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Review

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Taking Stock of Recent Progress in Livelihood Vulnerability Assessments to Climate Change in the Developing World

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Abstract: Over the past few decades, the use of vulnerability assessments has grown substantially to support rural communities in developing countries. These studies aim to help these communities achieve their livelihood goals, such as sustainable resource use and adaptation to global changes, by evaluating their susceptibility to climate change impacts. This systematic review critically examines the extensive body of literature on Livelihood Vulnerability Index (LVI) assessments related to climate change impacts in developing countries. By synthesizing findings from various studies, this review highlights patterns and methodologies used to understand the effects of climate change on vulnerable populations. Key focus areas include geographical distribution, methodological approaches, and the frameworks utilized in vulnerability assessments. The review identifies prominent frameworks, such as the LVI and LVI-IPCC, which integrate indicators of sensitivity, exposure, and adaptive capacity to evaluate climate risks. Findings reveal a concentration of studies in Asia and Africa, with a strong emphasis on agricultural and coastal ecosystems. Methodologically, there is a notable reliance on stratified random sampling to accurately capture community and household-level vulnerabilities. A detailed comparative analysis of the LVI, LVI-IPCC, and Sustainable Livelihood Framework (SLF) is also presented, highlighting their characteristics, benefits, and limitations. The review underscores the need for methodological refinements to better address temporal and regional variations in vulnerability. It concludes with recommendations for future research, integrating broader climate scenarios, exploring sectoral interdependencies, and adopting dynamic approaches to enhance the accuracy and applicability of vulnerability assessments.

Keywords: livelihood vulnerability index; vulnerability assessment; adaptive capacity; developing countries; socio-economic impacts

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1. Introduction

One of the most serious environmental issues that humanity is currently experiencing is the impact of climate change [1]. While the parties responsible for addressing the causes of climate change are still being debated, impoverished communities around the world are already feeling the effects in the form of more frequent natural disasters, extreme weather events, and increased climate variability. Therefore, it poses a new kind of hazard that is not only brought on by the predicted increases in temperature and sea level but also by the inability to appropriately address the poverty that comes along with it. According to the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (AR4), poor countries and communities with considerable development constraints are likely to experience the effects of human-induced climate change first [2,3]. The IPCC predicts that these events will intensify and become even more frequent as greenhouse gas concentrations in the atmosphere rise [4]. Hence, the environment and socio-economic sectors, including water resources, agriculture and food security, human health, and biodiversity, are all affected both directly and indirectly by climate change, as well as climate variability and extreme events [5].

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Vulnerability is a concept that is used in a variety of fields, including finance, security, public health, economic development, natural hazards, and, of course, climate change [6]. However, regardless of disciplinary preferences, vulnerability continues to have its own informal, general meaning. The literature on sustainability science provides one official definition of the concept of vulnerability [7]: The degree to which a system, subsystem, or system component is likely to suffer damage as a result of exposure to a danger, such as a stressor or disturbance of stress, is known as vulnerability. On the other hand, the concept of vulnerability in the context of climate change has evolved over time [8]. According to the IPCC's Third Assessment report, vulnerability to climate change was defined as "a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" [9]. This conceptualization has acquired widespread acceptance because it incorporates components from a variety of pre-existing vulnerability literature [10]. However, this appears to conflict with conceptual frameworks developed and used in fields outside of climate change research, such as those concerning natural disasters and poverty [11].

The concept of vulnerability has been commonly used in livelihood literature which refers to the possibility that livelihood stress will occur, with more stress or a higher probability signifying increasing vulnerability. The IPCC has added physical as well as socio-economic components, thus strengthening and broadening the concept of livelihood vulnerability and emphasizing various variables like the socio-economic status of the population, geography, social network, and adaptive techniques that influence the livelihood-related vulnerability of people. Climate variability is one of the pervasive stresses that vulnerable individuals and communities in various parts of the world have to cope with. Moreover, it is also negatively threatening the security of their livelihood options [12]. The risks of climate extremes are high for the livelihoods of vulnerable people who depend on agriculture, livestock, and fisheries and have insufficient ability for adaptation. Hence, vulnerability assessments were conducted to comprehend the ramifications of climate change and the challenges associated with development. These assessments use a variety of approaches to carefully analyze how people interact with their environment by taking into account both physical and social elements.

Climate change hotspots include the semi-arid regions of Africa, the mountainous ecosystems of the Himalayas, the Deltaic regions, and the river basins in South Asia fed by glaciers, where people are exposed to a variety of multiple overlapping vulnerabilities linked to their geographic location and exposure to climate-related impacts [13,14]. In light of these varied geographical regions, researchers and scholars do not reach a consensus regarding a livelihood vulnerability framework that could be universally applicable to all ecosystems. Nevertheless, significant value has been attributed by researchers to the foundational research conducted by Hahn et al.'s 2009 study which evaluated the vulnerability of community livelihoods in Mozambique, and subsequently, researchers utilized the same approach to examine communities and regions within diverse developing countries.

Despite the expanding use of vulnerability assessment frameworks, few attempts have been made to generate a systematic review of worldwide livelihood vulnerability assessments due to climate change. This paper serves as an up-to-date systematic review and critical assessment of the current published literature, in which we prioritized major areas of study, scale, indicators of vulnerability, and common methodologies. The themes selected by us underscore the following questions: Where and who are the most vulnerable groups? What level of perspective has been adopted in research (macro/micro)? Which method has been employed frequently by researchers? Addressing the above questions is the central focus of climate change and livelihood vulnerability research, aligning with the UNFCCC's objective of safeguarding and providing compensation to the most vulnerable groups [15]. Furthermore, it will help readers comprehend the conceptualization and evaluation of livelihood vulnerability for communities residing in climate-sensitive regions. This will offer a comprehensive understanding of the utilization of the livelihood vulnerability framework using various approaches, methodologies, and tools in a place-specific context.

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We outline key ideas, provide guidance on commonly used language in vulnerability assessment, describe assessment techniques, discuss method choice, and make suggestions for how to clearly communicate and apply the results. This review can act as a summary of the sources that are accessible to readers looking for more in-depth or specialist information. Some recent systematic reviews/bibliometric analyses have reviewed vulnerability due to climate change, but livelihood vulnerability has not been the central focus of these review articles. Moreover, these review articles failed to examine the various approaches that the scientific community has used to answer the growing demand for livelihood vulnerability assessments in different geographical regions. Hence, the objectives of this review are: (1) to examine the general characteristics of livelihood vulnerability assessments (geographical location, scale, ecosystems) followed by a detailed review of vulnerability frameworks and data collection and (2) to identify the gaps in the current conceptualization of livelihood vulnerability and assessment methods.

2. Review Approach

A critical component of any discipline is conducting a review of the pertinent literature assessment. It aids in mapping and assessing the current state of information and knowledge gaps on particular subjects, which will help to expand the knowledge base [16]. A systematic literature review is used to gather, identify, and critically evaluate the research works that are currently available (such as articles, conference proceedings, books, and dissertations) [17]. It informs the reader of current literature on a subject [18]. SLR is different from a traditional literature review as it answers a research question using all evidence or data that are relevant and is extensive, based on strict inclusion and exclusion criteria, and covers multiple databases [19]. The objective is to review key concepts of current understanding on a topic related to research questions to identify topics for additional investigation [20].

Our analysis starts with an extensive, systematic search of literature using Google Scholar and the Morris Library Database at the University of Delaware. We also sourced literature from bibliographies of previously reviewed papers. Our search strategy is structured around three key themes: livelihood vulnerability index, climate vulnerability index (CVI), and climate change, linked together with the search operator "AND" to ensure comprehensive coverage. Given the variability in terminology across relevant literature, we included alternative search terms for each theme, connected by the search operator "OR".

Following an initial review of all 92 search results, 60 papers were deemed potentially relevant and subjected to a more detailed examination. At first, the title, abstract, and keywords were screened manually to exclude articles that were not useful for the purpose of the present study. After this preselection, the full text of 60 selected papers was reviewed in detail, and a total of 52 papers were included in the final selection of peer-reviewed literature (see Figure 1 for methodological flow chart). Following their selection, the articles were classified according to (1) publication year, (2) geographical scale, (3) methodological philosophy, (4) frameworks, (5) research method, (6) studies conducted to inform policymakers, and (7) types of limitations. A complete list of the reviewed papers is presented in the Supplementary Materials. This research was confined to peer-reviewed journal articles in English, published from 2010 to 2023. Articles from before 2010 were excluded, and the study did not consider any unpublished papers or gray literature, including government or organizational reports.

The selection criteria for this study included (1) an index aimed at evaluating household vulnerability to climate change and variability, particularly in developing nations, (2) original research articles, and (3) a detailed description of the factors and methods employed in the index's validation.

Exclusion criteria comprised any non-English literature, grey literature, policy documents, articles focused exclusively on vulnerability to non-climatic risk, and unranked journals and publishers.

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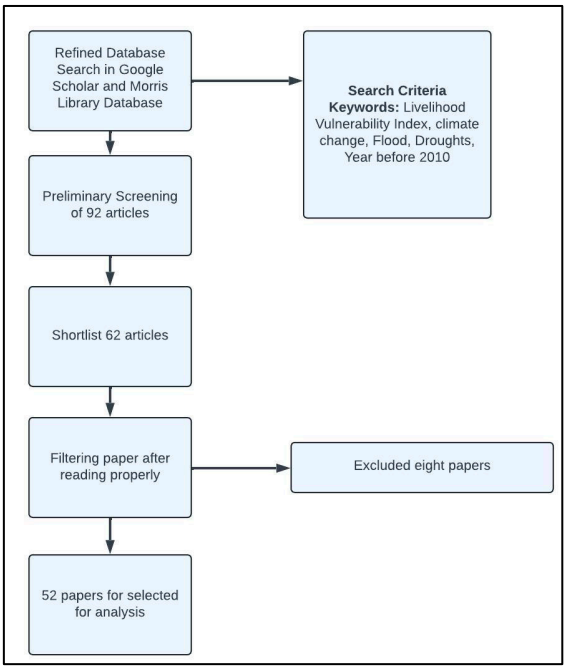

Figure 1. Methodological flow chart.

3. Results

3.1. Geographical Location, Scale, and Ecosystems

Of the 52 articles we reviewed, Asia was the most studied region geographically. It was the focus of 48% of the 52 articles. Out of 48%, 23% of the articles looked solely at South Asia (India, Nepal, Bangladesh), and 9% of the articles were focused on Southeast Asia (countries like Vietnam, Indonesia, and China). After Asia, the continent that received the most attention was Africa, in which Ghana, Nigeria, and Ethiopia were predominant in livelihood vulnerability assessment. Other parts of the world that received far less attention were the continent of South America (Peru and Bolivia) and the Caribbean Islands (Trinidad and Tobago). Moreover, the continents that received no attention were Europe and North America.

All 52 studies adopted a sub-national level as the scale of analysis. Of those studies examined, 54% of the articles focused on the district level; analysis at the level of villages, counties, and households was also common, with at least 23% of the articles mentioning at least one of these three.

Most studies focused on the agricultural sector and agroforestry (42%), followed by coastal, freshwater, and river ecosystems (32%), mountainous (16%), and vulnerable ecological regions (6%).

3.2. Frameworks

The frameworks that were predominant in all studies to calculate vulnerability assessments were LVI, LVI-IPCC, and SLF, as shown in Figure 2. A significant portion of the studies, approximately 80%, adopted a combined approach by first identifying and defining the major components under the LVI and then using these components to compute the IPCC-categorized contributing factors, namely sensitivity, exposure, and adaptive capacity. Among the 52 studies, only one study based in Peru calculated livelihood vulnerability using descriptive analysis. Moreover, the majority of the studies used the equation of the balanced weighted average approach to calculate LVI. It is a method in which every sub-component equally contributes to the overall index.

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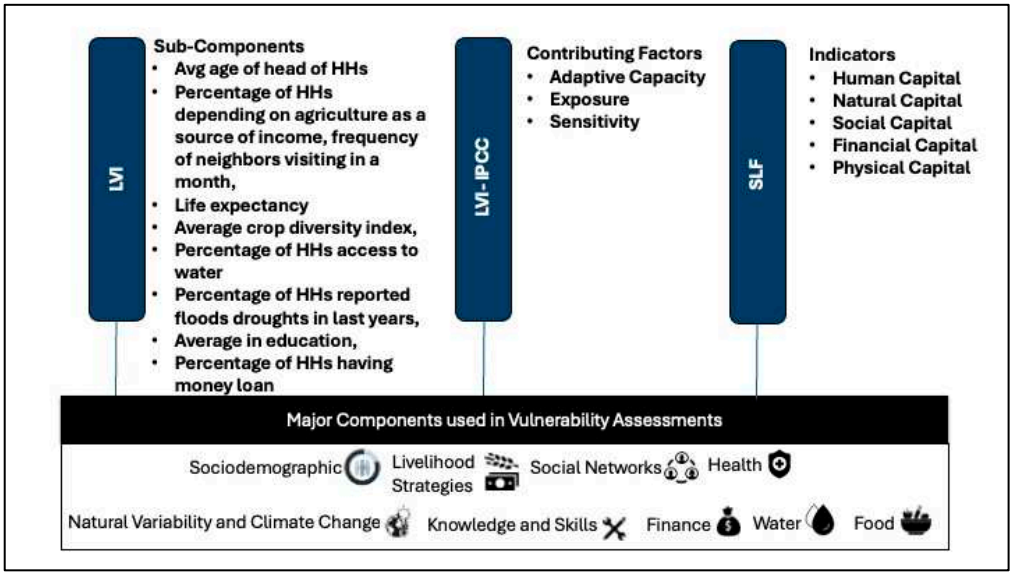

Figure 2. Vulnerability Assessment Frameworks used in studies.

3.3. Data Collection

A total of 90% of the studies reviewed in this paper used a multistage sampling method or stratified random sampling technique to select households for data collection. This multistage sampling method includes choosing a larger region (country) known for its vulnerability to climate change, then choosing a region where climate-dependent livelihood activities are predominant, and then using random sampling to obtain a proportional number of households or respondents. Once households are selected, the household head is interviewed by trained field staff using a set of predetermined questions. The aim of these questions is to assess the status of each household's vulnerability indicators. Coupled with this technique, qualitative methods, like focus group discussions and semi-structured interviews, are also used to collect respondent perspectives on various climate and socio-economic variables.

3.4. Key Dimensions and Components of Vulnerability

Our analysis found two main patterns in terms of dimensions that researchers focused on. The first and most frequent is the IPCC definition of livelihood vulnerability. The majority (87.5%) of studies are rooted in this definition, stating that livelihood vulnerability is a function of adaptive capacity, sensitivity, and exposure. Adaptive capacity is defined as the "ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences" [2]. 'Sensitivity' refers to how much a community will respond to a change in climate or extreme weather event, whether that response is positive or negative. 'Exposure' is the degree of climatic stress on a particular unit of analysis, and it is captured by the frequency of extreme weather events and/or changes in climate variability. From these three main components, researchers have developed systems of indicators to assess how exposed and sensitive a household is to climate change, as well as their capacity to adapt to their surroundings.

The second pattern was researchers' use of Hahn et al.'s 2009 study in Mozambique. A total of 80% of studies used this technique to assess vulnerability. This study was one of the first to coin specific indicators of vulnerability. Hahn specified seven primary components of vulnerability, including natural disasters and climate variability, socio-demographic profile, livelihood strategies, social networks, health, food, and water. Each component has various sub-components that researchers modify and use to inspire survey questions. When combined with the IPCC's three factors of vulnerability, natural disasters and climate variability are classified under exposure; health, food, and water are considered sensitivity; and socio-demographic profile, social networks, and livelihood strategies are

Version of Record at: https://doi.org/10.3390/cli12070100

classified under adaptive capacity. Within those major components, we analyzed the number of sub-components and pinpointed the prevalent indicators and subdimensions utilized for characterizing the vulnerability of communities in different countries. There were significant differences in the overall number of sub-components employed in each of the reviewed articles. Table 1 lists the specific sub-dimensions that are included under each vulnerability component (at least according to many studies), along with the unit to quantify them. Researchers used various sources to identify sub-components, including literature reviews, field knowledge, firsthand observations, and discussions with local stakeholders and experts.

Table 1. Detailed Sub-Dimensions of LVI by Component with Quantifying Units.

Component	Metric Unit	Sub-Component
Natural Disasters and Climate Variability	Percentage	• Average flood, drought, and cyclone events in the past six years • Increased occurrence of landslides resulting from extreme precipitation and a higher frequency of disasters like cloudbursts, floods, and landslides • Percent of households that did not receive a warning prior to these events • Percentage of households that suffered an injury or fatality from the most severe natural disaster in the last six years • Average monthly standard deviation of daily maximum temperature • Average monthly standard deviation of daily minimum temperatures • Average monthly standard deviation of precipitation levels
Socio-demographic Profile	Count, percentage, ratio	• Dependency ratio (population under age 15 and over age 65/population between ages 19 and 64) • Percent of female-headed households • Percent of households where the head has not attended school • Percentage of households that include orphans
Livelihood Strategies	Percentage	• Percentage of households with a family member employed in another community • Percent of households that rely exclusively on agriculture for income • Average agricultural livelihood diversification index
Social Networks	Percentage	• Average receives/gives ratio • Average borrows/lends ratio • Percentage of households that have not sought assistance from their local government in the past year
Health	Percentage	• Average travel time to a health facility (minutes) • Percentage of households with a family member suffering from a chronic illness • Percentage of households with a family member who was absent from work or school due to illness in the last two weeks • Average index of exposure to malaria • Percentage of households without a toilet
Food	Percentage	• Percentage of households dependent on family farm for food • Percentage of households with orphans • Average number of months households struggle to find food • Average crop diversity index • Percentage of households that do not save crops • Percentage of households that do not save seeds • Damage to agricultural lands, soil erosion on hilly tracts, livestock losses, and decreases in yield

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Table 1. *Cont.*

Component	Metric Unit	Sub-Component
Water	Percentage	• Percentage of households experiencing water-related conflicts • Percentage of households that use a natural water source • Average travel time to water source (minutes) • Percentage of households without a reliable water supply • Inverse of the average amount of water stored per household, measured in liters

4. Discussion

4.1. Geographical Location, Scale, and Ecosystems

Climate-induced livelihood vulnerability analysis was primarily confined to developing and impoverished countries in Asia, Africa, and South America as illustrated in Figure 3. The IPCC study relates vulnerability to climatic change and emphasizes how a region's susceptibility is greatly influenced by its income and how poverty reduces an area's capacity for adaptation. It also contends that the socio-economic systems are "usually more vulnerable in developing nations where economic and institutional conditions are less favorable". In developing countries, the significance of numerous water-related issues, such as the time required to collect residential water, the health risks associated with it, and the accessibility and availability of water for productive activities and small-scale farming, is especially significant. Since the climate-induced vulnerability index placed a strong emphasis on water-related issues, researchers in developing and underdeveloped countries tended to use it more frequently to measure vulnerability [21]. Among these regions, a notable observation was the extensive use of the vulnerability assessment framework in studies conducted in South Asian countries. This can be attributed to the fact that South Asia, which includes Pakistan, India, and Bangladesh, is home to more than one-fifth of the global population and is recognized as the most disaster-prone region worldwide. Factors such as rapid population growth, degradation of natural resources, poverty, and food insecurity contribute to the high vulnerability of this study area to the impacts of climate change [22]. For instance, India is one of the top countries already feeling the effects of climate change, with pressure mounting on food systems, poverty, land degradation, and agricultural production [23]. Moreover, a number of pressures and a lack of adaptation capability also make Africa one of the continents most susceptible to climate change and variability, according to the Intergovernmental Panel on Climate Change [24]. Communities in African countries are encountering critical difficulties due to the combination of various stressors. These stressors encompass infectious diseases, economic instability resulting from globalization, privatization of resources, and civil conflicts. Moreover, the lack of resources for adaptation further exacerbates the situation, intensifying the struggles faced by these communities. In a similar vein, small island developing countries in the Caribbean region are categorized as a global "hotspot" as they are highly vulnerable to climate change. The adverse impacts of climate change on these lands, such as rising sea levels and changing precipitation patterns, are already exacerbating negative consequences. This leads to agricultural losses and degradation of ecosystems, thereby affecting both food security and employment opportunities. These sectors are vital not only for the economy but also for the tourism industry, which serves as a significant component of the economy in these countries; hence, LVI assessment has been the focus of researchers in these countries [25].

The majority of studies conducted focused on the district or village level, highlighting a notable gap when it comes to national and global scales. This is due to the fact that local context plays a major role in vulnerability assessments. Understanding the complications brought on by climate change requires a regional vulnerability assessment because the ability of communities to adapt depends on their institutional, financial, technological, cultural, and other capabilities [26]. Therefore, studies have tailored indicators and weightings to align with local conditions. Apart from major extreme weather events and natural

Version of Record at: https://doi.org/10.3390/cli12070100

disasters, the responsibility of managing climate risks has traditionally fallen upon households. Consequently, people living in different regions have developed unique coping mechanisms to address their climate-related vulnerabilities [27]. Therefore, conducting studies at the district or village level provides a more accurate understanding of the vulnerability experienced by local communities. At the household level, the assessment of a livelihood vulnerability index offers a clear indication of the necessary capabilities, assets, and activities for achieving a sustainable means of living for each specific household [28]. While whole regions and countries can be assessed, vulnerability assessments at a small spatial scale reveal the local variations within countries. The majority of the non-climatic data necessary for determining a region's vulnerability to climate change and for planning adaptation measures are accessible at the district level [29]. It is crucial to develop suitable adaptation policies and programs to tackle livelihood challenges, especially considering that a considerable amount of development planning and program execution takes place at the local level in developing countries such as India, Pakistan, and others.

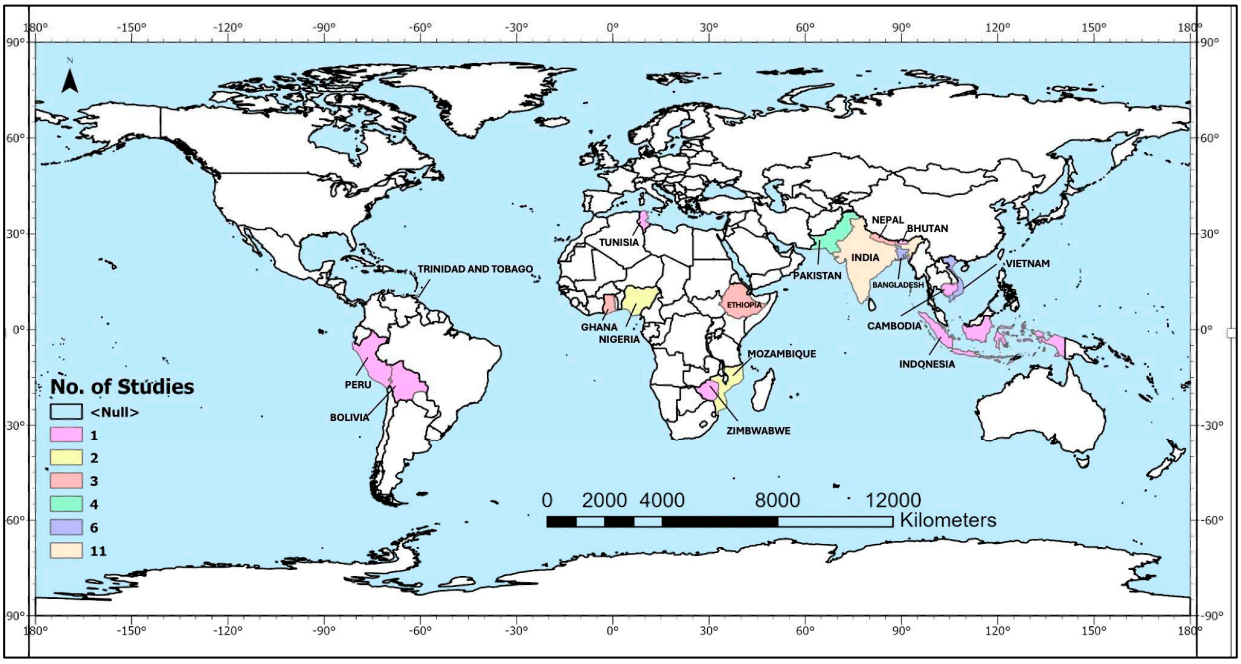

Figure 3. Geographical distribution of studies.

In comparison to mountainous and coastal ecosystems, agricultural ecosystems were given more attention in research studies. Agriculture is typically the principal source of employment for substantial portions of people in developing countries, as well as the foundation of those countries' long-term economic success. It contributes to 26% of GDP in the economies of many low-income developing countries and is one of the sectors most vulnerable to climate change. Its sustainability greatly depends on temperature, rainfall, and frequency of weather events [30]. Three continents (Asia, Africa, and South America) are characterized by small-scale farmers because of a lack of alternative options for livelihood, strong cultural ties to the land, and provision of subsidies for small-scale farming [31]. Given the close connection between smallholder farmers' agricultural output and household income, the vulnerability of farmers is increased when crop yields are negatively impacted by climate change. Therefore, climate change not only affects farmers' ability to produce agricultural goods but also jeopardizes their family's welfare and food security [32]. Since these households have limited livelihood assets, vulnerability assessment is conducted to comprehend the extent of vulnerability of small-scale farmers and how climate change threatens the farmers' livelihoods. After agriculture, coastal and river ecosystems have also been the focus of studies as the livelihood of the majority of the

Version of Record at: https://doi.org/10.3390/cli12070100

population living in these ecosystems depends on the natural resource of fisheries. Due to their highly dynamic geomorphology, coastal, estuarine, and deltaic low-lying areas are particularly susceptible to a variety of phenomena, including sea level rise, heightened storm surges, unusual temperatures, rainfall patterns, and flooding [33–35]. In South and Southeast Asia, specifically in countries such as Bangladesh, Nepal, Pakistan, India, and Vietnam, communities in coastal fishing areas, riverbank regions, char lands, and Haor areas face the highest levels of exposure to flooding, cyclones, and riverbank erosion [36–38]. In developing countries located close to the tropics, small-scale fisheries (SSF) are the main source of income following agriculture. Small-scale fishing groups face considerable obstacles within their industry that include the inability to increase the value of their catches, limited market options, the need to maintain the quality of fish products, diseconomies of scale, and limited access to funding [39]. As a result, these elements help to make these fishing communities among the most socioeconomically disadvantaged in such areas.

With the additional natural stressor of climate change, coastal and riparian communities suffer the disruption of land-based infrastructure and fishing operations. Therefore, vulnerability studies carried out in Vietnam, Bangladesh, Nigeria, and Trinidad and Tobago have specifically targeted small-scale fishing communities as they aim to gain insights into how these communities are currently adapting to the impacts of climate change at the local level in order to inform and shape future adaptation strategies [25,32,39]. Communities in mountainous ecosystems also have limited livelihood options due to their remoteness and fragile mountainous settings and less incentive to stay in balance with surrounding ecosystems. The mountainous terrain supports fertile land and biodiversity, which are essential natural resources for local livelihoods. Nevertheless, due to their physical characteristics, such as complex topography, climatic events, seasonal variations, and geomorphic activities, mountains are susceptible to natural disasters and the impacts of climate change [40]. The majority of studies have concentrated on marginalized communities residing in environmentally sensitive regions such as Nepal, Bhutan, Tibet Plateau, and the Himalayan region. Unstable soil, land, migration, and land fragmentation are extrinsic and intrinsic variables that worsen the chronic vulnerability of agricultural populations living in mountainous regions. These studies aim to provide valuable insights to develop adaptations that ensure the continuity of ecosystem services in areas such as biodiversity conservation, protected area management, water resources security, and overall human well-being. Research is comparatively scant on mountainous ecosystems in Africa and South America.

The rapidly changing climate has similarly impacted urban areas, where the effects are particularly noticeable due to unplanned construction, unequal distribution of amenities, and alterations to the urban ecosystem. The assessment of climate change vulnerability among people living in various urban livelihood sectors has been deemed insufficient. This might be explained by urban areas' higher levels of development in comparison to rural areas, their greater capacity for adaptation, and their decreased reliance on livelihoods that are climate-sensitive since natural resources are not significant assets in urban landscapes. Commercialization and modernization that follow urbanization contribute to a shift in employment from agriculture to industry, and in particular, to the service sector [41], which has led to little attention from researchers.

4.2. Vulnerability Assessment Frameworks and Methodology

A variety of methods are employed in vulnerability assessments to carefully investigate interactions between humans and their social and physical environments. In the domain of climate change adaptation analysis, many scholars have worked to close the gap between the social, physical, and natural sciences and have provided fresh approaches to quantify how communities will adapt to changing environmental conditions. The primary shaping factors of these vulnerability assessment studies are climatic risks, such as floods and droughts, leading to a relatively lesser exploration of non-climatic risks, such as governance and power issues, in the context of vulnerability studies. At the local level, these vulnerability assessment frameworks help researchers understand the effects of climate

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change on people's lives and livelihoods. There are two methods that can be used to study climate vulnerability: qualitative and quantitative. Within the quantitative method, either econometric models are used to understand the factors that influence the extent to which climate hazards impact people's lives and livelihoods and the economic impacts of vulnerability, or an index is constructed through indicator-based approaches. Econometric models mostly rely on secondary data and exhibit a higher margin of error when applied at the community or individual levels; hence, they are better suited for utilization at the national level [42]. The latter approach gained more preference and utility for several reasons, with one of the primary ones being that the LVI offers various institutions an applied tool at the community level. This tool enhances comprehension of demographic, social, and health factors that play a role in climate change [43]. It is crucial for comparing vulnerabilities in various contexts, tracking vulnerabilities through time and geography, and allocating funds for mitigation and adaptation measures [44]. It can also be used to assess the efficacy of development policy frameworks [45]. To determine the context and place-specific vulnerability, a variety of indicator-based methods are available, such as the SLF [46], LVI, LVI-IPCC [47], CVI [48], LEI [49], and Physical Vulnerability to Climate Change Index (PVCCI) [50]; however, there is no consensus on which instrument is most suitable to gauge vulnerability [51]. To provide a comprehensive understanding of the characteristics, benefits, and limitations of the LVI, LVI-IPCC, and SLF, a detailed comparative analysis is shown in Table 2 that offers a clear and concise comparison, enhancing understanding and aiding in the selection of the most suitable framework for specific contexts. The SLF, introduced by Robert Chambers and Gordon Conway in 1991, is a household-level vulnerability framework. This approach has been adopted by major donor institutions like Care, Oxfam, and the Department For International Development (DFID) as a foundation for their development programs and practices. However, the SLF examines vulnerability in the context of external shocks and stressors but does not account for the spatial and temporal analysis of biophysical and socio-economic vulnerability factors, often focusing on a single type of shock or stressor [52]. Moreover, it addresses sensitivity and adaptive capacity concerning stressors on assets and overlooks the exposures that put individuals at risk. Building on this framework, Hahn et al. (2009) developed the LVI, which utilizes household-level data for strategic community-level planning. Unlike the SLF, the LVI specifically focuses on exposure to climate change. It incorporates SLF-based indicators within the IPCC AR4 framework, addressing both socio-economic vulnerability and hazard exposure. This allows the LVI to provide a more comprehensive analysis of vulnerability by considering multiple factors and their interactions over time and space.

Research studies reviewed in this article primarily used the combination of LVI and LVI-IPCC, which are based on the IPCC definition of vulnerability. The LVI, a composite index, consists of seven critical components: social networks, livelihood strategies, socio-demographic profiles, access to food, healthcare, water, and the effects of climate variability and natural disasters.

There are several sub-components for each major component, allowing for the addition or removal of indicators depending on the necessity and scope of research in each given area [49]. LVI-IPCC is an alternative to the former approach that combines the seven components into the three variables identified by the IPCC as contributing to vulnerability: sensitivity, exposure, and capacity for adaptation. Within the LVI-IPCC, the index value of these three dimensions is calculated separately. The LVI and LVI-IPCC both take into account the same primary components and measure the index value of each major component using the same method. Additionally, these two methods use linear scoring in determining the vulnerability profile with LVI using the range of 0–0.5, and LVI-IPCC assessed profile between +1 and −1 range. Moreover, these approaches have been the focus of researchers as they cover socio-economic and biophysical elements of vulnerability. However, LVI-IPCC deviates from the LVI in the method of combining the major components. This approach is different from other methods as it uses primary household data for accurate projections rather than relying on large-scale climate models. Instead of

Version of Record at: https://doi.org/10.3390/cli12070100

integrating the major components directly into the LVI in the equation below, they were first grouped into three categories: exposure, adaptive capacity, and sensitivity. This grouping was performed using the subsequent equation:

$$\text{LVI-IPCC} = (\text{exposure index} - \text{adaptive index}) \times \text{sensitivity index}$$

Table 2. Comparative Analysis of LVI, LVI-IPCC and SLF.

Sr No.	Vulnerability Assessment Frameworks	Description	Characteristics	Benefits	Limitations
1.	SLF (Chambers and Conway, 1992) [46]	Analyzes livelihood resources, livelihood activities, and livelihood outcomes under the impact of external context, institutions, and policies	—People-focused and participatory —Conducted in partnership with the public and private sector —Examines natural, social, political, human, physical, and economic assets	—Enables a comprehensive understanding of the numerous stressors influencing the flow of various assets within communities —Components are well-defined and consistently utilized by researchers worldwide, making indexing with these components widely accepted —Essential for developing effective regional and global climate change initiatives	—Limited in capturing the dynamic nature of capital assets over time and requires high levels of resources and expertise to implement effectively on the ground —Focuses on the stocks of assets rather than the flow of services they provide; this is especially critical for natural capital, as the flow of services can change significantly in response to climate change without necessarily altering the overall stocks of natural capital
2.	LVI Hahn et al. (2009) [47]	—Uses a balanced weighted average approach, where each sub-component contributes equally to the overall index, even though each major component of different livelihood assets is comprised of a different number of sub-components	—Composite of seven equally weighted components —Focus on local and household level —Adaptable to include indicators specific to local conditions and particular communities	—Utilizes primary data from household surveys —Valuable for planning and policymaking to prioritize and allocate natural resources to the most vulnerable populations	—Subjectivity in indicator selection —Does not account for variance between study populations —Oversimplifies a complex reality and lacks a straightforward method for validating indices composed of diverse indicators
3.	LVI-IPCC Hahn et al. (2009) [47]	Derives from the IPCC vulnerability definition that characterizes vulnerability with three components: exposure, sensitivity, and adaptive capacity	—Focus on community and HH level and also at the regional level	—Provides a comprehensive understanding of livelihood vulnerability, specifically concerning flooding	—Assigns equal weights when aggregating the index values of different contributing factors of vulnerability; however, it is inappropriate to assume that all components contribute equally to vulnerability

The LVI-IPCC calculates the overall index by subtracting the adaptive capacity value, multiplied by the sensitivity index, from the exposure value. The index rises with an increase in system exposure and sensitivity, while it decreases with the system's adaptive

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capacity. Generally, the combined factors of exposure and sensitivity characterize the possible influence of climate change on a system, with the system's adaptive capacity playing a role in shaping its vulnerability to climate change by modifying exposure and sensitivity. A significant limitation of the LVI and LVI-IPCC is their potential to produce inconsistent conclusions, which arises from the complex and multifaceted nature of vulnerability. The difference lies in the integration of components in the LVI versus the LVI-IPCC. The LVI typically averages each component, offering a straightforward but potentially oversimplified view of vulnerability. In contrast, the LVI-IPCC groups components into three main categories—exposure, sensitivity, and adaptive capacity—using a different formula (the LVI-IPCC formula). This approach can lead to varying vulnerability scores and interpretations, even when using the same underlying data, as demonstrated by studies in Bhutan and Indonesia [53–55].

The prevalence of LVI and LVI-IPCC suggests that climate change livelihood vulnerability assessments have primarily emphasized quantitative approaches over qualitative methods for contextual exploration. These assessments have utilized the cross-sectional data and focused on evaluating vulnerability at a specific moment in time without adequately considering temporal vulnerability and historical trends of change. A better insight can be provided by exploring temporal heterogeneity in livelihood vulnerability by using the panel data. A research gap also exists regarding the utilization of LVI and LVI-IPCC to examine the impacts of local policy interventions by adjusting the values of sub-components as required. Moreover, in 2014, the IPCC revised its definition of vulnerability by eliminating the exposure component and defining vulnerability solely in terms of sensitivity and adaptive capacity. However, subsequent studies on climate change vulnerability across various regions have persisted in incorporating the exposure component into their measurements, even after the concept of vulnerability was redefined in the report. As more accurate indicators, models, and data become available, indicator-based approaches to vulnerability assessment can still be improved. A microscale perspective of livelihood vulnerability is beneficial for policymakers to design location-specific adaptation measures and management plans; however, a household's livelihood is highly dynamic, and no results can be utilized in the longer term. The assessment of future livelihood vulnerability must encompass system dynamics, as it will be molded by not only climate change but also closely intertwined with technological advancements, demographic shifts, and socio-economic trends. These factors collectively influence the capacity of households and communities to adapt.

Multistage sampling is frequently used while conducting vulnerability assessments since it is easier to perform than simple random sampling. The sampling units are hierarchically arranged into primary (districts), secondary (villages), and tertiary (households) units that provide a more comprehensive sample of the population than a single technique like cluster sampling [56]. Moreover, it also reduces the cost of data collection; for instance, in a single-stage sample of households in a province, one would have to list the districts in the whole region, whereas, in multistage sampling with districts as primary sampling units, researchers can easily restrict listing activities to a sample of districts. However, multistage sampling has a loss in efficiency that outweighs any operational benefits. For the associated sample estimates, a multistage sample typically yields higher sampling error than a simple random sample of the same size [57].

5. Conclusions

We have systematically reviewed studies using vulnerability assessments to assess the vulnerability of poor communities around the world to climate change. This was done in order to better understand patterns in the field regarding key frameworks, common areas of study, data collection methods, significant/insignificant indicators of vulnerability, and data analysis methods. Overall, there were three main frameworks that have been used in research: LVI-IPCC, Indicators of Vulnerability as developed by Hahn et al. (2009), and the SLF. The adaptability of these frameworks has been proven through their modification and

Version of Record at: https://doi.org/10.3390/cli12070100

evolution through the years to fit specific studies and datasets. Common areas of study include low-lying farming communities around the world, and subsistence farming and fishing households. The main method of data collection was the purposive selection of an area, district, or village, followed by a stratified random sampling of households using a questionnaire. These data were analyzed by standardizing indicators and calculating the overall vulnerability of a certain community. Significant indicators of vulnerability included little income diversification, access to government and institutional services, and exposure to flooding and cyclones. While these methods of research have challenges, they are effective in identifying vulnerable communities, what makes them vulnerable, and strategies that can be used to build adaptive capacity.

We find that LVIs still face numerous limitations that can affect the validity and applicability of their findings. One major issue is the potential for indices like LVI and LVI-IPCC to produce non-convergent conclusions due to the complex and multidimensional nature of vulnerability. The selection and weighting of indicators within these indices are somewhat subjective, which could mask the real circumstances affecting vulnerability and lead to a misrepresentation of the severity and directionality of different factors. Studies' reliance on cross-sectional data limits their capacity to explore changes over time in livelihood vulnerability, which could be improved with dynamic panel data. Moreover, focusing only on household-level analysis may overlook regional factors that shape local vulnerability. In terms of methodology, the use of an equal weight scheme is simplistic and may not reflect the true impact of each component on vulnerability. Another limitation is the sample size, which was insufficient to represent the entire population and focused narrowly on landowning cultivator households, excluding non-agricultural and non-farm households. This focus restricts the study's ability to generalize its findings to the broader population, particularly ethnic minority populations, which may have different experiences with climate change and associated risks. Further limitations include the inability of the assessment to provide medium- or long-term predictions due to its current situation analysis, insufficient focus on urban areas, neglect of the unique vulnerabilities and adaptive challenges faced by urban populations in developing countries, and the exclusion of key parameters such as effects of the COVID-19 pandemic. Data collection was also constrained by limited resources and time, which could affect the depth and breadth of the findings.

6. Recommendations for Future Livelihood Vulnerability Assessments

For future studies, it is recommended to increase sample sizes for improved precision, incorporate a broader range of exposure-related parameters, and utilize local knowledge in selecting indicators through participatory approaches to more accurately reflect experiences of climate shocks. Future livelihood vulnerability frameworks should also integrate spatial and temporal dimensions to provide a more dynamic, evolving understanding of vulnerability. Using the insights gained from dynamic vulnerability assessments will enable the identification of emerging risks and trends, allowing for proactive adaptation measures rather than reactive responses. This anticipatory approach can mitigate potential impacts before they escalate. While livelihood vulnerability assessments can provide valuable insights, their methodologies need to be refined to account for the complexity of vulnerability, include broader and more diverse populations, and consider incorporating an unequal weighting approach when calculating the LVI. This method recognizes that indicators and components contribute differently to overall vulnerability, addressing the oversimplification inherent in equal weighting. By using principal component analysis (PCA) to assign varied weights, researchers can achieve more reliable and precise assessments. Adopting this approach will enhance the accuracy of vulnerability analyses, providing a more nuanced understanding and a stronger foundation for effective policymaking and adaptation strategies. As climate extremes become more severe, vulnerability assessments must account for potential non-linear responses and tipping points in ecological and social systems, identifying critical thresholds where impacts could accelerate rapidly. Given the growing unpredictability of climate extremes, these assessments should include a broader range of

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climate scenarios and prioritize robust decision-making under uncertainty. Furthermore, they should examine how climate risks in one sector (e.g., agriculture) can cascade into other sectors (e.g., water resources, energy), potentially amplifying overall vulnerability.

It is also essential to investigate the correlation between livelihood vulnerability and livelihood-strategy choices. Investigating the correlation between livelihood vulnerability and livelihood-strategy choices is crucial for understanding how communities can better adapt to changing environmental conditions. This research can inform policymaking and enhance the resilience of vulnerable populations. To offer a comprehensive depiction of vulnerable environments, it is essential to expand the components of the LVI under the exposure dimension. The LVI currently includes components such as natural variability and climate change. However, it should also encompass specific indicators directly related to climate change, such as concerns about climate change and the indirect effects of compound climate extremes. These indicators could include the frequency and severity of extreme weather events, changes in seasonal patterns, and the impact of these changes on agricultural productivity and water resources.

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