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Review

Investigating Vulnerability, Adaptation, and Resilience: A Comprehensive Review within the Context of Climate Change

Linpei Zhai [1] and Jae-Eun Lee [2,*]

[1] Law School, Zhejiang Normal University, Jinhua 321004, China; linpeizhai@zjnu.edu.cn
[2] Department of Public Administration, Chungbuk National University, Cheongju 28644, Republic of Korea
* Correspondence: jeunlee@chungbuk.ac.kr; Tel.: +82-43-261-3337

Abstract: This review seeks to enhance the understanding of the critical concepts of vulnerability, adaptation, and resilience within the context of global environmental challenges, with a particular focus on climate change. Climate change is characterized by rising global temperatures and an increase in extreme weather events, making the comprehension and addressing of these concepts crucial for effective adaptation strategies. Despite widespread recognition of the interconnectedness of vulnerability, adaptation, and resilience, there remains a gap in a comprehensive understanding of how these concepts interrelate. Through synthesizing existing literature, this review provides a detailed examination of their definitions and the interrelationships among vulnerability, adaptation, resilience, and climate-related disasters. Additionally, it explores the impact of climate change on future disaster risk reduction efforts by analyzing the nexus between climate change adaptation and disaster risk reduction. Key findings highlight the necessity of incorporating social, institutional, economic, and environmental factors into adaptation planning and call for innovative approaches to boost adaptive capacity and resilience. This review not only furthers the discourse in research, policy, and practice in this vital area but also offers strategic insights for developing more resilient and adaptive societies amidst the challenges posed by climate change.

Keywords: vulnerability; adaptation; resilience; climate change; disaster risk reduction

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1. Introduction

Climate change has intensified extreme weather events, leading to an increase and normalization of climate-related natural disasters globally. These events have had a devastating impact on human lives and pose a significant threat worldwide. Climate change-related disaster extreme events, whether they are created by nature or by humans, make adaptation challenging and result in catastrophic property losses and the paralysis of income and livelihoods [1]. Unfortunately, additional natural catastrophes caused by climate change, such as floods, heat waves, droughts, and other multi-hazard situations, have been impacting many countries and regions around the world.

The impacts of climate change are vast and already significantly affecting various sectors, including national income, economic growth, agriculture, industry, and tourism, as well as human health, labor productivity, energy demand, and even political stability and migration patterns. Particularly in developing countries, vulnerable populations striving for sustainable development face additional threats from increased temperatures, unpredictable extreme weather events, and shifts in precipitation patterns [2]. Climate change influences people's lives both directly and indirectly by disrupting the environmental and social determinants of health [3]. It poses comprehensive challenges to public health, manifested through rising global temperatures [4], more frequent and intense heatwaves [4,5], increased incidents of injuries and deaths due to extreme heat and wildfires [3,6], alongside a decrease in cold-related mortality [7]. Moreover, climate change escalates the risks of floods and droughts [8], facilitates the spread of infectious diseases, alters the distribution

and severity of disaster risks, and increases malnutrition [4,9]. Beyond physical health, extreme weather events are also a significant source of acute mental health issues, including anxiety, depression, and post-traumatic stress disorder [10,11], especially for children who experience the cumulative effects of exposure to disasters [12]. The ongoing loss of livelihoods, displacement, disruption of social cohesion, and the overarching uncertainty brought about by climate change can lead to long-term mental health disorders, highlighting the need for comprehensive strategies to address both the immediate and extended impacts of climate change on human well-being [13].

These events have significant adverse effects on society as they intensify natural environmental processes and result in catastrophes. While natural disasters can strike anywhere, their impacts can be mitigated, even if the events themselves are unavoidable [14]. The extent to which climate change affects different regions depends largely on the vulnerability of their natural ecosystems and infrastructure to climate-related changes and extreme weather events, as well as their capacity to respond and adapt to new environmental conditions [15].

In recent decades, the rapid acceleration of climate change has highlighted the critical need for a comprehensive understanding of and effective responses to its complex impacts. Addressing vulnerability, adaptation, resilience, and the growing frequency of climate-related disasters has become increasingly important. Central to this challenge are the concepts of vulnerability, adaptation, resilience, and the significant challenges posed by the more frequent climate-related disasters to societies worldwide. Although various definitions and conceptual frameworks for resilience exist, particularly in the context of disasters, a universally accepted definition of catastrophe resilience remains elusive. However, these definitions commonly emphasize three core elements: disaster resilience, adaptive capability/adaptation, and vulnerability. Resilience and vulnerability are key concepts across numerous scientific disciplines [16,17] and have gained prominence in efforts to minimize disaster risks. Some scholars consider resilience as a concept integrated within a framework of vulnerability [18,19]. According to Klein and Thomalla [20], resilience influences adaptive capacity. Furthermore, several studies have identified resilience as a component of adaptive ability [21], underscoring its importance in managing and mitigating the impacts of climate change and disasters.

Regardless of the focus on vulnerability, resilience, or adaptation in specific research, the field of disaster research has significantly addressed their interconnectedness. The frequent, high-risk, and abrupt nature of hazards associated with climate change demands policies and processes that are not only more rigorous and refined but also resilient and adaptive. This requires a deep understanding of how vulnerability, resilience, and adaptation are interlinked and grounded in a comprehensive risk analysis. Such analysis is essential to evaluate our experiences, responses, and actions, enabling the development and enhancement of prevention and response strategies. These strategies are crucial for adapting to climate change and preparing for future catastrophic events.

In this context, this review seeks to critically analyze the existing body of literature on vulnerability, adaptation, resilience, and climate crises. This review used a variety of academic databases, including Web of Science and Google Scholar, and used keyword combination searches to ensure that a wide range of literature resources were obtained. After an initial screening, we assessed the quality and relevance of the selected literature, paying particular attention to the definition and understanding of concepts such as vulnerability, adaptability, and resilience. This review strives to deepen the understanding of how these concepts are interconnected and their significance for efforts to adapt to climate change. By synthesizing and evaluating a wide array of studies, inductive and comprehensive analysis methods were used to organize and summarize the extracted data and present the results of the literature review in the form of text descriptions, charts, and tables, clearly demonstrating the differences in different kinds of literature. Definitions and relationships of vulnerability, adaptation, resilience, and the climate crisis are provided. Our goal is to shed light on the intricate dynamics between these concepts while identifying new trends,

pinpointing gaps, and suggesting directions for future research. This comprehensive examination of the literature provides a detailed exploration of the definitions and relationships between vulnerability, adaptation, resilience, and climate-related disasters. The aim of this review is to enhance collective comprehension of the complex challenges presented by climate change, thereby supporting the development of evidence-based policies and interventions aimed at bolstering societal resilience against climate-induced disasters and uncertainties. Furthermore, we explore the impact of climate change on future disaster risk reduction efforts by delving into the interplay between climate change adaptation and disaster risk management.

2. Overview of the Concepts of Vulnerability, Adaptation, and Resilience

2.1. Vulnerability

Birkmann [22] explores the evolution of the concept of vulnerability, initially defined narrowly to focus solely on the inherent characteristics of natural hazards and their associated risks. This perspective gradually shifted towards a more human-centered view, emphasizing the potential for harm to individuals. The definition was further expanded to encompass sensitivity and the capacity for adaptation. Thus, exposure and adaptability are considered separate yet integral aspects of vulnerability. Consequently, the widely recognized definition of vulnerability now embraces a multidimensional approach, incorporating institutional, economic, social, and physical dimensions.

Dow [23] posits that individuals, communities, ecosystems, and technological entities all exhibit vulnerability. This vulnerability is defined and assessed based on its capacity to respond to specific hazards, such as floods, earthquakes, or droughts, acknowledging that this capacity varies greatly. While few may consider themselves invulnerable, others may perceive them as such. Vulnerability can be described through three key factors: exposure, capability, and potential for recovery. The human-centered approach to vulnerability, according to this framework, focuses on the ability of individuals or groups to anticipate, cope with, manage, and recover from the impact of natural hazards [24]. Therefore, strategies aimed at reducing vulnerability typically involve decreasing exposure, enhancing coping mechanisms, improving recovery potential, and strengthening damage mitigation efforts to minimize adverse effects. Pelling [25] identifies three critical components of vulnerability: exposure, resistance (the capacity to withstand negative impacts), and resilience (the ability to adapt and recover). The concept emphasizes the ability of people or communities to predict, manage, resist, and recuperate from environmental hazards. Factors such as age, gender, race/ethnicity, social standing, physical and mental health, educational level, and religious beliefs all contribute to defining vulnerability [26]. Therefore, standard and recommended responses to vulnerability typically involve reducing exposure, enhancing coping abilities, boosting recovery capacity, and fortifying damage control measures to minimize adverse effects. Turner et al. [27] define vulnerability as "the extent to which a system, subsystem, or component of a system is susceptible to damage when subjected to hazards".

Vulnerability is exposure to stressors and unforeseen circumstances, as well as the difficulty of coping with them [28]. Hence, vulnerability has two facets: an internal component of defenselessness, which denotes an inability to cope without suffering losses, and an external aspect of the dangers, shocks, and pressures to which an individual or household is exposed. The state of a particular region in terms of risk, exposure, readiness, prevention, and reaction qualities to a certain natural hazard is known as vulnerability. It assesses this group of elements' capacity to survive an event with physical features [29]. The link between vulnerability and resilience is the subject of disaster risk [30].

Vulnerability has been defined from a sociological perspective as the flaws in social structures when they are paired with outside influences that lead to disasters. The genesis of disasters lies in the very nature of the social system [31]. According to this theory, disasters are a blatant illustration of underlying social vulnerability, or more specifically, a flaw in the social system or structure. The mechanism by which disasters originate is

their source or cause. They should not be viewed as outside factors influencing the social system, like how an appearance disaster goes beyond how the danger affects the victims' various lifestyles. Instead, disasters have their roots in the flaws of the social structure that have revealed themselves, depending on the dynamics of that system. This claim puts forth the sociological stance that the primary cause of disasters is the social system's "underlying" fragility or weakness. As a result, a natural disaster—like a flood—occurring in two separate towns might have very different effects and implications. One group may experience societal devastation, while the other may not. The distinguishing characteristic will be the inherent strengths of each community's vulnerability (or resilience and fragility).

Vulnerability is the danger that could be brought about by several people, things, activities, or projects that are put at risk. This risk can be brought on by natural, technological, social, purposeful, or complex dangers, and it may result in a disaster. Vulnerability is a social construct since decision-making processes primarily consider social, economic, political, and cultural aspects. For instance, vulnerability can be divided into six groups based on social origin and external threats/causes: 1. Total vulnerability: resulting from a lack of planning or readiness to deal with the possibility of a disaster; 2. Economic vulnerability: resulting from a shortage of suitable jobs; 3. Technological or technical vulnerability: resulting from technological dangers; 4. Persistent vulnerability: a lack of adaptation in modernization; 5. The susceptibility to delinquency: brought on by dishonesty, carelessness, and other wrongdoing; 6. New vulnerabilities: brought on by environmental changes [32].

Vulnerability is a result of the inability to access resources and a lack of coping skills, and these two factors are indicated by four indicators: "poverty, marginalization, and access to resources; resource dependence and diversity; inequality and marginalization; and the sufficiency of institutional structures to enhance resilience". The extent to which governmental institutions and "market structures" exist in impacted communities, as well as how easily or difficult it is for them to adjust to and cope with disasters, all play a significant role in how vulnerable they are. This perspective is comparable to sociological thought, which sees agents' behavior—not vulnerability—as the product of social systems [33].

In the field of climate change, vulnerability has a complex relationship with this occurring climate change; for example, it is wide-ranging and involves many factors [34]. Ford views climate change as a stimulus that may cause damage to the system and vulnerability as the risk of exposure. Therefore, vulnerability is highly dependent on the nature of the stimulus, including its intensity, frequency, spatial distribution, duration, and impact on exposure [35].

Vulnerability describes the study of climate change and its related fields of natural hazards and disaster management, ecology, public health, poverty and development, secure livelihoods and famine, sustainability science, and land change [36]. Related research on vulnerability seeks to determine where, how, and why human systems are affected by climate change [37].

Vulnerability assessment is a commonly used tool to represent the potential for damage to human and ecological value systems in response to global climate change [21]. Vulnerability depends on estimates of potential climate change and adaptive responses, and the degree of vulnerability is determined by the adverse consequences that remain after the adaptation process has occurred [38]. Climate-related vulnerability assessments consider various factors, including the characteristics of the vulnerable system, the type and number of stressors, their root causes, their impact on the system, and the time frame of the assessment [39].

Moss et al. [40] identified three dimensions of vulnerability to climate change. The first is the physical environment dimension, which accounts for hazards caused by climate, referring to the climatic conditions in a region and the biophysical effects of climate change, such as changes in agricultural productivity or the distribution vectors of diseases. The second is the socioeconomic dimension, which refers to a region's ability to recover from extreme events and adapt to long-term changes. The third dimension, external aid, refers

to the extent to which a region has access to assistance as it attempts to adapt to change. This aid may come from allies and trading partners, diaspora communities in other regions, and international arrangements.

2.2. Adaptive Capacity and Adaptation

Adaptive capacity does not only refer to the static capacity of the system to prevent disturbances but also encompasses the mobilization of various resources of the system to respond to changes in the external environment [41]. Adaptive change occurs over several stages that integrate collective subjectivity and coordinated behaviors over time and space (preparation, reaction, recovery, and transformation) [42].

As the effects of climate change on social and natural systems continue to worsen, it has been widely acknowledged that human societies must adapt to the changing climate [43]. Adaptation is often the result of the interaction of climate and other factors. Adaptation to changes depends not only on climatic stimuli but also on respecting other non-climatic conditions, sometimes called intervening conditions, which help to influence the sensitivity of the system and its property adjustments. For example, a series of droughts may have similar effects on crops. Two regions may have different yields but different economic and institutional arrangements. The two regions are likely to have very different effects on farmers, and therefore adaptive responses in both the short and long term are significantly different [44]. Hazards and vulnerability need to be considered when examining how climate change affects catastrophe risk [45]. Adaptation takes place in response to rapid changes in technology, globalization processes, and demographic, cultural, environmental, and economic changes [46].

Some researchers view resilience as an aspect of adaptive capacity [47], while others see adaptive capacity as a component of resilience [21,48]. Adaptation is the act of managing a system's resilience, with adaptability being the ability of individuals within a system to influence that resilience [49]. This concept highlights human abilities to manage resilience within social-ecological systems. Generally, adaptation is defined as the process, action, or capacity of an individual or system to modify its inherent genetic or behavioral characteristics to better cope with change, often through social learning. To reduce future catastrophes, community resilience must incorporate "passive and active aspects" that bring together adversity recovery (pre-element) and environmental adjustments [50]. To respond to unpredictable disturbances, adaptation entails the avoidance of risks and the exploitation of advantageous possibilities, which includes reducing negative impacts and maximizing their potential opportunities [51]. Since adaptive capacity is "location and context specific", it is strongly route-dependent [52]. This comprehensive approach to vulnerability and resilience contends that knowledge of physical change alone does not shield society from the risk of climate change, and governments, communities, and organizations may learn a lot from it. Human institutions can play a vital role in minimizing the adverse effects of climate change and seizing the opportunities it presents. In particular, the role of adaptation is crucial for assessing the potential impacts of climate change [44]. Also, the forecast may not offer what one might expect given the non-linear findings of natural hazard causation from the point of climate change. Even if one is fully aware of a particular natural hazard's features, adaptation may still fail owing to a lack of resources, paired pressures from other hazards, such as technical dangers, deteriorating social connections, a lack of institutions, etc. Likewise, infrastructures influence individual adaptability because they determine a system's access to resources. Information has always been an important part of developing strategy. In climate change scenarios, a better understanding of the nature of weather hazards and changes enables systems to study, analyze, plan, and implement adaptation measures. Systems are better able to formulate strategies, thus increasing their ability to adapt [34]. It is also crucial to remember that social approval in its traditional sense will not exist. A society will automatically adapt if there is a lack of political will and motivation [53]. Hazards, exposure, resilience, and adaptive capacity continue to be influenced by similar amounts of risk as well as the type of social risk components as their

configurations change. This is because the adaptability of the system is not fixed and will change with time, region, and society. The economic situation of a country or group is one of the decisive factors affecting adaptive capacity, such that rich countries are better able to withstand the costs of climate change impacts and risks than poorer countries [34].

2.3. Resilience

The term "resilience" was first used by Holling to refer to "a measure of the persistence of a system" and "its ability to absorb changes and disturbances and still preserve the same relationship between populations or state variables" [54]. As more countries acknowledge that not all threats or disasters can be prevented and that they cannot eliminate all risks, resilience has become increasingly important recently [55]. Instead, nations must learn to adapt to risks and manage them in ways that have the least detrimental effects on people and other systems. Resilience is a term used in the world of disaster management to describe the capacity to cope under difficult conditions in the face of great hardship. To maintain some relevance in the disaster sector, its philosophical foundations must be established in the body of catastrophe knowledge.

According to Bruneau et al. [48], the term "resilience" is frequently used across several academic fields; these fields define "elasticity" as "the ability of a material or system to restore equilibrium after displacement" [56]. Some scholars contend that resilience "should entail initial loss of function and subsequent recovery, followed by quick restoration of important functions" from a psychological point of view [57]. Notwithstanding the effects of the traumatic incident, resilient individuals or communities can recover to a state that restores "basic functioning". This method views resilience as a quality that is be-stowed upon the impacted subjects, whether they be resilient individuals, resilient groups, or resilient communities. Those who are resilient can be described as unstoppable, buoyant, persistent, and flexible: those who recover from trauma exposure [58].

According to the majority of resilience researchers, resilience is defined as the capability of a social system's to "bounce back" from adversity [59]. This word suggests the capacity to adjust to normal or anticipated levels of stress to account for unexpected shocks and needs. This idea can be viewed as a strategy in the context of hazards that includes both pre-event and post-event actions intended to stop damage and loss caused by hazards as well as to react to and lessen the effects of disasters.

It is believed that social systems' capacity to deal with and recover from disasters is influenced by both innate elements that help them absorb the effects of disasters and recover from them and post-event adaptation processes that support social systems' capacity to reorganize, change, and learn in response to threats [19]. Recovery is defined by Fisher et al. [60] as "returning and/or recovering to a level of normal functioning as rapidly and efficiently as possible".

When considering natural catastrophes, resilience is a crucial concept commonly defined as the ability to withstand and bounce back from losses resulting from disasters [30]. Although vulnerability and resilience are distinct concepts, Engle [61] points out that they are connected through adaptive capability. As the idea has been used in so many different contexts, there is not a single definition that is universally recognized. From a cross-domain viewpoint, some scholars offer an interpretive study of resilience, identifying three levels of description for each resilience domain [62]. Some scholars consider the population's capacity to lower risk, prevent loss, and recover from social disturbance with little to no disruption, as well as their inner fortitude and capacity for adaptability in the face of environmental shocks and disruptive occurrences [18,63,64].

Although there is not one widely accepted definition of resilience, there are at least three that can be used to describe it [65]: response to perturbations, self-organization, and learning and adaptability are the first three. Building and developing resilience in the context of climate change is an important but complex social process [66]. When it comes to urban climate adaptation, a resilience-based approach encourages practitioners to consider innovation and change to help recover from possible or unpredictable stresses

and shocks. For complex social-ecological systems that are dynamic and face high levels of uncertainty, resilience as a strategic approach offers many advantages over traditional system management [49]. As the conceptualization of resilience becomes more advanced, resilience shifts from being more outcome-oriented to being more process-oriented. The goal of disaster risk management is to reduce the number of fatalities and livelihood for post-disaster and disaster victims while ensuring that the community or system returns to normal as quickly as feasible. While it would be illogical to portray this negatively, it should be possible to make the case that resilience is connected to people's capability to go beyond the bare necessities of survival [67]. The Climate-Related Hazards Community Resilience Framework (CDCRF) in the context of climate change focuses on climate change-related hazards such as coastal hazards such as floods and hurricanes [68]. Although the hazard framework can be applied to different geographical areas regardless of the types of hazards they face, conceptualizing resilience to a specific hazard or set of hazards limits its applicability to regions where these hazards exist. For example, as climate change continues, poorer areas may be more severely affected than other areas. Therefore, enhancing the regional ability to withstand climate change disturbances and enhancing the long-term stability of the economy, society, and environment, that is, building sustainable resilience in response to climate change, is the key to human prosperity and social development [69].

3. Exploring the Relationships between Vulnerability, Adaptation, and Resilience

Although vulnerability and resilience are distinct concepts, Engle [61] argues that they are linked by adaptive capacity and that resilience is frequently viewed as a positive aspect of resilience, with vulnerability and adaptive capacity serving as the concept of disaster. In a vulnerability framework, Gallopin [70] merges the elements of resilience and adaptation capacity into responsiveness; resilience is a subset of responsiveness, which is itself a subset of sensitivity, exposure, and responsiveness.

The processes underlying exposure, sensitivity, and adaptive ability are frequently interconnected and intrinsically intertwined at various dimensions [71]. The ability to adapt varies with scale and location, with country, community, social group, and individual differences, as well as with time.

According to Lucini, Zhou et al., and Nelson, these are connected ideas rather than being diametrically opposed [30,41,59]. They both effectively convey the key elements of how people proactively react to forces of change, the two concepts are not opposites; rather, they are connected, exhibiting features of systems or victims that may be at risk. Resilience and vulnerability are opposite extremes of a continuum, demonstrating susceptibility to unfavorable or benign consequences when exposed to high-risk contexts [72]. In other words, while vulnerability indicates unfavorable results after adversity, resilience represents positive results. The distinctions between vulnerability and resilience, as well as other related notions like adaptability and adaptive capacity, are sometimes hazy despite being extensively explored [19,21,70].

In the context of climate change, vulnerability is viewed as a consequence of a community's exposure to climate change and its capacity for adaptation (i.e., how the community transforms itself to cope with those conditions) [35,73]. This notion of vulnerability includes two elements: exposure to risks and capacity for adaptation. Ford and Smit view resilience and adaptive capacity as a subset of vulnerability when resilience is considered as a term that is somewhat comparable to adaptive capacity [35].

The IPCC links the ideas of adaptation, vulnerability, and resilience with the social goals of equity, health, and well-being, as outlined in the Paris Agreement. The concept of vulnerability offers a unique perspective into the effects of climate change on diverse communities, people, and ecosystems, particularly considering factors such as racial, gender, and wealth inequality. Resilience, being a broad term, encompasses both outcomes and processes. It involves maintaining necessary functions and having the potential to transform. If implemented effectively, resilience efforts will support the creation of a

climate-resilient society, advance the objectives of sustainable development, and address social objectives of equity, well-being, and ecosystem health [74].

Hence, disaster resilience should encompass not only the capacity to "bounce back" or "move on" following a disaster [75], but also the capacity to proactively rebuild and adjust oneself to handle future disasters more effectively. Restoring internal balance is only one aspect of community resilience, but it must also facilitate growth. Therefore, being disaster-resilient entails proactively rebuilding and adjusting to better handle future calamities. Community resilience encompasses the power to rebound from a catastrophe as well as the ability to restore homeostasis. In other words, the process of developing resilience following a disaster must include the social change that occurs as the impacted society adjusts to its new environment.

Lei et al. [51] conceptualize the relationship between vulnerability, adaptation, and resilience in terms of disaster risk. Adaptation is the proactive change of one's structure and function to adapt to environmental changes or associated hazards. In contrast to resilience, which is typically a proactive response to a crisis, adaptation is typically a proactive move in the event of a disaster that is predicted to reduce any potential risks or negative effects beforehand. To enable the transformation of transient resilient reactions into durable strategies, adaptation typically denotes a long-term process. Systems have an inherent vulnerability that makes them susceptible to the negative effects of hazards and enhances readiness for prospective dangers. Resilience is the capacity to withstand, take in, adapt to, and recover from the consequences of risks quickly and effectively. This capacity is typically a reactive response to continuous dangers. Contrarily, adaptation is generally proactive behavior in reaction to impending dangers to reduce any risks or adverse effects. Long-term adaptation (LTA) and short-term adaptation (STA) are two more divisions of the adaptation process (LTA).

Based on these prior conceptualizations, the concepts of resilience, vulnerability, resilience, and adaptive capacity were originally interrelated rather than mutually inclusive (Figure 1). Resilience includes the response and recovery when a disaster occurs, and the ability to quickly return to a normal state or even develop from a disaster; adaptation refers to adaptability and sustainability, the process by which individuals and groups proactively respond to changes through continuous learning; exposure and sensitivity is a factor that characterizes vulnerability, including multidimensional exposures and sensitivities, the ability to anticipate risks, and manage and bear negative consequences.

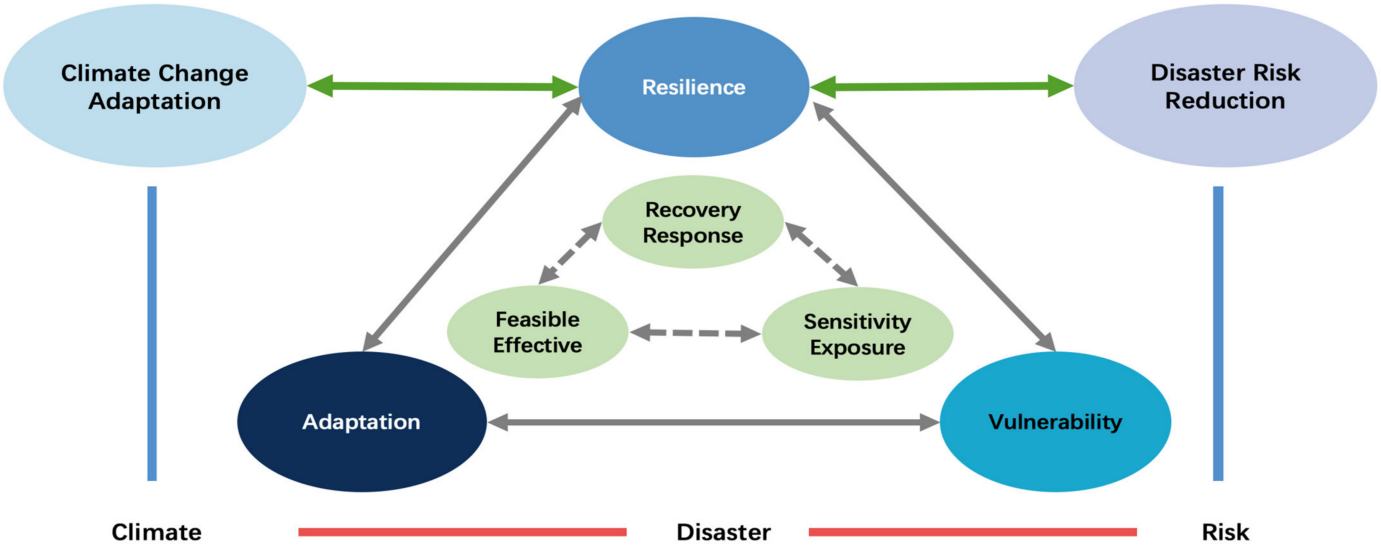

Figure 1. Links between vulnerability, adaptation, and resilience.

4. Climate Change and Climate-Related Disaster

4.1. Climate Change

One of today's most significant global challenges is climate change, posing numerous ecological, environmental, social, and economic threats to human survival and development. The changing global climate emerges as a new global threat that plagues modern society [76]. Both human activities and natural environmental changes contribute significantly to global climate change, with human-induced greenhouse gas emissions being the primary driver of global warming [77,78]. Global warming has led to adverse effects such as melting glaciers, rising sea levels, and an increase in extreme weather events, including heatwaves, droughts, intense tropical storms, and heavy precipitation [79]. According to the 2022 IPCC report, anthropogenic climate change, including more frequent and severe extreme events, has caused widespread damage to nature and human systems, surpassing the normal rate of climate variability. Vulnerable populations and systems seem to be disproportionately affected across various sectors and geographical regions. Extreme weather and climate events are on the rise, exceeding the capacity of both natural and human systems to adapt and resulting in irreversible consequences [74]. The United Nations Framework Convention on Climate Change (UN-FCCC) defines climate change as "climate change that is directly or indirectly attributable to human activities, which alters the composition of the global atmosphere and is in addition to the natural rate of climate variability observed over comparable periods" [80]. This definition is in line with and expands upon that definition.

Climate change is a complicated and enduring threat that is both a natural occurrence and a danger brought on by human-caused emissions of greenhouse gases. According to the IPCC [81], a discernible change in the status of the climate is called climate change, for instance, through statistical analyses of its mean values and/or variability, and that lasts for a long time, typically decades or more. A new notion of climate change, distinguished into "anthropogenic climate change" and "natural climatic variability", has been developed by the UNFCCC. Science investigates all climate change without considering the sources of change, but the international policy process solely considers anthropogenic climate change. This is the major distinction between the IPCC and UNFCCC definitions. While the Earth has endured significant changes long before human existence, both the IPCC and UNFCCC agree that human impacts on climate are likely to push the planet into a state that has never been experienced before [45].

Unquestionably, humanity is confronting a climate emergency, which is already here. As the number of climate-related calamities rises, the unbearable amount of human suffering, which is already immense, is escalating quickly [82]. Many scientists are quite concerned since it happened faster than they had anticipated. In other words, our society needs to undergo a significant historical shift in response to the current global climate emergency [83]. Political and scientific issues related to climate change are complex [84]. The dangers associated with climate change are both complex and enduring. Oceans are warming more slowly than land areas. On a continental, regional, and ocean basin scale, numerous additional long-term shifts in the climate have also been noted [85]. Across the world, areas impacted by drought have expanded since the 1970s, and over the past 50 years, the frequency of some extreme weather occurrences has increased relative to their intensity. Heat waves and heavy rains have also become more common [86].

Climate change is expected to cause precipitation to rise in intensity in many parts of the world. Already, the most vulnerable and impoverished nations have suffered from climate change [87]. More moisture can be stored in warmer air, which suggests that precipitation would probably increase in both amount and intensity. Widespread flooding is one possible outcome of this increase in precipitation [45]. Climate change-related sea level rise exacerbates the effects of other natural disasters and presents considerable problems to coastal regions. Coastal floods, erosion, and storm surges pose significant threats to low-lying communities, causing the most harm [88]. Predictions suggest that global warming will lead to an increase in extreme weather patterns, including greater dry

periods, intense downpours, violent hurricanes, more frequent flooding events, and more frequent and catastrophic wildfires [86].

Also, as the sea level rises, coastal flooding will get worse. Also, it is expected that storm and tropical cyclone-related floods will get worse in the upcoming years, leading to an increase in storm surges and flooding incidents. The most catastrophic coastal flooding, which poses a hazard to human life, is predicted to occur in tropical locations, including island nations in the Pacific and some areas of the United States [89]. Longer droughts in tropical and subtropical areas have been observed, as have more frequent intense rainfall events over most land areas and stronger tropical cyclones in the North Atlantic. These changes are anticipated to have widespread repercussions in the form of floods and droughts [90].

4.2. Climate-Related Disasters

Hazards must be considered when analyzing the impact of climatic emergencies on disaster risk, including both their effects and non-effects. Throughout human and planetary history, the Earth's climate has changed due to various hazards. This includes long-term trends, shifts in baseline and condition, variability, and cycles [45]. Several interconnected phenomena, such as general warming trends, modifications to precipitation patterns, sea level rise, and changes in rapidity, may contribute to these changes.

For instance, rapid Arctic warming may increase the risk of zigzagging and obstruction in Northern Hemisphere summer rapids, resulting in disasters including heat waves, floods, and droughts. What is certain is that in the face of a system of growing uncertainty and frequent disasters, climate change is worsening the impact on human hazards, livelihoods, communities, and infrastructure. It is also eroding the resilience of livelihoods [91]. There was a record-breaking heat wave in Siberia in the Arctic Circle, the Atlantic hurricane season cost more than $46 billion in damages, and deadly floods and landslides in Southeast Asia caused the displacement of over 12 million people. The year 2020 is one of the hottest on record. To stop the current cycle of fatal climate degradation and stop the melting of the Arctic, every effort must be taken to reduce emissions and enhance the removal of carbon from the atmosphere. Due to persistently increasing emissions, self-reinforcing climate feedback loops, and impending tipping points, scientists are already discovering [92]. There is mounting evidence that climate change has a terrible effect on people's lives and constitutes a serious threat to the entire world. Even infrastructure management systems may suffer from the effects of climate change, including relocations, population shifts, and financial losses [93]. Climate change does make some risks worse, which in turn makes some calamities worse [45]. According to the emergency events database (EM-DAT), there were 387 natural disasters and catastrophes in the world in 2022 that claimed 30,704 lives, affected 185 million people, and resulted in economic damages of about $223.8 billion. Over 16,000 people were killed by heat waves in Europe, while 88.9 million people in Africa were afflicted by droughts. In the Americas, Hurricane Ian caused $100 billion in damage [94]. Natural disasters are also happening more frequently; in fact, the number of natural disasters in 2022 (387) is higher than the average for the previous 20 years when compared to the data from 2002 to 2021 (370) (Figure 2).

Although there is significant year-to-year variation in drought, present trends point to a potential increase of more than 30% over the 30 years from 2001 to 2030 [95]. Extreme weather occurrences occur more frequently each year and are expected to roughly quadruple between 2001 and 2030 based on present patterns. The expected effects of climate change on catastrophe risk include both vulnerability and the hazard component. Climate change alters average weather patterns over the long term and increases the frequency and severity of extreme weather events. Since local environmental circumstances are changing so quickly, climate change makes people more vulnerable.

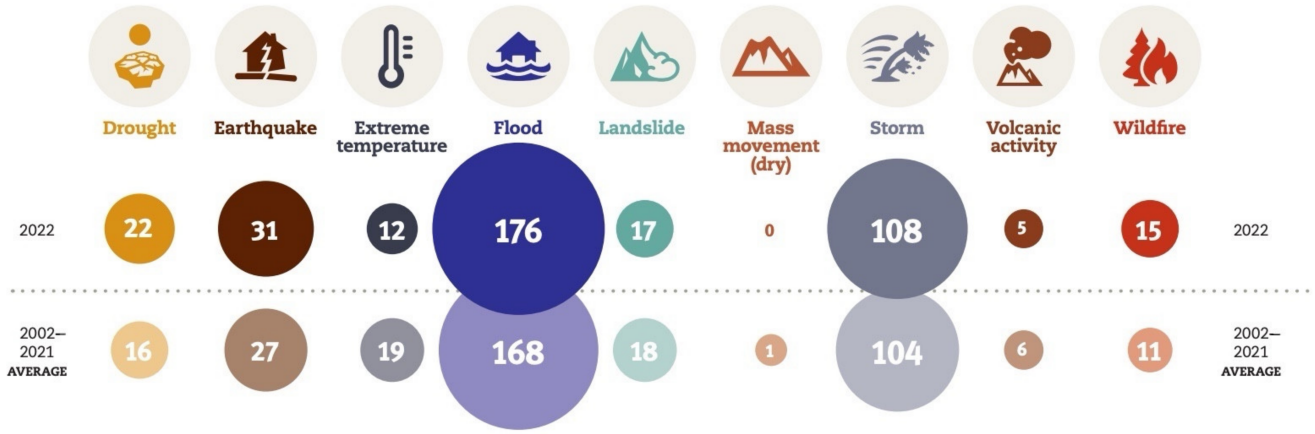

Figure 2. Occurrence by disaster type: 2022 compared to the 2002–2021 annual average from Ref [94].

Formerly rare occurrences of tragedies and calamities are becoming commonplace. The degree to which the natural resources and ecosystem services that people depend on are susceptible to climate change determines how vulnerable people are to it [96]. Regrettably, the poor in low-income countries, which make little contribution to the buildup of greenhouse gases, suffer disproportionately from these disasters. It might even be claimed that catastrophic events can be damaging for developing nations with weaker resistance to disasters [85,97]. This condition is most extreme among the poorest people.

One factor contributing to the danger of disaster is climate change [45]. As a result, instead of directly impacting disaster capabilities, climate change affects hazard parameters, sometimes making hazards worse and other times mitigating them. For instance, July 2019 set a record for warmth on a global scale. According to NASA data on global warming, between 2001 and 2018, there were 17 of the 18 warmest years ever recorded in the previous 136 years [98]. Global emissions are rising instead of declining, having significant cumulative effects on the climate system, the natural world, and the ecosystems that make up the world's food chain [83]. The overall number of deaths in 2022 was 30,704; among the types of deaths affected by disasters in 2022, the top three are disasters related to climate change, namely extreme temperatures, floods, and droughts. Among them, the number of deaths caused by extreme temperatures will reach 16,416 in 2022, which is twice the average annual rate from 2002 to 2021. Secondly, the number of deaths affected by floods will reach 7954 in 2022, and the number of deaths caused by drought will reach 2601 (Figure 3). Due to the enormous reduction in societal resilience and the ability to adapt to future crises, these concurrent and sequential effects are pushing society to its breaking point [82].

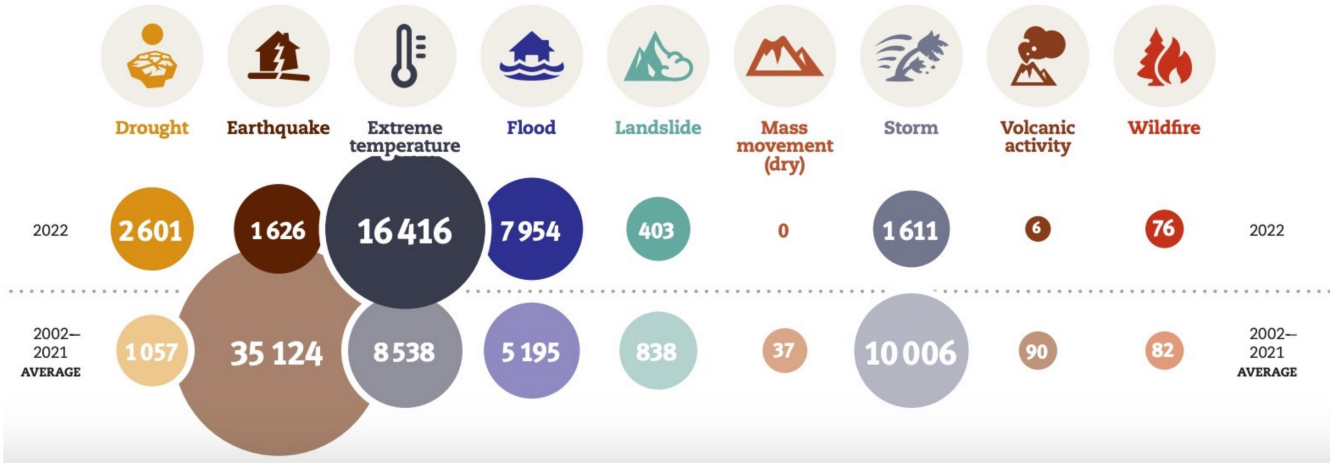

Figure 3. Number of deaths by disaster type: 2022 compared to the 2002–2021 annual average from Ref [94].

A disaster is a sudden, unfavorable, catastrophic event that harms people, plants, and animals significantly. The majority of catastrophes, or more precisely, the risks that cause them, cannot be prevented, but their impacts can be lessened. Proposals to lessen the effects of catastrophes are not brand new. The annual spike in climate disasters shows that, if things continue as they are, we are currently facing a serious climate crisis and global catastrophe. Moreover, humanity is on the verge of having the chance to fundamentally alter life as we know it on Earth [82].

5. Exploring Climate Change's Impact on the Future of Disaster Risk Reduction

5.1. Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR)

Within the broader context of sustainable development, DRR is defined as "the systematic creation and deployment of policies to reduce the impacts of methods and practices that minimize vulnerability, risks, and the incidence of disasters on society as a whole" [99]. Socioeconomic conditions, environmental factors, and the availability of knowledge and technology shape the capacity for adaptation and mitigation. However, there is significantly less information on the costs and effectiveness of adaptation strategies compared to mitigation efforts [86].

Recent climate disruptions have tested, and sometimes exceeded, our ability to cope. Without efforts to reduce exposure and enhance coping mechanisms, the rapid changes caused by climate change will increase the vulnerability of many areas. Adaptive capacity refers to the ability to adjust to minimize negative impacts and maximize any positive outcomes from climate change. Good adaptation involves managing and reducing the risks associated with climate change. It is a comprehensive concept that encompasses actions by private sector companies, public institutions like governments, and individuals and communities. Successful adaptation reduces vulnerability by improving and strengthening current coping strategies and resources, implementing specific measures to address climate change vulnerabilities, and integrating these efforts into broader policy frameworks [100].

The national development plan, which encompasses the formulation of budgets, plans, laws, and budgetary allocations, serves as the perfect platform for integrating disaster risk reduction (DRR) and climate change adaptation (CCA) into the development process. This framework also allows for the establishment of specific initiatives aimed at disaster risk prevention and management strategies [101].

Mercer highlights the differences between DRR and climate change adaptation (CCA) (Table 1). CCA is defined as the process of reducing the adverse effects of climate change while seizing opportunities to find innovative solutions [90]. Unlike DRR, which focuses on existing and historical risks to develop strategies based on past and present conditions, CCA looks towards the future, acknowledging uncertainties and emerging threats. Thus, independent of past mitigation efforts, there is a need for more adaptation measures at regional and local levels to mitigate the adverse impacts and variability of projected climate change. However, as the severity of impacts is likely to increase over time, adaptation alone may not be sufficient to address all expected effects of climate change, especially in the long term. While there are numerous adaptation strategies available, a broader range of options than currently available is necessary to reduce vulnerability to climate change [86].

Table 1. Summary of differences between DRR and CCA.

DRR	CCA
Relevant to all hazard types	Relevant to climate-related hazards
Most concerned with the present	Most concerned with the future
Historical perspective	Future perspective

Table 1. *Cont.*

DRR	CCA
Traditional/indigenous knowledge at community level is a basis for resilience	Traditional/indigenous knowledge at community level may be insufficient for resilience against types and scales of risk yet to be experienced.
Traditional focus on vulnerability reduction	Traditional focus on physical exposure
Community-based process stemming from experience	Community-based process stemming from policy agenda
Practical application at local level	Theoretical application at local level
Political and widespread recognition often quite weak	Political and widespread recognition increasingly strong

Source: Adapted from Mercer [90].

5.2. Community Disaster Resilience as a Means for Disaster Risk Reduction

The concept and practice of disaster risk reduction include making systematic attempts to identify and mitigate the causes of disasters [102]. All levels of society are subject to governance, a process involving the state, non-state actors, and the private sector. It contains a set of tools, such as institutions, methods, and processes, as well as the ability of individuals to rule using these tools. Consensus-driven, participatory, effective, efficient, fair, transparent, and accountable are all characteristics of good governance.

All parts of the DRR system must take governance issues into account. DRR itself should be considered as bolstering control over the full system of political, economic, and administrative management. DRR is a method for identifying the causes of catastrophes and preparing for their effects. DRR is cross-cutting and cross-disciplinary. Interventions to reduce the risk of disaster must therefore also be planned to increase overall development process governance [99].

Disaster governance is a significant road to attaining DRR procedures and outcomes since governance is a fundamental factor in achieving DRR and bad governance is a key potential generator of catastrophe risk [103]. By carrying out its governance, which includes creating an environment that supports disaster risk reduction, a dedicated government empowers people who are at risk to fulfill their obligation to protect against the effects of catastrophes. The institutional structure (policies, laws, goals), resources, and activities make up the enabling environment. A crucial step in political governance is the creation of institutional frameworks.

Severe weather conditions converge with localized poverty, ineffective government, and deteriorated infrastructure. Extreme phenomena such as droughts, floods, fires, and storms disproportionately impact poorer communities, as disasters often result from the convergence of these factors. Poverty prohibits people from adequately preparing for catastrophes, and disasters frequently entail environmental components that are challenging to address. Effectively managing climate change remains a critical challenge [104]. As a result, the influence of climate change on disaster risk is more in terms of hazards than vulnerability, modifying the parameters of hazards, sometimes escalating risks and other times reducing them.

As disasters occur with increasing frequency, the concept of building community resilience as a strategy for reducing risk, recovery, and rebuilding after catastrophes has become a more prominent consideration [56]. The global dialogue on DRR has gained momentum, defined as "the concept and practice of minimizing disaster risks through systematic efforts to analyze and manage the causes of hazards. This includes reducing exposure to hazards, decreasing the vulnerability of people and property, wisely managing land and the environment, and enhancing preparedness for adverse events" [102].

Disaster risk reduction focuses on reducing or eliminating the likelihood and impact of hazards, with the goal of "handling" these hazards in a way that minimizes their effects on

society. This approach is central to disaster management [105]. Sharifi and Yamagata [106] suggested that incorporating resilience thinking can help transition from short- to long-term planning. This is particularly relevant because disaster risk management often prioritizes short- and medium-term strategies.

Activities for reducing the risk of disasters can involve analyzing the risk from past occurrences or being proactive [105]. Relocation plans, insurance programs, updates to building codes, retention systems, detection systems, educational initiatives, and behavior change are a few examples of disaster risk reduction measures, It is well acknowledged that catastrophe risk reduction is an essential component of disaster management and that it affects all areas of the disaster management community.

There are more opportunities for humans to increase disaster resilience and decrease vulnerability so that disaster risk can be reduced regardless of climate change, and this means that understanding how climate change affects disaster risk cannot disentangle disaster risk from community disaster resilience. As a result, disaster risk reduction, climate change, and community disaster resilience are completely interconnected.

6. Conclusions

Although vulnerability, adaptation, and resilience are distinct concepts, they are closely interrelated and intrinsically linked. In the context of climate change, understanding the role of these three elements, particularly in disaster risk reduction, requires a comprehensive and in-depth understanding of their intrinsic linkages. Supporting a long-term perspective by integrating climate change into disaster risk reduction will further contribute to addressing vulnerability processes and recovery processes in the long term [45].

This review synthesizes the existing literature to provide an in-depth exploration of the definitions and interrelationships of vulnerability, adaptation, resilience, and climate disasters. Additionally, it provides an overview of the development of climate change, from climate change to the current climate crisis. Finally, the impact of climate change on future disaster risk reduction efforts is explored by describing and analyzing the relationship between climate change adaptation and disaster risk reduction.

Firstly, vulnerability assessments are essential for identifying the most at-risk populations, regions, and ecosystems and for understanding the underlying drivers of vulnerability. The expected effects of climate change on disaster risk include vulnerability as well as hazard factors. Climate change makes people more vulnerable by rapidly changing local environmental conditions, which makes it difficult for local environmental knowledge to keep up and makes it less useful for things like managing pests and local food and water resources. Policymakers and practitioners can create tailored adaptation and resilient strategies that address the underlying causes of vulnerability and improve adaptive capacity by having a thorough grasp of vulnerability.

Secondly, adaptation is critical to building resilience and reducing vulnerability to the impacts of climate change. Additionally, it helps communities obtain a greater awareness of the hazards associated with natural disasters, enabling early risk identification, interventions to improve adaptive capacity, and the encouragement of a culture of independence, reciprocal assistance, and community networks [107]. To successfully decrease risk, respond to and recover from disasters, and share the economic, financial, and social costs, governments must do more to involve local communities. To make communities resilient, residents and organizations can contribute their capabilities by working with local governments without being overbearing and impeding their creativity, flexibility, and efficiency [108]. However, disaster risk management usually places a premium on short- and medium-term planning, as noted by Sharifi and Yamagata [105], who suggest that adding resilience thinking can help move the focus to long-term planning. It is important to further refine the vulnerability, adaptation, and resilience framework and explore innovative approaches to climate change adaptation that prioritize equity, social justice, and sustainability.

Thirdly, resilience-building measures are critical to enhancing the ability of communities, ecosystems, and infrastructure to withstand and recover from climate-related disasters and stresses. To successfully reduce risk, communities must prioritize their plans and initiatives within the framework of regional expertise and resources. Community resilience focuses on common hazards and offers local agencies, groups, and organizations a framework to anticipate and address their own challenges [108]. Resilience-based approaches emphasize the importance of integrating social, institutional, economic, and environmental factors into adaptation planning and implementation. This review emphasized the importance of integrating the concepts of vulnerability, adaptation, and resilience into climate change and disaster risk reduction policies and practices. By utilizing a framework that considers the complex interactions between social, economic, and environmental factors, stakeholders can develop more effective and equitable adaptation strategies that increase resilience, lessen sensitivity to climate change, and improve ecosystems' and populations' capacity to adapt and prosper.

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