A Methodological Framework for Building an Index for Vulnerability Assessment in Rainfed Agriculture

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Abstract

This chapter presents a methodological framework to build an index for participatory vulnerability assessment of rainfed agriculture in Ngayokheme rural community, Senegal. Through a participatory approach, the chapter identifies components/resources of rainfed agricultural system, evaluated their exposure, sensitivity, and adaptive capacities to climatic and non-climatic stressors. A review of the main vulnerability indices developed in the literature highlighted gaps. And based on the weaknesses of the existing indices, a new index combining exposure, sensitivity,

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and adaptive capacities is proposed. A tool for vulnerability assessment replicable in different contexts and accessible to all disciplines has been built. The vulnerability of the whole system of rainfed agriculture as well as each of its components was quantified using a participatory approach. The chapter attempts to provide a detailed framework for assessing vulnerability to climate change of the rainfed agriculture, in such a manner that all countries of the region can follow it. Climate change is affecting rainfed agriculture in Senegal. To mitigate impacts of climate change and increase the resilience of the sector, a good vulnerability assessment is required. This is why an index for assessing vulnerability to climate change of the rainfed agriculture has been suggested. This focused on strengthening the vulnerability evidence base to support climate change policy, advancing knowledge and training to understand climate change impacts, and implementing adaptation measures. The framework presented on this chapter could yield substantial benefits for Senegalese and other Sahelian countries.

Keywords
Index • Vulnerability • Assessing • Participatory approach

Introduction

The adverse effects of climate change on natural and human systems are becoming more and more severe and complex. This is why the question of understanding the level of vulnerability of natural and human systems has become a major concern and a challenge for the academic, political, and development practitioners' communities. Several studies on vulnerability analysis have been undertaken. Many of them were performed using the participatory approach. The participatory approach has emerged with the "Activist Participatory Research" during the 1960s. Ever since, several variants of participatory approach have been developed. Thus, in the 1970s, variants such as "Field Research on Farming Systems," "Participatory Research (PR)," "Rapid Rural Appraisal (RRA)," and "Agro-ecosystem Analysis" have emerged. Later, in the 1980s, other variants of the participatory approach were developed and strong. Thus, "Applied Anthropology" and "Participatory Rural Appraisal (PRA)" have emerged. The 1990s saw the emergence of Participatory Action Research (PAR) (Chambers 1994). The participatory approach has been experimented, initially in developing countries' rural areas, and has enabled community to share their perceptions and identify, prioritize, and appraise issues from their knowledge of local conditions (Rabinowitz 2013; Van Aalst et al. 2008). A participatory approach is a process in which every stakeholder in the intervention has a voice. Everyone who has a stake should be invited to the table. In a participatory approach, all stakeholders' voices are heard and respected and that everyone has some role in decision-making (Rabinowitz 2013).

Researches that have used participatory approach have proved useful because they have informed on how natural and human systems are vulnerable to climate hazards. However, these studies have failed to meet the needs of academia, policymakers, and practitioners to quantify the vulnerability in order to understand its severity level and plan responses to climate change effects.

To fill this gap, researches to quantify vulnerability to climate change have been made. The modelers have undertaken most of them and limited vulnerability assessment to analysis of climate change impacts on a number of sectors such as agriculture, health, water resources, forests, etc. However, these studies had shown some limitations related to the fact that impacts of climate change are measured on a limited number of parameters although studies generally focused on systems. So, understanding the vulnerability of such a system cannot be reduced to impact of climate change on few elements of the system. In addition, social, cultural, economic, and political aspects are barely considered in these models. This is why studies using modeling do not give a full measure of the vulnerability of a system.

In recent years, we have witnessed emergence of new studies trying to combine qualitative and quantitative approaches to vulnerability. These studies are to quantify the vulnerability using the participatory approach. They seek, through community participation, to provide a quantitative measure of vulnerability and to explain it. These researches are based on the definition of a conceptual framework that allows them to start identifying determinants or parameters of vulnerability. These studies propose models of relationship between parameters of vulnerability to calculate the value of the vulnerability and produce vulnerability indices.

According to the definition of vulnerability, several types of model relationship between the determinants have been proposed. However, most models that establish relationship between determinants of vulnerability do not accurately express the link between these determinants. Many models build on subtraction or addition relationship or combine both. However, these two types of relationship do not sufficiently reflect the relationship between the determinants of vulnerability. This arises the following question: which model faithfully expresses the relationship between the determinants of vulnerability?

The aim of the present chapter is to feed thought and efforts made to construct appropriate vulnerability index. More specifically, the present chapter proposes a methodological framework for building an integrated index to assess vulnerability to climate change of rainfed agricultural system in Senegal through a participatory approach. To do this, a review of approaches to vulnerability will be made in the first place. This review will be followed in a second phase of a critical analysis of computational models of vulnerability. In a third step, a model of the relationship between the various determinants of vulnerability will be offered, followed by a description of the methodological framework to construct the index of vulnerability.

Review of Vulnerability Approaches and Indexes

Climate change mainly is manifested in adverse effects on livelihoods in developing countries that are most vulnerable. The effects are often complex and difficult to understand. The need for understanding vulnerability justifies that of analysis and assessment of vulnerability.

Vulnerability has been abundantly analyzed and defined, especially in the climate change literature (Luers et al. 2003; Füssel 2009). However, first definitions arose from geography and ecology (Cutter 1996). Timmermann (1981) has provided to the scientific community with the first reference definition of vulnerability. He defined vulnerability as “the degree to which a system acts adversely to the occurrence of a hazardous event. The degree and quality of the adverse reaction are conditioned by a system’s resilience (a measure of the system’s capacity to absorb and recover from the event).” But it is in risk and disaster management and recently in environmental change and in development and environment areas that the word vulnerability is mostly used. Indeed, during the past two decades, the concept of vulnerability acquired an important place, especially with the IPCC Assessment Reports. Owing to the abundance of the analysis of the concept, further work on vulnerability assessment, including approaches, methods, and tools, had been undertaken and several conceptual and methodological approaches of vulnerability have been developed (Cutter 1996).

Despite this important scientific production, fundamental conceptual differences remain about definition and approaches of vulnerability. Broadly, there are three major schemes of vulnerability frameworks. The first one distinguishes biophysical and socioeconomic vulnerability (Füssel 2009). The second scheme recognizes external factors *that are not part of the system* and internal factors *that are part of the system*. A third scheme that can be presented as the most comprehensive deals with vulnerability as contextual (starting point) and vulnerability as an outcome (end point) (O’Brien et al. 2007; Brooks 2003; Füssel 2009; Kelly and Adger 2000; Turner et al. 2003 ; Maru et al. 2014). The key element on which the focus is put when explaining vulnerability of human or natural systems distinguishes these approaches.

Biophysical Approach

The biophysical approach highlights the key role played by external/natural hazards in the occurrence of vulnerability of human and natural systems. Thus, Gabor and Griffith (1980), Mendelsohn et al. (1994), Polsky and Esterling (2001), and Sanghi et al. (1998) have emphasized how cash income of farmers is affected by natural hazards. Adams (1989), Kaiser et al. (1993), and Olsen, Bocher, and Jensen (2000), Kurukulasuriya and Mendelsohn (2006) also studied the vulnerability of agriculture by linking climate change stressors to agricultural yields. Similarly, Martens et al. (1999) in health sector; Du Toit et al. (2001), FAO (2005), Xiao et al. (2002) in food security and water availability sectors, and Forner (2006) and Villers-Ruiz and Trejo-Vázquez (1997) in ecosystems sector studied climate change effects. All these studies put the focus on natural/external factors as causes of economic, social, agricultural, health, and vulnerability.

This approach has the advantages of providing relevant and measurable information. It helps to know the extent of the impacts of natural hazards on different natural systems. However, this approach often adopts a negativistic, futuristic, and quantitative perspective of impacts of climate change. In addition, this approach often has a negativistic and futuristic perspective of the impacts of climate change. The impact assessment focuses on the damage areas and is based on the predictions of climate models and other agricultural, economic, and health models. Thus, any comprehension of the current vulnerability is provided (Gabor and Griffith 1980). It also gives only quantitative data. Certainly very informative, this approach however does not demonstrate what these impacts mean for communities. For example, 50 % of lower yield due to climate change does not mean the same thing for a Senegalese farmer and for an American farmer. In the same vein, even if development of mosquitoes due to climate change can drive the resurgence of malaria, this increase will not have the same effect for two individuals or communities that have unequal access to health services and monetary income. This physical/natural approach does not take into account the adaptive capacities of systems having been affected by the climatic stimuli.

Social Sciences Approach

This approach emphasizes factors related to the socioeconomic and political status of individuals and communities, in short, the social system, including changes in status between individuals and communities (Füssel 2007, 2009). This approach considers that there are a variety of social status between individuals and between and within communities (Füssel 2007). These differences can be approached through gender, social and political class, education level, wealth, access to health services, natural resources, credit, agricultural inputs, technology, formal and/or informal social capital, etc. (Adger 1999). These factors are major social determinants of vulnerability (Allen 2003; Kelly and Adger 2000). This socioeconomic approach of vulnerability has the advantage of highlighting importance of internal resources available to an individual, a community, and a sector or system to reduce the negative effects of a shock. It shows that an individual, community, or system does not remain inert when it is attacked. It often responds to attacks drawing on its resources. The vulnerability is seen as an internal state of a system before the external forces of nature occur (Allen 2003).

The limitations associated with this approach are related to the low inclusion of natural/external factors. Yet, the role of the latter cannot be ignored when interpreting vulnerability. For example, two communities with similar socioeconomic conditions, but subject to natural hazards of different intensity and frequency, do not have the same level of vulnerability. Although socioeconomic factors are crucial in explaining the vulnerability, neglecting natural factors leads to a partial understanding of the vulnerability. Reconciling the two approaches seems to provide benefits to the full understanding of vulnerability.

Integrated Approach

However, although having obvious benefits in terms of vulnerability assessment, both biophysical and social approaches do not have less limitation from the perspective of an integrated assessment of the socio-environmental dimensions of vulnerability. Reconciling the two approaches seems to be advantageous to take the full measure of vulnerability. This is the main characteristic of the integrated approach that combines both social sciences and biophysical sciences approaches to determine vulnerability (Füssel 2007). In this regard, an adaptation of the IPCC definition of vulnerability can help reconcile the approaches of biophysical and social sciences into an integrated approach. The IPCC defines vulnerability as "the degree to which a system is susceptible to, or unable, to cope with the adverse effects of climate change, including climate variability and extreme weather conditions" (McCarthy et al. 2001, p. 995). While the IPCC definition specified directly to change climate, particularly to climate risks, an integrated approach of vulnerability needs to integrate biophysical and socioeconomic factors in addition to climate risks. The adaptation of IPCC conceptualization integrates internal and external factors and biophysical, socioeconomic, and climatic stressors. Vulnerability according to IPCC depends on the nature, extent, and rate of climate variation to which a system is exposed and the sensitivity and adaptive capacity of the system. The exposure parameter includes external factors, while sensitivity encompasses internal dimension as for adaptive capacity.

An Overview on Vulnerability Index

Based on these approaches, indices have been developed to better quantify and assess vulnerability level. Adger (1996, p. 49) developed a vulnerability index where vulnerability to climate variability is function of social vulnerability and environmental risk:

1. Vulnerability to climate variability = f(social vulnerability, environmental risk)

*where environmental risk can be indicated by the return period of a threshold physical hazard: Environmental risk = Impact * Pr*

where Pr = 1/R (Pr = probability and R = recurrence interval (years)).

Although this index takes into account the natural and social factors, the relationship between the parameters is not clearly established. It considers vulnerability as a function of social vulnerability and environmental risk, but does not clearly indicate the type of relationship between these parameters. In addition, the adaptive capacity parameter is not explicitly taken into account in the calculation of vulnerability. It is not clear whether it lies in social vulnerability or not.

Moss et al. (2001) determined vulnerability index (VI) by assigning a negative value to sensitivity and a positive value to adaptive. They establish relationship between parameters through this equation:

2. Vulnerability = (adaptive capacity)–(sensitivity + exposure)

This equation considers vulnerability as the difference between adaptive capacity and sum of exposure and sensitivity. This relationship model has a number of limitations. The relationship between sensitivity and exposure does not seem to be well translated by an addition as shown in this equation. The addition relationship links two parameters of a similar nature. However, sensitivity is totally different from exposure as sensitivity mainly refers to the internal structure system, while exposure is related to external factors. Also, the order of the parameters in this equation is not appropriate. Before talking about adaptive capacity of a system, it must have been exposed to and affected by a hazard. A system never adapts ex nihilo, it adapts to a hazard. So the exposure and sensitivity should come before adaptive capacity. That is why adaptive capacity should come after in the order of parameters, because it has to be deducted from the exposure and sensitivity, and not the contrary. In addition, the adaptive capacity plays an attenuator or dissolving role of effects of exposure and sensitivity. In this regard, the subtraction is not the best type of relationship.

Yohe et al. (2006) have developed indices of (aggregated outcome) vulnerability to climate change that vary according to different assumptions regarding climate sensitivity, development of adaptive capacity, and other calibration parameters. The aggregated vulnerability is calculated as

3. $Vi(t) = \frac{\Delta Ti(t)}{ACi(t)}$,

whereby $\Delta Ti(t)$ *is the projected change in national average temperature (i.e., a rational-scaled variable) and* $ACi(t)$ *is a normalized index of national adaptive capacity (i.e., an ordinal-scaled variable)* (Brenkert and Malone 2005).

This index has a specific climate and futuristic orientation. The risk in question here is a projected climate risk and is neither a current risk nor a non-climatic risk. Furthermore, the sensitivity parameter which is very important in the vulnerability of a system or sector is not integrated into the development of this index.

In summary, these indexes that have been developed have two main limitations. The first is related to the inappropriate nature of the relationship posed by these indices. The second limitation is related to the fact that these indices do not incorporate both natural and socioeconomic as well as the adaptive capacity of the whole area in question. In short, these indices are not based on a systemic approach of the systems studied. A third shortcoming of the indices is related to the fact that many of them are built for a national level and not do not take into account local specificities.

Methodological Framework for Building an Integrated Participatory Assessment Vulnerability Index

Conceptual Definitions

The development of a new vulnerability index in this study is yet based on the IPCC definition of vulnerability, but goes beyond. It is not focused exclusively on climate change as a hazard, but includes all significant factors that are sources of vulnerability for rainfed system at community level. The IPCC (2007) definition shows that vulnerability depends on three parameters: exposure, sensitivity, and adaptive capacity. However, the relationship between them is not specified (Fussel 2009). Before proposing the relationship between these three parameters and that result in a situation of vulnerability, it is important to make an analysis of these three parameters

Exposure. The first parameter of the vulnerability in the IPCC definition is identified by a group of words, namely, *the nature, magnitude, and rate of climate variations to which a system is exposed*. It is in this expression that the term *exposure* appears. So exposure is closely related to risk and hazard. Exposure is defined as the situation or position to which a system, a sector, a social group, or an individual is within the reach of a hazard. Being exposed is to be not sheltered from a risk; being exposed is to be in a situation where one is potentially reachable by a hazard.

One can note that exposure involves a hazard and a system. To be exposed, there must be a stressor and a stressed object. It also requires that the characteristics, nature, extent, and strength of the stressor allow it to reach the exposed system. However, it should be noted that exposure does not necessarily mean being in danger. People can be exposed without running the risk of being damaged, to see their physical or moral integrity affected. In addition, exposure can be assimilated to risk in the sole condition that there is a possibility of damage to the exposed element.

Sensitivity and impact. The second parameter of the IPCC definition of vulnerability is about sensitivity. Being sensitive is reacting (positively or negatively) if one is affected by an external force. A system is when it reacts and changes state regardless of the time, when it loses its trajectory, its identity, and its natural properties be it temporarily or permanently. Sensitivity is the susceptibility of a system to react, to respond to an attack, change positive or negative when the agent reached it. It mainly depends on the constitution of the internal structure of the system. The sensitivity is very important in the sense that regardless of the strength of a stimulus, if the system has no sensitivity, the stimulus can never be a risk, the system cannot be considered exposed.

Sensitivity is closely related to the impact which is the result of the sensitivity of a system and the nature of the shock that affects the system. The impact is a product of the sensitivity of a system and the intrinsic characteristics of stress (magnitude, force, rhythm, frequency of the stress).

Adaptive capacity. Adaptive capacity is defined as the set of resources available to a system to reduce the negative effects of stressors or to take benefit from them. It is a function of human resources, technology, social and cultural resources, access to information, and institutional, economic and financial, and physical and natural resources.

Vulnerability. Based on these conceptual definitions, it can be noted that the exposure and sensitivity when they increase or decrease tend to produce the same type of effect on a system. Their common growth increases the vulnerability of an element, while their decrease reduces vulnerability. However, adaptive capacity has an opposite effect on the vulnerability. Indeed, when the adaptive capacity increases, it tends to reduce vulnerability and vice versa. The relationship between exposure and sensitivity as well shows that if each increases by one unit, the resulting increase is more than the sum. The relationship is better expressed as a multiplication. Adaptive capacity does not play a role of subtracting the combined value of the exposure and sensitivity, but tends to diminish or invalidate effects produced by exposure and sensitivity. Adaptive capacity acts as divisor of the product formed by the exposition and sensitivity. In this regard, the best relationship that binds adaptive capacity to exposure and sensitivity is a division relationship. The division is the best relationship that leads a factor toward zero.

Given the relationship between exposure and sensitivity on the one hand and between these two parameters to adaptive capacity on the other, we propose to calculate vulnerability using the following formula:

$$V = {}^{E \times S}/_{Ac}$$

where

V = Vulnerability
E = Exposure
S = Sensitivity
Ac = Adaptive capacity

An adaptation of the IPCC definition that incorporates the nature of risks or hazard (continuous or discontinuous hazard) could lead to consider vulnerability as function of the magnitude and rhythm, or force and probability of a hazard, sensitivity, and adaptive capacity of the system.

Approach for Building the Integrated Index

Participatory Evaluation of Parameters of Vulnerability Through Focus Groups

To build the integrated index, the rainfed agriculture has been approached as a system. Our unit of analysis corresponds to community level. Designed as a system, rainfed agriculture then includes several components or resources, including climate. With farmers of Ngayokhème rural community as the study area, the various components of the rainfed system resources have been identified. These are climate, soil, water, seeds, fertilizers, mechanical equipment, draft animals, labor, the values attached to agriculture, vegetation, and slopes. In terms of hazards, it not only undergoes the weather but is also affected by economic nature and social, cultural, institutional, political, and biophysical vagaries. So to understand the vulnerability of agriculture, it is necessary to take into account all the resources but also all types of hazards.

Given the large number of organizations and the size of the study area, we had identified four zones based on socioeconomic and ecological criteria. Each zone comprised between four and six villages and hosted two gendered focus groups. In total, eight focus groups with men and women had been organized. The practical course of these grouped interviews relied on research protocols. These consisted of matrices drawn on the flipchart and pasted on the walls of the room where the focus groups were held. Each matrix contained as many columns and rows as identified components and stressors of rainfed agricultural system. Each stressor was crossed to each component to identify the impact. To mention each impact on the flipchart, we had to find a consensual response of all members of the group. Once the components and stressors of the farming system and the impacts are identified, the following step was to proceed with the evaluation of the parameters of vulnerability.

In a second stage of building the index, the determinants of vulnerability which are exposure, sensitivity, and adaptive capacity were assessed in a participatory way. The evaluation was made based on a scale from 0 to 5 which were defined with communities. The rating scale is defined by mutual agreement between the different actors. Each scale value represents a level of each of these three parameters. Level 0 corresponds to a total lack of vulnerability. Levels 1, 2, 3, 4, and 5 correspond, respectively, to 20 %, 40 %, 60 %, 80 %, and 100 % of vulnerability. However, the evaluation was conducted with a small number of farmers (05), compared with focus groups. Indeed, as the matter is to assign numerical values to these parameters, members of the focus group should have a certain level of instruction that enables them to fully understand the meaning of each level but also the parameters of the vulnerability. They should also be active farmers that have experienced effects of climate change and be able to remember them. As we worked with the Federation of Farmers Associations, persons meeting these criteria have been provided by the Federation. Reaching consensus on the value to assign to exposure, sensitivity, and adaptive capacity of each component or resource guided the evaluation phase of the vulnerability.

Weighting of the Components

The components of the rainfed agricultural system do not have the same weight. Each component had been attributed a weight. This weighting was done by consultation with experts in the rainfed system who have accumulated extensive experience in the study area but also with the local farmers with a certain level of education allowing them to assign weights to the various components. Experts comprised agronomists (03), agricultural extension agent (01), professor (01), practitioners (01), and leaders of farmers' organizations (04). They were called at first to correct or validate the component inventory of rainfed system identified by grassroots communities in the focus groups. And secondly, they assigned a weight to each component of the system on a scale of 100. For components, some changes in terms of merging were made. Indeed, the experts asked for a definition of the content of each component. Once this is done, no significant changes in terms of addition or removal of components have been made. The values assigned by each expert were averaged to obtain the weight of each component of the system.

After attributing value to exposure, sensitivity, and adaptive capacity of each component regarding the stressors that affect them, and after pondering each component, the equation has been applied to quantify the level of vulnerability of each component and the global vulnerability of the rainfed agricultural system by multiplying each component to its weight.

Discussions

The objective of this chapter was to propose a methodological framework for building a vulnerability index to assess vulnerability of rainfed agriculture.

The analysis of various studies and vulnerability assessments revealed several gaps due to their sector or inappropriate nature. Vulnerability to climate change has been analyzed and assessed in an exclusive climate perspective or at national level. This gives an incomplete understanding of the whole impacts of climate change. Indeed, climate change does not only act directly on the elements of the natural and human systems. It also affects them indirectly through other elements. This indirect action is not always taken into account by the study and assessment of vulnerability to climate change.

The index proposed here integrates both vulnerabilities to climatic and to non-climatic shocks. In this respect, it gives the full measure of vulnerability to climate change. In fact, it takes into account the direct and indirect impacts of climate change. The construction of this index which is based on a participatory approach has shown that the qualitative and quantitative approaches can be integrated. This index and the approach that enabled to build it are applicable in different contexts because of their flexibility to adapt to different environments.

Despite these advantages of this index, it should be noted some limits. The first relates to the lack of precision that is associated with values assigned to the exposure, sensitivity, and adaptive capacity as well as components of rainfed system. Another limit refers to the fact that there is no differentiation made between farmers. The integrated index is done at community level.

Conclusion

This tool for vulnerability assessment is replicable in different contexts and accessible to all disciplines. The vulnerability of the whole rainfed agriculture as well as each of its components was quantified using a participatory approach. This tool provides a detailed framework for assessing vulnerability to climate change of rainfed agriculture, in such a manner that it can be applied by all countries in the region. Climate change is affecting rainfed agriculture in Senegal. To mitigate the impacts of climate change and increase the resilience of the sector, a robust vulnerability assessment is required. This is why an index for assessing vulnerability to climate change for rainfed agriculture has been suggested. This chapter focused on strengthening the vulnerability evidence base to support climate change policy, advancing knowledge and training to understand climate change impacts, and implementing adaptation measures. The framework presented in this chapter could yield substantial benefits for Senegal and other Sahelian countries.

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