecture where the mean Absolute Standardized Precipitation Index (SPI) exceeds 1, indicating substantial deviations from usual rainfall patterns.
	Extreme heat exposure	A household is considered exposed to extreme heat if it resides in a prefecture where at least 25 percent of days during the reference period recorded maximum temperatures above 35°C, reflecting sustained heat stress conditions.
	Fire Hazard Exposure	A household is considered exposed to fire hazards if it resides in a prefecture where more than 10 percent of the territory burned at least once during the reference year, indicating significant landscape-level fire events.
	Soil moisture deficit exposure (SMI-based)	A household is considered exposed to soil moisture stress if it resides in a prefecture where the Soil Moisture Index (SMI) is below 50 percent, indicating insufficient soil moisture levels that constrain crop growth and agricultural productivity.

	Low vegetation productivity (LAI-based)	A household is considered exposed to vegetation stress if it resides in a prefecture where the Leaf Area Index (LAI) is below 3, reflecting limited vegetation density and reduced biomass development.
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3.3.1 Exposure

The exposure dimension captures the likelihood that households are affected by climatic hazards associated with their location. It is measured independently of household sensitivity or adaptive capacity and reflects the spatial distribution of environmental risks. To operationalize this dimension, the index combines remote sensing indicators that capture complementary forms of climate stress relevant to livelihoods and agriculture, including temperature anomalies, rainfall deviations, vegetation condition, soil moisture, and wildfire occurrence. Specifically, the proportion of hot days and the Absolute Standardized Precipitation Index measure climatic anomalies, while the Soil Moisture Index and Leaf Area Index reflect moisture conditions and vegetation performance linked to agricultural productivity. Burned area is included as an additional hazard with direct implications for crops, assets, and livelihoods. Other indicators, such as the Vegetation Health Index, tropical nights, and flood exposure, were tested but excluded because they showed limited spatial variation or weak discriminatory power in Togo. Because household surveys rarely provide adequate information on localized environmental conditions, exposure is derived from publicly available satellite-based datasets processed in Google Earth Engine. Pixel-level indicators were aggregated to the prefecture level, the lowest administrative unit available in the survey, to ensure consistency when linking geospatial and household data. Prefectures where more than 10% of the territory burned at least once during the reference year were classified as exposed to fire hazards. Similarly, prefectures where at least one out of every four days registered maximum temperatures above 35°C were considered exposed to extreme heat. The exposure index for each prefecture was then computed as the proportion of indicators in which the prefecture was classified as exposed. These results were then associated with each household.

3.3.2 Sensitivity

The sensitivity dimension captures the degree to which households are affected when a climatic hazard actually occurs. While exposure reflects the likelihood of living an extreme condition in first person, sensitivity describes how severely livelihoods are impacted once the event materializes. It is therefore shaped by socioeconomic conditions, the quality and resilience of housing and infrastructure. Indicators are derived exclusively from the household survey. These factors include conditions related to small-scale agricultural production (following FAO’s definition of small-scale food producers), participation in agriculture, physical and infrastructural attributes of the dwelling, characteristics of household members, income and employment conditions.

3.3.3 Adaptive (In)capacity

The adaptive incapacity dimension captures the extent to which households lack the resources and conditions needed to cope with, adjust to, and recover from climate-related shocks. Unlike sensitivity, which reflects how strongly households are affected, adaptive incapacity refers to limited capacity for response and recovery. It is measured using household survey indicators

related to education, asset ownership, communication and mobility, productive capacity, and access to support mechanisms. In particular, the dimension includes constraints in the use of agricultural inputs, mechanization, irrigation, and land ownership, as well as limited access to social protection and informal support networks. Households deprived in these areas are considered less able to manage risks, adapt livelihoods, and recover from adverse climate events.

3.3.4. Weights

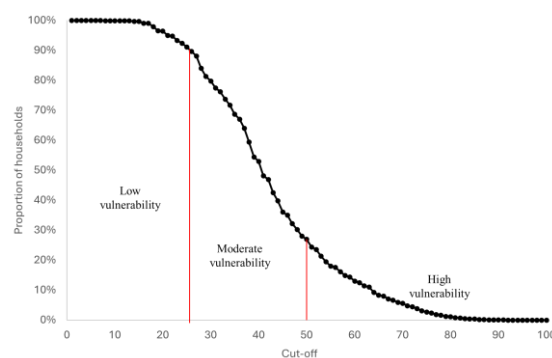
Recognizing that physical exposure to climatic hazards constitutes the primary determinant of climate vulnerability, the Exposure dimension was assigned a weight of 50 percent in the overall index. The remaining weight was distributed equally between Sensitivity and Adaptive (In)capacity, each receiving 25 percent. Within each dimension, indicators were assigned equal weights to avoid introducing implicit normative priorities and to maintain transparency and methodological simplicity in the aggregation process.

3.4. Identification and aggregation

Aggregation follows the Alkire-Foster framework through the construction of a weighted vulnerability score at the household level. The composite score is obtained as the weighted sum of exposure, sensitivity, and adaptive capacity indicators. A second cutoff is then applied to classify households into different vulnerability levels.

Households were classified as having **low vulnerability** when they accumulated less than 25% of the identified factors, **moderate vulnerability** when they accumulated between 25% and 50%, and **high vulnerability** when more than 50% of the vulnerability factors were present. This classification reflects increasing intensity of simultaneous exposure, sensitivity, and adaptive capacity constraints.

Figure 1. Vulnerability identification cut-off



3.5. Robustness and validation tests

The initial construction of the Sensitivity and Adaptive Capacity dimensions considered a broader set of approximately 40 candidate indicators. The final selection of 14 indicators per dimension resulted from a structured screening process that assessed data availability, missing values, and statistical redundancy. Tests of association were conducted to avoid overrepresentation of highly correlated variables and to ensure that each retained indicator contributed distinct informational content to the composite measure.

To evaluate robustness, a leave-k-out strategy was implemented. For each value of k , k indicators were removed, the remaining indicators were proportionally reweighted, and all possible subsets were re-estimated. Results show that the mean values of both dimensions remain highly stable across all scenarios, indicating that neither dimension is driven by any single indicator or small subset of indicators. Although dispersion increases as more variables are excluded, deviations from the full-information estimate remain moderate, confirming the structural stability of the selected indicator set.

4. Main Results

Climate vulnerability in Togo in 2019 was widespread. Only 8.4% of households (7.6% of the population) were classified as having low vulnerability, while 54.8% of households (61.1% of the population) were moderately vulnerable and 36.7% of households (31.2% of the population) were highly vulnerable. In total, nearly 92% of households (> 6.8 million of people) were exposed to moderate or high levels of climate vulnerability. This indicates that vulnerability to climate-related risks is not a marginal phenomenon but a systemic national challenge (see 2).

Table 2. Climate vulnerability in Togo 2019

Climate vulnerability	Households		Population	
	Number	Percentage	Number	Percentage
Low	151,138	8.4	563,575	7.6
Moderate	1,100,314	54.8	4,524,857	61.1
High	463,561	36.7	2,312,054	31.2
Total	1,715,014	100	7,400,486	100

Source: Author's elaboration

Climate vulnerability shows a pronounced rural bias. In rural areas, 47.8% of households are highly vulnerable compared to only 17.9% in urban areas. Conversely, urban areas concentrate a larger share of moderately vulnerable households (67.1%) and a higher proportion of low-vulnerability households (15.0%) than rural areas (see Table 3). These results reflect the greater exposure of rural population to climatic hazards, disadvantageous socioeconomic conditions that make it more sensible and their lower adaptive capacity.

Table 3. Climate vulnerability in Togo 2019, by rural and urban area

Climate vulnerability	Household percentage			Population percentage		
	Rural	Urban	Total	Rural	Urban	Total
Low	4.6	15.0	8.4	4.9	11.5	7.6
Moderate	47.7	67.1	54.8	51.8	74.6	61.1
High	47.8	17.9	36.7	43.3	13.9	31.2

Source: Author's elaboration

Vulnerability is spatially concentrated. The northern regions of Kara and Savanes show the most critical situation. In Savanes, 87.2% of households (88.9% of the population) are highly vulnerable, while in Kara 61.9% of households (65.5% of the population) fall into the high-vulnerability category. In contrast, Maritime and Lomé Commune display predominantly

moderate vulnerability levels, with relatively small shares of highly vulnerable households (See Table 4). This north–south gradient suggests that climatic stress and structural fragilities intensify as one moves toward the northern agro-ecological zones.

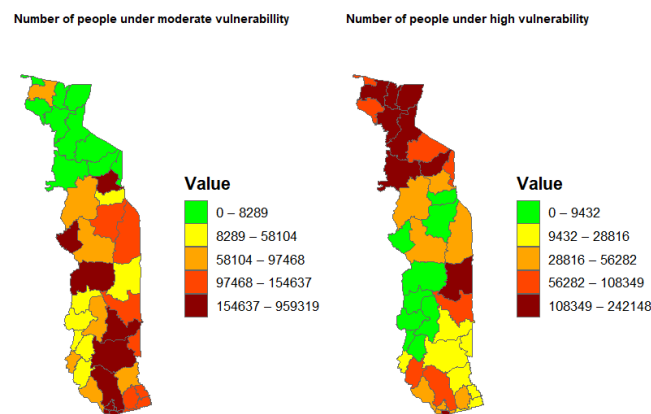
Table 4. Climate vulnerability in Togo 2019, by region

Climate vulnerability		Low	Moderate	High	Total
Household percentage (by region)	Maritime	21.0	66.8	12.2	100
	Plateaux	15.0	64.4	20.6	100
	Centrale	13.8	72.8	13.4	100
	Kara	2.2	36.0	61.9	100
	Savanes	0.0	12.8	87.2	100
	Lomé commune	2.3	87.9	9.8	100
Population percentage (by region)	Maritime	14.3	69.3	16.4	100
	Plateaux	14.2	63.8	22.0	100
	Centrale	12.2	74.2	13.6	100
	Kara	2.5	32.0	65.5	100
	Savanes	0.0	11.1	88.9	100
	Lomé commune	2.6	87.7	9.8	100

Source: Author’s elaboration

high vulnerability is heavily concentrated in northern prefectures. The largest numbers of highly vulnerable populations are observed in **Oti (242,148)**, **Tone (233,328)**, **Kpendjal (211,177)**, **Dankpen (182,234)**, and **Doufelgou (111,166)**. Additional significant concentrations appear in **Binah (97,137)**, **Tandjoare (95,973)**, and **Cinkasse (92,529)**. These prefectures, largely located in the Savanes and parts of Kara.

Map 1. Concentration of population in moderate and high climate vulnerability of risk across Prefectures



The decomposition of this vulnerability shows that the Exposure dimension accounts for nearly half of total vulnerability (49%) in both moderate and high categories. Within this dimension, drought exposure (SPI-based) and soil moisture deficit are the most significant contributors. In the moderate vulnerability group, drought alone accounts for 22.3% of total vulnerability, confirming that rainfall anomalies and water stress are the dominant climatic risks. Extreme

heat, vegetation stress, and fire hazards also contribute but play a secondary role relative to drought-related pressure (See Table 5)

Table 5. Contributions of dimensions and indicators to moderate and extreme climate vulnerability

Table 5: Contributions of dimensions and indicators to moderate and extreme climate vulnerability (%)

Dimension / Indicator	Moderate	Extreme
Sensitivity (dimension total: 22% moderate; 27% extreme)		
Small scale food producer	1.0	1.6
Agricultural household	1.7	2.3
Inadequate housing quality	1.6	2.2
Lack of electricity access	1.8	2.3
Lack of improved sanitation	2.2	2.3
Lack of safe drinking water	1.3	1.3
Female household head	1.3	0.8
High dependency ratio	0.7	0.7
Household head elderly or very young	0.5	0.4
Household in severe food insecurity	5.0	8.2
Bottom 40% income	1.6	1.4
High non-employment ratio	1.3	0.7
Youth NEET (not in education, employment, or training)	0.6	0.4
Poor household	1.4	1.7
Adaptive (In)capacity (dimension total: 29% moderate; 25% extreme)		
Low adult educational attainment	2.6	2.4
Adult illiteracy	2.1	2.2
Lack of mobile phone ownership	0.4	0.7
Low asset ownership	2.6	2.6
Lack of transport ownership	3.0	1.7
No use of agricultural mechanization	1.2	1.4
No access to private transfers	3.7	2.5
Lack of social protection coverage	3.3	2.1
Lack of fertilizer use	0.8	0.9
Lack of improved seeds	1.4	1.8
Lack of pesticide or herbicide	0.9	1.3
Lack of irrigation	1.7	2.3
Lack of agricultural machinery	1.2	1.4
Lack of agricultural land ownership	3.9	1.4
Exposure (dimension total: 49% moderate; 49% extreme)		
Drought exposure (SPI-based)	22.3	6.5
Extreme heat exposure	4.7	11.7
Fire hazard exposure	2.0	8.8
Soil moisture deficit exposure (SMI-based)	13.7	11.2
Low vegetation productivity (LAI-based)	6.8	10.6

Source: Author's elaboration.

Note: Percentages may not sum exactly due to rounding.

Sensitivity contributes between 22% and 27% of total vulnerability. Severe food insecurity stands out as the single most important sensitivity factor, particularly among highly vulnerable households (8.2%). Structural dependence on agriculture, inadequate housing conditions, and limited access to basic services such as sanitation and electricity also increase sensitivity to climatic shocks. These findings indicate that pre-existing socioeconomic fragilities amplify the impact of environmental stress.

Adaptive incapacity also accounts for around one quarter of total vulnerability (25–29%) . The most binding constraints include lack of agricultural land ownership, absence of private transfers or remittances, limited social protection coverage, low asset ownership, and low adult educational attainment. These factors limit households' ability to absorb, cope with, and recover from climate shocks. Strengthening access to productive assets, education, financial transfers, and social protection mechanisms emerges as central to improving resilience.

5. Conclusion

The results provide a comprehensive and spatially explicit picture of climate vulnerability in Togo in 2019. By identifying how many households are vulnerable, where they are located, and which factors drive their vulnerability, the index offers an operational tool for decision-making. For government institutions, the findings support territorial targeting of climate adaptation policies, particularly in northern prefectures where high vulnerability is concentrated, and in rural areas where structural fragilities amplify climatic risks. For international cooperation partners, the index helps prioritize investments in drought resilience, agricultural adaptation, social protection expansion, and asset-building strategies. For researchers, the dataset opens avenues for further analysis of climate–poverty interactions, shock transmission mechanisms, and policy simulation exercises.

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