sustainability

Review

Vulnerability Assessment Models to Drought: Toward a Conceptual Framework

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Abstract: Drought is regarded as a slow-onset natural disaster that causes inevitable damage to water resources and to farm life. Currently, crisis management is the basis of drought mitigation plans, however, thus far studies indicate that effective drought management strategies are based on risk management. As a primary tool in mitigating the impact of drought, vulnerability assessment can be used as a benchmark in drought mitigation plans and to enhance farmers' ability to cope with drought. Moreover, literature pertaining to drought has focused extensively on its impact, only awarding limited attention to vulnerability assessment as a tool. Therefore, the main purpose of this paper is to develop a conceptual framework for designing a vulnerability model in order to assess farmers' level of vulnerability before, during and after the onset of drought. Use of this developed drought vulnerability model would aid disaster relief workers by enhancing the adaptive capacity of farmers when facing the impacts of drought. The paper starts with the definition of vulnerability and outlines different frameworks on vulnerability developed thus far. It then identifies various approaches of vulnerability assessment and finally offers the most appropriate model. The paper concludes that the introduced model can guide drought mitigation programs in countries that are impacted the most by drought.

Keywords: vulnerability; assessment; factor; drought; risk management

1. Introduction

Drought is known as one of the most expensive natural disasters and occurs in virtually all regions of the world as a normal part of climate [1]. For example, the drought in the U.S. between1987 and 1989 cost the government and private sectors an estimated $39 billion and affected up to 70% of the country's population [2]. Drought also differs from other natural hazards in several ways. First of all, since drought is a natural hazard with a slow-onset, it is often referred to as a creeping phenomenon [1]. Because of the gradual nature of drought, its effects accumulate slowly over an extensive period of time [3], making the onset and end of drought difficult to determine and causing scientists and policy makers to disagree on the basis (*i.e.*, criteria) that determine when to declare the end of a drought. Due to the large scale and long lasting nature of drought, it also affects more people than any other natural hazard. According to Wilhite and Glantz [4], drought is classified into different types: (1) meteorological drought; (2) hydrological drought; (3) agricultural drought;

and (4) socio-economic drought. Meteorological drought is defined as a significant decrease in climatologically-expected precipitation and is quantified using the Palmer Drought Severity Index (PDSI). Hydrological drought is defined as a period when there is an inadequate supply of surface and groundwater to water crops and is quantified using the Surface Water Supply Index (SWSI). Agricultural drought occurs when a water deficit limits vegetative growth. In other words, when soil moisture causes extreme plant stress. Agricultural drought is quantified using the Crop Moisture Index (CMI). Socio-economic drought is related to human factors and deals with especially complicated elements due to human expectations that may or may not be realistic. For example, a pastoralist who grazes a herd of cattle may experience the consequences of drought sooner and more frequently than a pastoralist herding camels. Therefore, the process of quantifying socio-economic drought is multifaceted and varies from one population to the next.

The impacts of drought are diverse and can be broadly classified as economic, environmental and social [5].The economic impacts of drought include increased commodity prices, demand for water, and credit. The social impacts include increased migration, poverty, reduced quality of life, and increased political conflicts. While the environmental impacts consist of increased pollution, destruction of plant diversity, reduced underground water, and soil erosion. Furthermore, the impacts of drought are often referred to as either direct or indirect impacts (Figure 1). In a society where agriculture is the primary economic activity, the direct or first-order impact of a drought is observed in the form of a decrease in food production via a decrease in cultivated areas and crop yield. Examples of second-order, or indirect, impacts are decreased employment and income. Moreover, the delay in sowing and transplanting crops caused by drought reduces agricultural employment, which in turn further reduces employment opportunities because of a diminished need for weeding and harvesting [6].

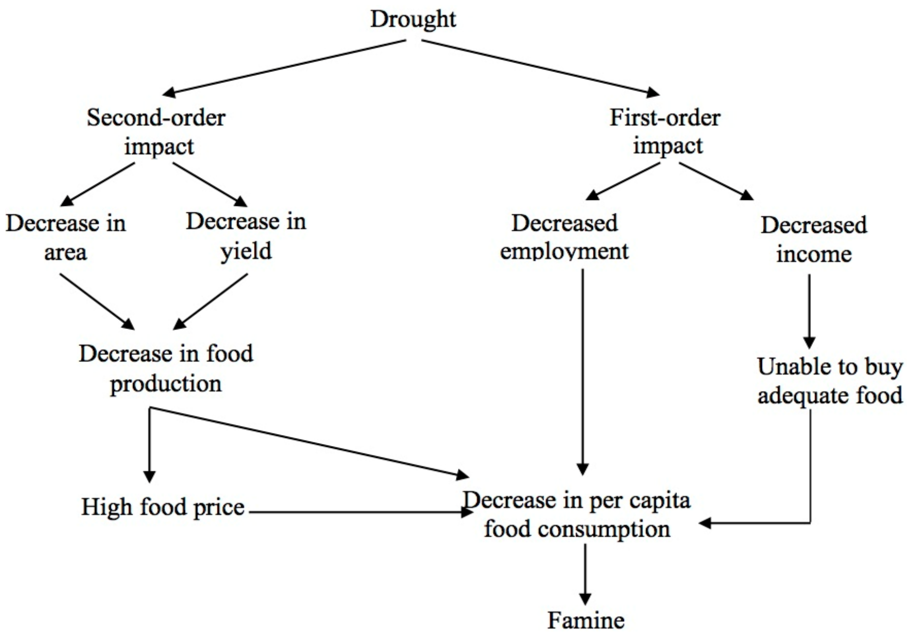

Figure 1. Drought impact [6].

Drought coping strategies are seen as effective activities that reduce the losses caused by this phenomenon [7]. Unfortunately, evidence indicates that in most countries, drought management has been based on crisis management [8]. Because of this emphasis on crisis management, society has generally moved from one disaster to another with little, if any, reduction in risk. This type of disaster management is an active approach in which efforts are made to reduce the impacts of drought after it has already struck. Many believe that this type of drought management is not only ineffectively manages time and is economically inefficient [9], but that it also causes a number of problems, such as dependency on government, social injustice, and higher costs. The inefficiency of crisis management strategies has led to the development of the risk management approach, which aims to improve the ability of farmers' to cope with drought before it has struck. This change in emphasis requires that drought policy makers invest in being prepared, in mitigation, and in prediction/early warning procedures that could reduce future impact of drought and lessen the need for government intervention [10]. Facing the challenges that droughts present, decision makers need to be better informed so that they can decide on the allocation of resources [11]. In the Unites States for instance, since its inception in 1995, the National Drought Mitigation Center (NDMC) has striven to promote drought mitigation planning and to increase the communication between federal, state, and local drought planners [10] so that the administration of drought management can reduce the vulnerability of rural communities. Risk management can improve farmers' ability to cope with the impact of drought by establishing a comprehensive system of early warning systems [12]. Hence, the identification of factors that influence vulnerability to drought is essential in developing coping strategies at the various levels, from the central government to the individual households. The main purpose of this paper is to set-up a vulnerability model so that a benchmark can be designed in order to mitigate the impact drought. This paper starts with various definitions of vulnerability and will outline different frameworks that have been developed in regard to vulnerability. Afterwards, it will identify various approaches in vulnerability assessment and finally offer the most appropriate model of drought vulnerability assessment that can guide drought mitigation programs in regions highly exposed to drought.

2. Materials and Methods

2.1. The Definition of Vulnerability

While there are numerous definitions for Vulnerability, since vulnerability is bound by context, a specific definition of vulnerability may not be justified. The Collins English Dictionary, however, defines vulnerability as, *inter alia*, the "capacity to be physically or emotionally wounded or hurt" [13]. Scholars from different fields of specialization have been conceptualizing vulnerability differently based on their objectives and the methodologies employed within their individual contexts. These differences limit the possibility of having a universally accepted definition of vulnerability. However, the knowledge of the existing conceptual and methodological approaches can influence the choice of one of the methods, or a combination of existing methods, in analyzing vulnerability for a specific area of interest [14]. The supplementary material provided at the end of this manuscript provides a clear definitions. The scientific use of "vulnerability" has its roots in geography and natural hazards research, but this term is now a central concept in a variety of other research contexts such as agriculture, ecology, public health, poverty and development, secure livelihoods and famine, sustainability science, land change, climate impacts and adaptation [15]. Vulnerability is defined as the degree of loss in a given element at risk and consists of a set of such elements that result from the occurrence of a natural phenomenon in a given magnitude and usually expressed on a scale from 0 (no damage) to 1 (total damage) [16]. According to IPCC [17], vulnerability takes on both negative and positive characteristics of a given population. In other words, vulnerability has both positive and negative dimensions. The positive dimension is related to vulnerability's connection to the process of adaption, which, in this instance, provides a framework for improving the capacity of people to respond to stress. In other words, adaptation is facilitated by reducing vulnerability.

Another definitive of Vulnerability is the capability of a person or group to anticipate, resist, cope with, and recover from the impact of natural or man-made hazards [18–21]. One of the advantages of this definition is that it identifies vulnerable groups and areas in a community. On one hand, this information is critical for drought management policy-makers who often need to prioritize limited resources when designing interventions to reduce vulnerability. On the other hand, the assessment of "who" is vulnerable and "why" recognizes the interactions between drought hazard and vulnerability that define the risk of serious impacts, and is one of the main aspects of drought mitigation and planning [22]. According to Sonmez *et al.* [23], the high economic cost and social vulnerability caused by problems from drought in recent years have led to an increase in attention to drought vulnerability. The losses due to drought events across the world also have significantly increased in line with the increased number or severity of droughts [21]. The impacts of which depend largely on societal vulnerability at the time the drought occurs. Recently, these losses increasingly result from societal vulnerability and in order to lessen the impact of drought, societal vulnerability must be reduced. Blaikie *et al.* [21] showed how the risks associated with drought area combination of this societal and hazard vulnerability. According to Adger [24], social vulnerability is the exposure of groups or individuals to stress as a result of social and environmental change, stress in this context referring to unexpected change and the disruption of livelihoods. This definition emphasizes the social dimensions of vulnerability contrasts the biophysical approach to drought vulnerability that mainly considers physical losses like yield, income and the like, ignoring many aspects of the adaptive capacity of the social dimensions.

Furthermore, drought vulnerability can differ for different individuals and nations. According to Brooks *et al.* [25], it is important to note that factors that make a rural community in developing country vulnerable to drought could be different from those of a wealthy industrialized nation. Even in a given system, vulnerability is unlikely to be the same for drought-affected areas in comparison to less affected areas [26]. Downing and Bakker [27] stated that hazardous weather differs from normal weather by its potential to do damage, and not by its physical or statistical properties.

In the remaining part of this paper, we have tried to examine the different approaches of vulnerability assessment to climate change. The following table differentiates the various approaches most scholars of this topic use to assess vulnerability (Table 1).

Table 1. Common approaches used in vulnerability studies.

Approach	Characteristics	Studies/Authors	Focus
RHA	The individual status during disaster is described to be more descriptive than explanatory. In other words, hardware dimension in vulnerability is emphasized.	Fussel [28]; Perkins [29]; Fussel [30]	Main focus on the field of engineering and technical terms on disasters.
PEA	The concept of vulnerability is characterized as "internal social vulnerability" or "cross scale social vulnerability" (software aspects). "Response capacity", "coping capacity", and "resilience" are the core features of vulnerability.	Wilhelmi and Wilhite [22]; Fussel [28]; Collinson [31]	Focuses on people and concerns with why and whom.
IAA	Mix method approaches, both internal and external dimensions of vulnerability are emphasized.	Deressa [14]; Fussel [28]; IPCC [17]; Cutter [32]	Biophysical and social determinant of vulnerability is the center of attention.
BPA	The semi-software dimension of vulnerability.	Deressa [14]	Social and biological dimension of vulnerability is the center of attention.

2.2. Factors Influencing Vulnerability

Vulnerable groups are unable to provide for their basic needs because of adverse economic and health conditions and mental status of those at risk [33]. Hence, the identification of vulnerable groups can act as an entry point to both understand and address the processes that cause and exacerbate vulnerability [25]. Interestingly, vulnerability varies from one region to another due to diverse economic, political, social, and historical influences [34]. Thus, some groups suffer more than other groups in the community [35]. This difference in vulnerability is due to different individual (e.g., gender, age, education, attitude), socio-economic (e.g., social class, religion, ethnicity, social networks, access to resources and power, political structures, income diversification, infrastructural constraints, poor technology, lack of market access and capital, land size), biophysical attributes (e.g., irrigation, type of product, type of irrigation), and access to infrastructural and access to information sources [10,18,19,22,27,34,36–38].

The study conducted by Paul [6] revealed that the social and economic characteristics of farmers affect their vulnerability to drought [6]. In other words, households belonging to lower socio-economic groups suffer the most. They receive the least support from the government, whose delayed responses were inadequately provided financial and other kinds of assistance to drought victims. In line with Paul's findings, Brant [38] identifies factors that affect the vulnerability of households in Brazil to drought. In this study, the variables identified as important determinants of vulnerability to drought include on-farm production, non-farm income, pensions (in particular), irrigation and plot size. Similarly, a study by Knutson *et al.* [10] examines the agricultural perceptions of producers on drought vulnerability and mitigation. They asked farmers to rank a range of factors of drought vulnerability. These factors were the amount of irrigation, climate, soil conservation practices, type of crops grown, amount of capital reserves, soil type, stocking rates, hay or feed availability, non-farm income and religion/prayer.

Theories of psychology can explain, to a large extent, the vulnerability of individuals to stress. Current studies [39–43] show that the personality characteristics of individuals can predict the degree of vulnerability. Researchers also note that the choice of coping strategies and how people respond to a stressful situation depends on personality characteristics. For example, Knutson *et al.* [42] argue that most drought situations that lead to stress that can result in a variety of responses.

These responses are categorized into problem-focused and emotion-focused coping strategies [44]. Problem-focused coping aims to problem solve or to do something to alter the source of the stress. Emotion-focused coping aims to reduce or manage the emotional distress that is associated with (or cued by) the stressful event [44]. Interestingly, individuals experiencing the same disaster over an extended period of time may vary in their vulnerability [39]. In addition, over the past 20 years, a large body of research has accumulated that shows that psychosocial resources, such as hardiness, perceived control, and social support afford critical protection to disaster victims [40]. Furthermore, the results of research by Benight and Harper [45] showed that coping in terms of self-efficacy, lost resources, social support, optimism and demographic variables strongly predict distress during the on-set of disaster.

The concept of vulnerability has also been studied by sociologists such as Gillard and Paton [46] and Carver *et al.* [44] who showed that vulnerability to disaster and stress represents a complex web of religious, cultural, social and psychological factors [44,46]. For example, there are strong relationships between religion and other factors likely to affect vulnerability, including education, socio-economic statuses and housing location and quality.

In the context of drought, vulnerability has different dimensions [17], with the drought intensity (exposure) farmers are faced with as a key issue. Farmers' adaptive capacity is also influential in how people cope with drought. Moreover, their sensitivity deals with how farmers are affected by drought. Overall, farmers' vulnerability to drought is affected by economic, socio-culture, psychological, technical and infrastructural factors (Figure 2).

According to the figure, vulnerability is a function of three major drivers, including exposure, sensitivity and adaptive capacity. Noticeably, these drivers differ according to the geographical location of the drought-prone areas around the world. Indeed, different areas produce different vulnerabilities to drought even within a narrowly bound geographic area [47]. Systems are vulnerable to a smaller extent may even be sustainable, *i.e.*, capable of tackling threatening hazards in the long term, if they are less exposed, less sensitive, or possess strong adaptive capacity in the face of hazards [48]. Peduzzi *et al.* [49] made a comparative study in order to evaluate the global exposure and vulnerability to natural hazards; including droughts, earthquakes, tropical cyclones and floods over a 26-year period from 1980 to 2006. The study countries were classified according to the degree of vulnerability by crossing the exposure of 32 selected socio-economic and environmental variables. They found that a country with large portions of arable farms is less likely to be influenced by a drought, overall, and might still be capable of producing enough food for its inhabitants. According to their study, vulnerability is mostly linked to the level of country development and the quality of its environment.

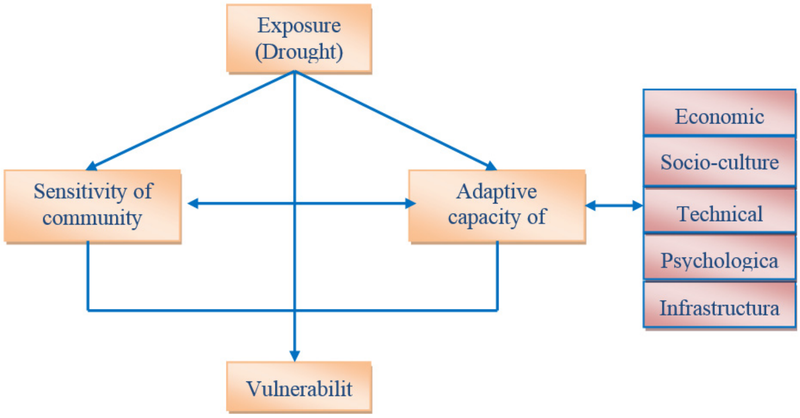

Figure 2. Conceptualizing vulnerability in the context of drought.

As a result, vulnerability assessment frameworks differ in their primary focus of analysis based on the level of exposure to specific social and/or environmental stresses, associated sensitivities, and related adaptive capacities of a specific area, sector, and/or the individual groups under consideration.

The most vulnerable groups and sectors during drought will be identified as a result of combining the three drivers discussed above. However, it is generally argued that households should be chosen as the main unit of analysis in vulnerability assessment since major decisions regarding adaptation to natural hazards change and because livelihood procedures occur at the household level [50]. Smit and Wandel [26] emphasized that the concepts sensitivity and exposure, as main components of vulnerability, may not be separable. In this regard, it is considered that households within the same agro-ecological region may be exposed to the similar levels of climate variation, such as drought [51]. Households are related to the broader community, which can significantly affect the decision-making process associated with the utilization of productive resources of a specific household. Therefore, it is necessary to discover the mechanisms of vulnerability and adaptation at the household level with regard to the broader cultural and socioeconomic processes taking place at the community level [52]. At the household level, sensitivity is represented in farming (*i.e.*, mixed or monoculture farming, tenure security of land and farm holding) with crop production as the main means of living. All of these assist in the second step of vulnerability assessment, which is selecting the key factors that define drought vulnerability. At the final stage, after identifying the impacts and analyzing vulnerability, appropriate adaptation policy assessments will be identified. Also during this final stage, the government decides whether and to what extent to assist the community to cope with the incident (drought). Adaptation measures will be selected in a way as to address those factors, which have an impact on vulnerability to drought and their causes. Such measures, for example, need to reflection development plans and on environment and natural resource management strategies as well as in post-disaster situations so that the adaptive capacity of vulnerable sectors, groups and institutions can be enhanced and become effectively prepared; gaining drought alleviation as well. Similarly, Shiferaw *et al.* [53] concluded that a proactive approach that mixes promising institutional, technological and policy interventions to handle the risks within vulnerable African communities is a step forward towards the proper management of drought and climate variability. Importantly, the whole process of vulnerability assessment within the proposed framework shows that vulnerability serves as an intermediate step embedded within the process of understanding and of adaptation, and is not the focus of the analysis itself. The next section describes vulnerability assessment and studies performed in this context.

2.3. Approaches in Vulnerability Assessment in Regards to Drought

As already mentioned, vulnerability has been studied in various different dimensions. This review tends to focus on drought and, the following approaches try to describe each and every approach within that context. In the review reported here, we use the term social vulnerability to emphasize the human dimension of this approach rather than a biophysical dimension that emphasizes the climate debate, assessing the overall scale of the problem of global warming with comparative estimates. For example, Fussel [15] suggested that the following are fundamental dimensions that describe a vulnerable situation:

(1) System/Method: Systems that are impacted by drought is comprised of human–environment systems, population groups, economic sectors, geographical regions, or natural systems. Thus, during the onset of drought, certain populations such as farmers and their families are affected. Therefore, farmers' income, location, and water resources are assessed when measuring vulnerability, because all these variables are affected to different degrees.

(2) Characteristics of system: In dealing with vulnerability from a societal perspective, the issue of values comes to the forefront. Examples of attributed values of concern include the subjectivity of human life and health, existence, income, cultural identity in a community, biodiversity, carbon sequestration potential and timber productivity in a forest ecosystem. Interestingly, the characteristics of farmers are influential during natural disasters. These characteristics are diverse and in most cases measurable. Vulnerability assessment in the context of drought should therefore consider farmers' livelihood as along with resources.

(3) Hazard: UN [54] defines a "hazard" broadly as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". This definition emphasizes the negative effects of natural hazards, however, most scholars in the field of climate change believe that drought as a natural hazard has both positive and negative effects. With regard to its positive effects, Zarafshani *et al.* [55] studied the application of the Theory of Conservation of Resources among drought affected farmers in Iran. They argued that farmers perceived drought either as a threat to resources or as an advantage and opportunity to gain more resources. In other words, the farmers managed to obtain more access to credit in order to deepen their wells or install pressurized irrigation systems.

(4) Temporal reference: Drought may occur at any point in time. In other words, temporal reference is not just calendric time; it also refers to the situation of the impacted system at the time of the impact. For example, whether farmers are ready or not, or whether they are mitigating the impact of drought.

Vulnerability has also been studied at a socio-level. Wisner [56,57] has presented four fundamental approaches to assess social vulnerability and these classifications can be used in the context of drought. For example, the demographic approach refers to individuals with different characteristics whom are engaged in drought processes such as farmers that have diverse demographic characteristics that enable them to adapt to varying degrees of drought. Based on a premise that different groups of individuals often suffer different degrees of death, injury, loss and disruption from certain phenomenon such as drought, the taxonomic approach deals with causes of social vulnerability. Moreover, individuals experiencing stressful conditions are faced with different degrees of difficulty, success or failure in the process of recovery. These approaches tend to break vulnerability down into different elements (social, economic, environmental, informational vulnerability, *etc.*), and to work on the basis of empirically developed taxonomies (for example, the vulnerability of women, children, the elderly, the disabled, ethnic/racial/or religious minorities and illegal immigrants).

The third approach proposed by Wisner [53] tries to go beyond these "laundry lists" and "taxonomies". The key question is not what kind of group, a person or family belongs to, but rather the nature of their daily life and their actual situation. This approach has a lot in common with the analysis of "household livelihood security" or the "access model" utilized by Blaikie *et al.* [21]. This approach is based upon a view of disasters that sees them not as "exceptional" events, but instead they are perceived as extensions of the problems confronted in "normal" or "daily" life. In the context of a drought situation, it is well known that farmers have fatalistic behavior that describes the nature of farmers' lives [8,55,58,59] in that "He (God) who has caused drought will take it away". In other words, farmers' vulnerability greatly depends on the nature of their lives more than any other variable.

Finally, the fourth approach, known as the contextual and proactive approach [56,57], emphasizes a participatory paradigm in determining the drought vulnerability of a given community. This approach is in line with Chambers' emic view that farmers determine their own drought vulnerability while development practitioners play the role of facilitator in participatory vulnerability assessment. The concept becomes a tool in the struggle for resources that are allocated politically. In some parts of Latin American and Southern Africa, such a community-based vulnerability assessment has become quite elaborate, utilizing all sorts of techniques to map and make inventories, seasonal calendars and disaster chronologies. There are also some ways in which the community-based vulnerability assessment resembles situational analysis as conducted by professional planners or employees of non-governmental organizations (NGOs). However, the main difference is that the community defines its own vulnerabilities and capabilities; whereas outsiders are passive and it is the insiders that analyze risks, whereby they decide which risks are acceptable and which ones are not.

Indeed, there is no universal view on vulnerability assessment and until now researchers have presented various model sand theories to assess vulnerability. Therefore, careful examination of each of the views is important in choosing the most appropriate model that fits the context of the users.

2.3.1. Risk-Hazard Approach (RHA)

This approach usually considers vulnerability, exposure, and coping capacity as distinct components. The risk-hazard framework hypothesizes that hazard events are state, rarely occur and are well-recognized [60]. This hard approach to vulnerability, rarely applies to communities or groups whose exposure to natural events substantially relies on their actions and attitudes, as identified by socio-economic drivers. For that reason, the vulnerability of people has sometimes been treated simply as "exposure to hazard" or "being in the wrong place at the wrong time" [15,61]. This approach is useful for assessing the risks of certain valued elements ("exposure units") that arise from their exposure to hazards of a particular type and magnitude [15]. This approach is most widely applied by engineers and economists in technical literature on disasters, and to a similar concept used in epidemiology. The definition of vulnerability mostly refers to physical systems, including built infrastructures, and is descriptive rather than explanatory. Since drought is a slow-onset disaster, it has a severe impact on the infrastructure of the community. Thus, this approach is also appropriate, since it measures only one dimension of vulnerability.

2.3.2. Political Economy Approach (PEA)

Based on the political economy approach, vulnerability is defined at the individual level. According to Adger and Kelly [62], vulnerability is defined as the state of individuals, groups or communities in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being. The political economy approach is rooted in literature on poverty and development [22]. This vulnerability concept deals with terms such as "response capacity", "coping capacity", and "resilience" [15], which, in turn, fall under the category of "internal social vulnerability" or "cross scale social vulnerability" [15]. In the context of drought, the political economy approach refers to those who are most vulnerable and why they are vulnerable.

According to this view, it is important to be self-efficient when confronting a disaster. In other words, farmers' efficacy in coping with drought is far more important than considering him as a resource poor or resource deficit individual. Less efficacious farmers are somewhat similar to being powerless.

This approach was a descriptive model to measure vulnerability. For example, in the context of drought, vulnerability assessment is made at farmer level and the outcome of such assessment indicates how farmers cope and adapt to slow-onset disasters such as drought.

This information helps policy-workers to prioritize limited resources for the most vulnerable groups.

2.3.3. Biophysical Approach (BPA)

Unlike the RHA that emphasizes physical systems, BPA assesses the level of damage that a given environmental stress causes on both social and biological systems. The damage is usually measured by making predictions or estimations using climate forecasting models [63,64] or by identifying sensitivity indicators by determining potential or actual hazards and extreme events as well as their frequency [65]. For instance, the monetary impact of climate change on agriculture can be measured by modeling the relationships between climatic variables and farm income [14]. When drought hits a community, the biophysical assets of the individuals affected are hindered. A farmer's well-being and his monetary assets, such as livestock, are damaged by drought. However, the biophysical approach has its own limitations despite being very informative. The main limitation is its major focus on physical damages, such as the drought has on yield. Considering all of this, these approaches are able to show the quantities of reduced yield due to climatic change, but the effects of the reduction on different groups of farmers or individuals are not clear. In general, this approach focuses on sensitivity (changes in yield, income, health, *etc.*) to climate change and misses much of the adaptive capacity of people that is related to their capital assets or internal features as suggested by Adger [24].

2.3.4. Integrated Assessment Approach (IAA)

The IAA combines both socioeconomic and biophysical approaches to determine vulnerability [14]. Integrated approaches to vulnerability research have their roots in human ecology. According to this approach, Cutter [66] defines vulnerability as the likelihood that an individual or group will be exposed to and adversely affected by a hazard. The most notable aspect of the hazard-of-place model is the interaction between the hazards of place, together with the social profile of the communities in question. An example of the "hazards of place" model was proposed by Cutter [32], in which biophysical and social dimensions are considered as determinants of vulnerability. According to Fussel and Klein [30], the risk-hazard framework (biophysical approach) is in line with "sensitivity" in the IPCC terminology. In the context of drought, the questions are: what is the extent of the drought, and do the costs that the drought incurs exceed the cost of greenhouse emission? Moreover, the adaptive capacity (broader social development) is compatible with the socioeconomic approach [15]. One of the interesting features of integrated vulnerability assessment is that both the internal dimensions of vulnerability (adaptive capacity and sensitivity) and the external dimension of vulnerability (exposure) are integrated in the IPCC framework [12,17]. Hegglin and Huggel [67] also presented a method to evaluate the vulnerability to hazards in Peru, integrating both physical (*i.e.*, hazards-related) and socioeconomic (*i.e.*, poverty, age, and awareness) factors. They found that the main challenges for measuring vulnerability consist of the difficulty to quantify socioeconomic variables and its combination with biophysical factors, as well as a lack of corresponding concepts. It can be concluded that drought has both internal and external dimensions in which both RHA and PEA should be used to assess drought vulnerability among rural communities.

Although there is no standard method for combining biophysical and socioeconomic indicators [68], in the context of drought, both empirical and theoretical methodologies can be used to combine the hard and soft dimensions of drought vulnerabilities. In the theoretical methods, however, researchers identified drought vulnerability indices by reviewing literature on existing vulnerability conceptual models in order to define the various determinants of vulnerability, components and potential vulnerability indices [69]. It is, however, useful to assume further distinction between the assessments of vulnerability to drought that are determined by current or future conditions, as proposed by Carter and Mäkinen [70]. They have adjusted the diagram developed by Preston and Stafford-Smith [71] to refer to vulnerability to climate variability and vulnerability to climate change, each encompassing biophysical and social determinants (Figure 3). This figure shows that there are two different time scales in assessing vulnerability, the short one for climate variability and the longer for climate change. This is especially important with regard to the practice of adaptation mechanisms. In other words, most vulnerability assessments that mix social and biophysical determinants also considerably superimpose future biophysical exposures onto existing adaptive capacities [72]. Therefore, it is important to pay more attention to the development of integrated scenarios that can be utilized in both studies of future biophysical and future social vulnerability to drought.

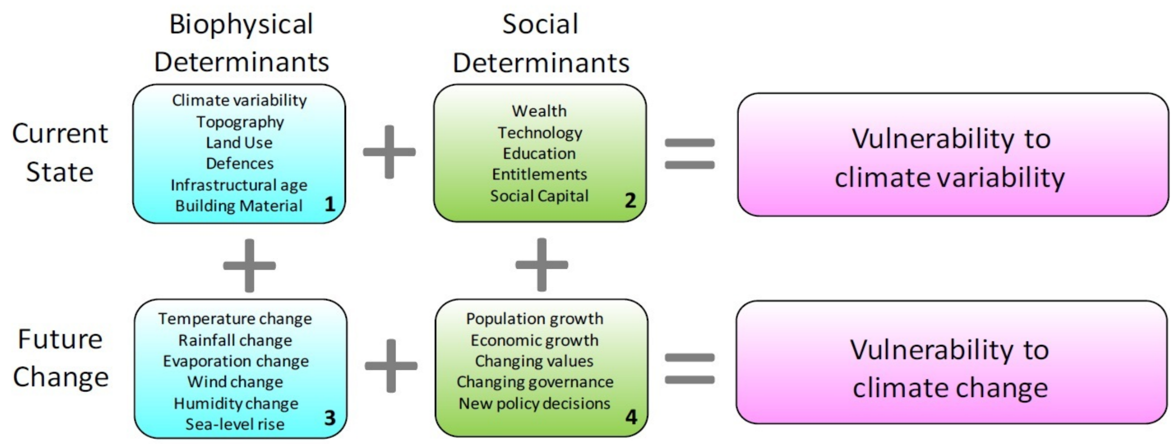

Figure 3. Current and future indicators of vulnerability to climate change and climate variability [72].

2.4. Vulnerability Assessment

Vulnerability assessment provides a framework for identifying the social, economic, and environmental causes of a disaster. It bridges the gap between impact assessment and policy formulation by directing policy attention to the underlying causes of vulnerability rather than to its result and negative impacts that follow triggering events such as drought [42]. On the one hand, the objective of the vulnerability assessment is to identify what causes risk and how risk is managed. In fact, vulnerability refers to the characteristics of a group in terms of its capacity to anticipate, cope with, resist and recover from the impact of drought. In other words, vulnerability assessment aims to identify vulnerable groups within a community and to determine ways to make the affected population less vulnerable, creating a more resistance population in areas with high risk, such as farming [73]. For rural development practitioners, this would mean a resilient population with strong adaptive capacities. It is through this adaptive population that it is possible to implement diverse empowerment projects. Indeed, this is the ultimate aim of integrated rural development projects.

Fussel and Klein [30] have presented four stages for vulnerability assessment to climate change: (1) impact assessments; (2) first-generation vulnerability assessments that account for important non-climatic factors such as demographic as well as personal measures; (3) second-generation vulnerability assessments that pay particular attention to the capacity of a system to adapt to climate change; and (4) adaptation policy assessments.

These strategies can be assessed based on how we conceptualize vulnerability. For example, some of the techniques that have been used in assessing vulnerability include: fuzzy modeling [74–76], statistical analysis [37], GIS and mapping techniques [22], cluster analysis [77,78] and using index [24,79,80]. With regard to the GIS and mapping techniques, by providing a visual overview of the major issues affecting vulnerability to drought, the maps represent the shortfalls and the information gap, which highlights the areas that need more attention. For example, Wilhelmi and Wilhite [22] developed a technique for spatial, GIS-based vulnerability assessment of agricultural drought in Nebraska. The framework for derivation of the map of agricultural drought vulnerability was generated by creating a numerical weighing system in order to assess the drought potential of the classes within each key identified as biophysical and social factors. Statistical techniques, correlation, regression, composite indexing and cluster analysis were mainly used to identify vulnerable people. Globally, the Committee for Development Policy [81] used a statistical approach with variables. By normalization and considering the average equal weight of each country, it constructed the composite index for 128 developing countries. Crowards [82] also used the same statistical approach for their variables for normalization and for combining equal weight to form the composite index.

Accordingly, the techniques used in vulnerability assessment are diverse, whereas in the past decades, considerable efforts to develop mathematical models for assessing vulnerability have been launched. In the next section, the main models to assess vulnerability are discussed.

2.5. Vulnerability Assessment Models

The diversity of vulnerability assessment models also reflects that "vulnerability is manifest in specific places at specific times" ([83] p. 276). That is, it is related to a specific context, place, time and the view of those who assess it. For example, within a socio-economic context, the overall vulnerability is identified by the combination of the result of vulnerability from the direct exposure to drought, and drought vulnerability from economic and social dimensions. For instance, given a particular farmland, the vulnerability is directly associated with the drought intensity. Conversely, given a specified drought event, a farming system that is less resilient to social and economic aspects, is more vulnerable. Generally, drought events impose the most pressure on poor and marginal farming systems. Accordingly, Yohe and Tol [84] suggested a method for determining the socio-economical indicators for the capacity of a system to cope with climate change. Afterwards, Ionescu *et al.* [85] utilized a simple index that just included the literacy rate, GDP, and participation rate of women labor to measure adaptive capacity. Yohe *et al.* [86] carried out the Vulnerability-Resilience Indicator Prototype (VRIP) proposed by Brenkert and Malone [87] as a representation for the index of adaptive capacity, taking into consideration the capacity to cope with environmental variations as a necessity in the assessment of vulnerability. Furthermore, Iglesias *et al.* [73] developed an Adaptive Capacity index with three key determinants that characterize human and civic resources, economic capacity, and innovations in agriculture sectors. A flexible approach and that can be employed in natural and managed ecosystems as well as socio-economic systems is the same approach that has been carried out within the context of a drought [88]. Given such empirical evidence and due to the specific context of vulnerability, there can be no single or common vulnerability model. However, Kasperson [89] argues that there is an interaction between the internal potential of humans to cope with or respond to a hazard and the external aspect (hazard). Similarly, the socio-economic vulnerability of populations shows similar interactions in the level of resilience that ecological systems have in the face of hazards. He proposed, therefore, that if major progress should be made in assessing the different vulnerability of places, regions, and individuals, there is also a need to develop an integrated approach to both natural and human systems.

The Intergovernmental Panel on Climate Change [17] has provided an operational definition for vulnerability. It emphasizes strategies to reduce the impact of adaptive capacity, sensitivity, and exposure. Dressa *et al.* [14] used the following formula to measure vulnerability:

$$V = (AC) - (S + E) \tag{1}$$

They analyzed the vulnerability of Ethiopian farmers to climate change using adaptive capacity (AC), sensitivity (S), and exposure (E). They also used socio-economic indicators such as wealth, literacy rate, technology, social institutions and infrastructure as the adaptive capacity. Sensitivity and exposure were measured using biophysical indicators such as potential for irrigation, frequency of droughts, and changes in temperature and precipitation.

The results of the study by Dressa *et al.* [14] indicated that the relatively least-developed, semi-arid, and arid regions are highly vulnerable to climate change.

Fontaine *et al.* [11] also used adaptive capacity, exposure, and sensitivity elements of vulnerability to assess drought vulnerability in the state of Washington. Although they used the same elements of vulnerability as applied by Dressa *et al.* [14], they utilized a different formula; as shown in Equation (2):

$$V = (E + S)/AC \tag{2}$$

In their algorithm, exposure and sensitivity are equally weighed. For instance, higher hazard exposure and higher sensitivity lead to a higher potential for impact and in turn higher vulnerability. Naturally meaning that higher adaptive capacity leads to lower vulnerability. Fontaine *et al.* [11] used the frequency and severity of drought to measure exposure. Furthermore, they measured sensitivity by using magnitude, duration, and the spatial extent of the drought and also applied farmers' managerial skills to measure adaptive capacities. Overall, results indicated that dry land farmers were more vulnerable compared to other sectors.

Some researchers express different equations to assess vulnerability. For example, Burg [90] proposes the Chronic Vulnerability Index (CVI) to measure the levels of vulnerability to food insecurity in Ethiopia. He used the following formula to reflect vulnerability:

$$Vulnerability = Exposure \ \ to \ \ Risk + Inability \ \ to \ \ Cope \tag{3}$$

According to this formula, the vulnerability results were not only from exposure to risk factors, but also from underlying socioeconomic processes which reduce the capacity of populations to cope with those risks.

In this study, coping indicators included: staple crop production per capita, cash crop prevalence, livestock assets per capita, pasture/browse availability, road accessibility, and the percentage of the population with access to safe drinking water. Moreover, the indicators used to measure exposure to risk comprised of the variability of staple crop production, malaria risk, drought risk, percentage of female-headed households, probability of rainfall shocks, and population density. Their results revealed that the CVI fails to capture the interactions between hazards and the human systems that produce and complicate them.

In other studies, the context-specific nature of risks is emphasized. For example, Webb and Harinarayan [91] used the following formula to study the relationship between vulnerability and malnutrition:

$$Vulnerability = Hazard - Coping \tag{4}$$

In their study, it was shown that the ability to cope with malnutrition depends on factors such as experience, access to information, community norms, and public assistance.

However, in other studies [56,57], the relationships between vulnerability, hazard, and risk were displayed as follows:

$$Vulnerability \times Hazard = Risk \tag{5}$$

Davis [92] further developed the above formula and added capacity to the equation. Capacity is a key element to reducing the harsh impact of disaster:

$$\frac{Vulnerability \times Hazard}{Capacity} = Disaster \tag{6}$$

Luers *et al.* [93] utilized the following equation to examine the vulnerability of socio-ecological systems. They argue that vulnerability should be extensive enough to be able to measure both quantitative as well as qualitative parameters. They developed generic metrics that attempt to assess the relationship between a wide range of stressors and the outcome variables of concern. In this equation, vulnerability can be viewed as:

$$Vulnerability = \frac{Sensitivity\ to\ Stress}{State\ relative\ to\ threshold\ \times\ Prob.\ of\ exposure\ to\ stress} \quad (7)$$

Finally, a model suggested by Me-bar, Valdez [94] has been proposed and was used by Zarafshani *et al.* [69] to assess the vulnerability of wheat farmers to drought in Iran. Their results revealed that the economic, socio-cultural, technical, psychological, and infrastructural factors influence the degree of vulnerability among farmers. The formula used in their study is presented below:

$$Vulnerability = 1/C_j(\sum_{i=1}^{n} P_i W_i) \quad (8)$$

P in this formula is a parameter value. For example, P denotes farmers' access to resources. W is a weight assigned to each parameter. C is derived from C_i =1/2 ($W_{max} \times k_i$) to the sum of all the weights, where W_{max} is the maximum value of the weight scale.

All of these equations have created broad methods and expansive literatureto measure vulnerability and to introduce useful measurements. Besides, the equations provide the reader with a more concrete understanding of "what" and "how" vulnerability measurements should be studied.

3. Discussion and Conclusions

This work addressed the challenge of defining a step-by-step conceptual approach for assessing drought vulnerability; the techniques of which are diverse. Indeed, there was no universal view to vulnerability assessment and until now researchers still present various models and theories to assess vulnerability. Therefore, a careful examination of each of the views is important to choose the most appropriate model that fits the context of the users. For this purpose, we reviewed the existing definitions of vulnerability and the most popular models of drought vulnerability assessment. There has also been an extensive review of the literature regarding vulnerability assessment models. For example, in a study conducted by Pearson, Langridge [95], more than 50 vulnerability assessment models were identified that have only been used in agricultural research applications. This diversity of methods is mainly due to an on-going debate in relation to the concept of vulnerability and its constitutive elements, along with an important diversity of theoretical approaches to assess it. It is noticeable, however, that despite the diversity of frameworks for conceptualizing vulnerability, the suitable choice of methodology is very much dependent on the "context", as the vulnerability concept is used broadly in various contexts, from medicine to development and poverty literature. In environmental change studies around the world, the term vulnerability usually comes from the social sciences [32,96]. In hazard studies, Chambers [95] cited that the vulnerability concept has external and internal spheres that are associated with the potential to respectively forecast, tackle or recover from the hazards, and from the exposure to hazard's risks. This is because many temporal, spatial, socio-economic, and bio-physical factors interact differently according to the context that significantly influences the degree of vulnerability [95]. Therefore, the formula for vulnerability could be workable as long as it takes into account as many relevant and contextual parameters with their correspondent weights. The diversity of vulnerability assessment models also reflects that "vulnerability is manifest in specific places at specific times" [83], (p. 276). That it is related to a specific context, place, time and the view of those who assess it. For example, within a socio-economic context, the overall vulnerability is identified by a combination of the direct exposure to drought, and drought vulnerability from economic and social dimensions. For instance, given a particular farmland, its vulnerability is directly associated with the drought intensity. Conversely, given a specified drought event, a farming system, which—from the social and economic aspects—has less resilience, is the most vulnerable. Generally, drought events impose the greatest pressure on poor and marginal farming systems. Accordingly, Yohe and Tol [84] suggested a method for determining the socio-economic indicators for the capacity of a system in coping with climate change. Afterwards, Ionescu *et al.* [85] applied a simple index including just literacy rate, GDP, and participation rate of women in the labor-force to measure adaptive capacity. Yohe *et al.* [86] carried out the Vulnerability-Resilience Indicator Prototype (VRIP) proposed by Brenkert and Malone [87] as a representation of the index of adaptive capacity, while taking into consideration the capacity to cope with environmental variations as a necessity in the assessment of vulnerability. Furthermore, Iglesias *et al.* [73] developed an Adaptive Capacity index with three key determinants that characterize human and civic resources, economic capacity, and innovations in agriculture sector. The same approach has been carried out within the context of a drought [88] that is a flexible approach and can be applied to natural and managed ecosystems as well as socio-economic systems. Given such empirical evidence and due to the specific context of vulnerability, there can be no single or common vulnerability model. However, Kasperson [89] argues that there is an interaction between the internal potential of humans to cope with or respond to a hazard and the external aspect (hazard). Similarly, the socio-economic vulnerability of populations shows similar interactions with the level of resilience that ecological systems have in the face of hazards. He proposed, therefore, that if major progress should be made in assessing different vulnerability of places, regions, and individuals, there is a need for developing an integrated approach to both natural and human systems. The review of literature also showed that the high complexity of this assessment requires a clear definition of the vulnerability concept and the associated terms. In other words, before undertaking any assessment, it is necessary to clearly define the vulnerable unit. Accordingly, vulnerability, from the perspective of drought planning, means assessing the threat from potential drought hazards to various aspects across social, economic, environmental, and political fields. This study revealed that during the past decade, a number of methodological frameworks have been defined in order to develop methodological models to assess drought vulnerability at different scales, sectors, socio-political contexts, and geo-climatic conditions.

Although all of these models have provided useful measurements, their application in policy-driven assessments has been limited by a lack of robust metrics to model and measure vulnerability within and across systems. Measuring vulnerability is complicated given that vulnerability is not a directly observable phenomenon. The models have their own shortcomings in quantifying vulnerability. For example, they are limited in their application by considerable subjectivity in the selection of variables and their relative weights. Moreover, they do not reflect a process-oriented view to vulnerability assessment and in some cases, adaptive capacity is neglected entirely. These shortcomings clearly indicate that researchers have paid more attention to the external side of the shocks which an individual or household is subjected (*i.e.*, the percent of income from agricultural activities, the number of household members who had recently migrated, and perception of negative income change); paid limited attention to the internal shocks to which vulnerable systems or communities are subjected (*i.e.*, national policies and land use within their jurisdiction) that represent the ability or lack of ability to adequately respond to and recover from external stresses [96]. Finally, these assessments are dominated by quantitative elements, giving less attention to qualitative aspects. Therefore, we argue that vulnerability assessments should shift away from a positivistic view that attempts to use quantitative indices to a mixed paradigm in which a combination of quantitative and qualitative measurements are used to assess vulnerability. Therefore, our intention is to present a step-by-step process with which policy-makers can reduce the drought vulnerability of affected populations and enhance drought resistant programs.

Given that, Figure 4 is a schematic representation of the main steps in designing a vulnerability assessment model. According to the figure, the vulnerability model should employ a mixed-method that includes a range of quantitative and qualitative approaches in order to assess various impacts and reduce and mitigate those impacts, both in the short and long term. In fact, using a mixed-method approach allows for a comprehensive understanding of the different aspects of the issue [97]. Antwi-Agyei *et al.* [98] used such approaches to identify the drought vulnerability of households and communities in Ghana. They found that within the same agro-ecological zone, communities and households undergo different degrees of climate vulnerability. Such differences can be sufficiently explained by socioeconomic characteristics like gender and wealth, as well as accessibility to capital. Thus, the process of designing a vulnerability assessment model is via a process of scoring, normalization, weighting, and integrating both quantitative and qualitative data into the assessment. All this should make the model effective enough to be able to be easily adapted to different drought vulnerability contexts by defining/selecting relevant indicators according to different temporal, spatial, socio-economic, and bio-physical aspects.

As the figure shows, the general methodology for designing a vulnerability assessment model relies on three main steps.

(1) *Understanding* the impact of drought and the main drivers of vulnerability. In other words, any conceptualization of vulnerability to climate change needs to consider exposure, sensitivity, and adaptive capacity of the vulnerable system. Exposure is the essence and extent to which a set of procedures encounters socio-economic or environmental stress. Sensitivity is the degree to which an individual or group (for example, farmers) is affected by exposure to stresses. The term adaptive capacity is used here as an equivalent to the ability of the system to respond to the exposures and the effects in order to adjust to and cope with the impacts of drought.

(2) *Identifying and assessing* drought vulnerability indicators and evaluating the weight of the indicators that contribute to drought risk and vulnerability. This step comprises of two phases: (1) identifying the vulnerability index; and (2) assessing the vulnerability of affected populations based on exposure, sensitivity, and adaptive capacity. In the context of drought, exposure may have two sides: (1) the characteristics of hazards, such as changes in the frequency, intensity, magnitude, duration, and the extent of drought. Thus, regions with increasing temperature and decreasing rainfall are identified as regions more exposed to drought; and (2) the socio-economic characteristics of affected populations such as government policies (rural institutions). Therefore, these characteristics may have both quantitative as well as qualitative components. Sensitivity in our study refers to places with a greater frequency of droughts (counts of the occurrences of drought in different parts of the region) and the negative impact on agriculture (*i.e.*, yield is reduced). Thus, agriculture in drought prone areas is more sensitive in terms of yield reduction. For the purposes of the vulnerability classification, we have created two categories of indicators associated with sensitivity: crop sensitivity and livelihood sensitivity. We grouped the indicators representing the specific sensitivity of agricultural production to climate risk with the first category (*i.e.*, type of crop planted in winter and summer cycles as a proxy for the differential sensitivity of distinct crops to climate stress, self-reporting of climate impacts and pest problems, reported crop losses in the season prior to the survey, and the farmer's perception that the climate was changing). The second category referred to indicators of the sensitivity of the overall livelihood strategy and household income to the external shocks of diverse types (*i.e.*, the percent of income from agricultural activities, the number of household members who had recently migrated, and perception of negative income change). According to our definition, adaptive capacity is a function of the resources of the rural household. Adaptive capacity allows farmers to counteract the sensitivity of farmers and thus reduce their vulnerability. We conceptualize adaptive capacities in terms of categories of assets, or capitals, such as human, social, physical, natural, and financial. In rural settings, human capital includes the farmers' age, education, and degree of family labor. Social capital includes trust, membership in water user associations, and social networks. Farmers' physical capital may include equipment, machinery, and infrastructural facilities. Natural capital may include land, water quantity and quality. Financial capital includes income, cost of production, and land ownership. Although farmers' capital extends well beyond our list, we have only provided a short list of indicators when measuring capitals. The next step in assessing the vulnerability of affected populations is to attach the weights to the vulnerability indicators. For this step, multicriteria decision making (MCDM) techniques may be used to weigh the indicators. Agricultural experts and local farmers may assign weights to proposed indicators.

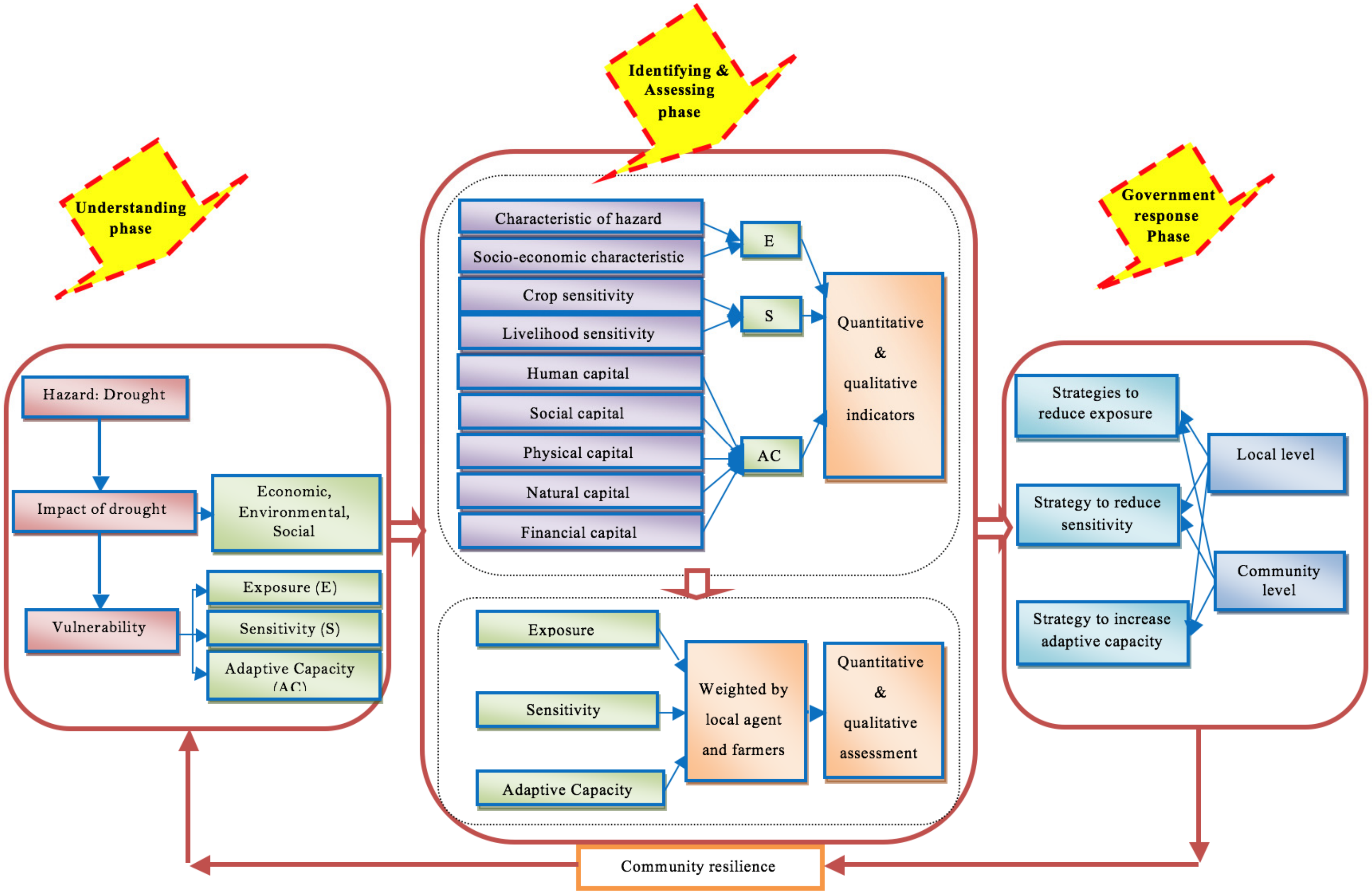

Figure 4. Conceptual framework on how to model vulnerability.

(3) *Government response:* The role of government support is repeatedly mentioned in the literature as an impediment to adaptation. This implies that governing equitable distribution and access to resources and the allocation of power by means of local institutions and arrangements will improve the adaptive capacity at the community level. In other words, any institutional interventions tend to empower the adaptive capacity of farmers and thus enhance community resilience. Thus, any government intervention would act as a mitigation plan and would feedback to future shocks.

Lastly, this study tried to introduce an alternative framework for conceptualizing and measuring vulnerability that will assist in increasing awareness among decision-makers at local, national and regional levels to the potential of the community assisting in drought vulnerability reduction. This can be a step forward in developing techniques for drought vulnerability assessments and in reducing the impacts associated with drought.

Supplementary Materials: In order to gain clear insight of keywords used in this study, a supplementary of keywords is provided. The following are available online at www.mdpi.com/2071-1050/8/6/588/s1, Supplementary: Terminology.

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