A conceptual framework to assess vulnerability: application to global change stressors on South Indian farmers

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Abstract

The objectives of the paper are (1) to apply Füssels (2007) conceptual framework of vulnerability to a concrete ongoing research and (2) to discuss on the resulting choice of an adequate vulnerability approach. The research aims at assessing the vulnerability of South Indian farmers to global change at two periods of time: medium term (2030-2040) to account for rapid global economic changes, and long term (2045-2065) to account for climate change and variability. The term vulnerability is defined in so many ways that its use has become controversial. Füssel proposed an original conceptual framework of vulnerability based on a common and transversal terminology understandable whatever the scientific domain of concern. This conceptual framework relies on the description of six dimensions of the vulnerability concept. The first four dimensions describes the vulnerable situation and the last two dimensions explain the factors of vulnerability. Füssel argues that with this set of dimensions, it is possible to class any conceptual approach of vulnerability found in the literature. After the six dimensions were adapted to South Indian farmers vulnerability, the use of a cross-scale integrated approach of vulnerability appears clearly as the most appropriate. Therefore, the use of the classical risk-hazard approach of vulnerability was dismissed as it focuses mainly on social systems and biophysical discrete and regional hazards. Our vulnerable situation fits with the so-called integrated approach of vulnerability. Integrated approaches are widely used in the context of global change and climate change. They can address continuous as well as discrete hazards and view the vulnerable system as a dynamic one. Among the integrated approaches is the one proposed by the Intergovernmental Panel on Climate Change (IPCC). This approach has been enlarged and applied to global change hazards: climate change and variability plus global economic changes, as the impacts of the last ones are often more severe at least in the medium term (Eakin and Bojórquez-Tapia, 2008; Belliveau et al., 2006; ?). The combination of the three concepts of sensitivity, adaptive capacity and hazard exposure brings the dynamic dimension of vulnerability. As a conclusion, we found the Füssel's transversal terminology particularly functional in a context of multidisciplinary research where communication and cross-understanding are of major importance. Going through the description of the six dimensions was also useful to argue on the choice of an appropriate approach of vulnerability. Finally, and as highlighted by Füssel, this conceptual framework gives sense and scientific robustness to the IPCC integrated approach of vulnerability that is now more and more developed in the applied research community.

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SHIVA website: http://www.shiva-anr.org.
Keywords: Adaptive capacity, Agriculture, Global change, India, Sensitivity, Vulnerability concept

1 Introduction

The assessment of farmers' vulnerability to global change is currently at the heart of agricultural policies, particularly when food production depends on irrigated agriculture and when agriculture is still a bedrock of countries' economy. Then, climate change poses the risk of further depressing the agricultural sectors economic performance. Authors have described the consequences in various countries, particularly exposed to global

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change such as South developing countries (Adger, 1999; Leichenko and O'Brien, 2002; O'Brien et al., 2004; Acosta-Michlik and Espaldon, 2008; O'Brien et al., 2009). Among these countries, Mediterranean ones are prone to vulnerabilities. They are undergoing rapid social and environmental pressures like population growth, urbanization and climate change with negative implications on natural resources (water resources in particular) (Iglesias et al., 2007). Consequences on farming systems sustainability are straight forward: crops yields are decreasing with some years important lost of production as a consequence of droughts. Crop diversity is suggested as an adaptation strategy but with no stable empirical evidence (Reidsma and Ewert, 2008).

The questions we try to answer (partially) in this paper, came from an applied study of the vulnerability of Indian farmers confronted to global change. We shall refer to that study (SHIVA ANR-research project) to give some idea of the difficulties that were encountered. Though, conclusions remain true for farmers under stressors of global change in other countries. Reading the literature on the subject (mainly written by geographers and public decision makers: Brooks (2003), O'brien *et al.* (2000), Alwang *et al.* (2001), Adger (2006), Smit *et al.* (2006), Füssel (2007), Eakin *et al.* (2009)) the main questions that arise are: what are we talking about? And what are we measuring when dealing with vulnerability? Otherwise stated: what is the relevant concept of vulnerability that is at stake?

Within multidisciplinary SHIVA research project, for example, hydrologists understand the term *vulnerability* as the natural system sensitivity to a well-known hazards such as a pollution or a specific climate events (sea-level rise, flood, *etc.*); geographers better see in *vulnerability* the amount of harm caused by the natural events; and economists view the concept either as a damage function of hazards or as a synonym of the resilience or the capacity to cope with any shocks. And finally, we wanted to use IPCC definition of vulnerability which is again an additional definition of the term. A concept only makes sense in a given context. Thus, we needed first a clear interpretation of IPCC definition in the context of global change and second a clear understanding of the concepts of vulnerability in each disciplines. To these conditions, we would be able to share a common vocabulary on vulnerability and parallel concepts as adaptive capacity, sensitivity, risk, hazard, *etc.*. In this search, we find Füssels paper (2007) particularly enlightening: it gives the means necessary to describe different contexts in which a concept of vulnerability may be put forward (or defined). More precisely, the vulnerability we may try to measure in a given context may differ from the vulnerability concept relevant in another context. The context mainly depends on the system under consideration. Then, the other elements of Füssels paper allow to make it more precise, so that at the end, the relevant concept emerges from its own. In the first part of the paper, we present Füssels analysis and show that it yields a complete grid to answer the two previous questions for most works done on vulnerability. In the second section we insist on elements of dynamics that are mentioned but not developed in Füssel's conceptual framework, along with examples developed in our study SHIVA. In the last part of the paper, we show that vulnerability concept used in our context are linked to behaviors. Indeed we show how, in some contexts, vulnerability is related to the ability/inability to make decisions. Through this approach, the relevance and sensitivity to dynamics may be more easily grasped.

In our study, adaptive capacity and sensibility factors are two expressions of the dynamic of the system under consideration. Here, given we consider human systems, part of the system is a group of decision makers. A decision maker reacts to hazards and uncertainties about social, economical and environmental factors. These uncertain phenomena have their own dynamics that the decision maker figures out through information. Information arrivals at some future dates are, in turn, the states from which the decision maker chooses among possible actions: thats the decision process dynamics. If the level of information is too low, for instance, the decision maker is unable to plan anything and is inhibited in making decisions. For example, the level of information about climate change is certainly too low at the individual level to have any prospective vision of the future. At the national level, however, this is not the case and decisions can be made, plans can be designed that will adapt to future information arrivals and national or regional programs may be developed to help individuals to adapt. Among those individuals, some may be more able to react to such plans, hazards and socio-economic uncertainties, this is what we try to measure by adaptive capacity factors. Sensitivity, as well, is an indicator of the possible impact of information on individual decision making.

2 Füssel conceptual framework of vulnerability: application to Indian farmers' vulnerability to global change

Füssel's conceptual framework combines a nomenclature of vulnerable situations and a terminology of vulnerability concepts aiming at characterizing the vulnerability concepts employed in the main schools of research. The nomenclature of vulnerable situations is described through four dimensions of a given vulnerable situation. The first fundamental dimension is the *system of analysis*. It addresses either natural systems (ecosystem, aquifer, plant, animal, soil, *etc.*) or human systems (a population, an economic sector, a country, *etc.*). As an example, within SHIVA study, we are concerned with the farmers of South India. By South India we mean a geographic area that shares the three following important characteristics to understand farmers' vulnerability to global change. (i) Food production relies mainly of groundwater irrigation. (ii) Farmers have to compose with semi-arid climatic conditions: with rainfall ranging from 600 to 1100 mm in this area, farming is greatly reliant on monsoon quantity and quality. And (iii) farmers are constrained by hard rocks geological context which limits groundwater storage in the aquifers (low recharge capacity). The focused area is presented in Figure 1. By farmers, we mean the operational landholders within their operational land unit (or the farming system). According to the focused area described above, we are then analyzing rural farmers and their farming system relying on monsoon and groundwater irrigation.

The second dimension of vulnerable situations is *the attribute(s) of concern*. The attributes of concern are "the valued attributes of the vulnerable system that are threatened by its exposure to a hazard". Attributes can again be natural (biodiversity, timber production, *etc.*) or socioeconomic (income, health, *etc.*). Going on with our SHIVA study, we are interested in how farmers' livelihood sustainability is impacted by global change. This is to say that we are considering a set of impacted attributes (income, water resources, soil, *etc.*) that defines farmers' livelihood resources. Our approach is based on Sustainable Livelihood Approach (SLA) (Orr and Mwale, 2001; Scoones, 1998). The SLA defines households capacities according to five capital assets: human, physical, natural, financial and social assets. The analysis of farmers' capital assets and their evolution further allows to discuss the farmers' livelihood strategy trends.

The third dimension is the *hazard* which Füssel defines as "a potentially damaging influence on the system of analysis" and "some influence that may adversely affect a valued attribute of a system". The hazard of interest is discrete (perturbations) or continuous (stressors). A fine description of the hazard under consideration is important as it introduce a temporal dimension in the analysis. As a consequence, a dynamic perspective of the system may be required. This is indeed the case in our research where we are studying the effects of the multiple stressors of global change in the future. As we focus on one side, on climate change and variability, keeping aside extreme events (storms, unusual floods, *etc.*), and on another side, on likely future economic changes, we are looking at *continuous hazards* in the terms of Füssel. Thus, vulnerability assessment must be dynamic as it translates a succession of adaptation procedures in reaction to ongoing changes (environmental and economic).

At last, the fourth dimension of vulnerable situations is the *temporal reference* which can be a point in time or a period of interest. This dimension introduces a kind of temporal limits to the dynamics we want to give to the vulnerability conceptualization. It is not clear in Füssel's framework how to tackle this issue within quantitative assessment. Continuing on SHIVA study example, two periods of time are considered in addition to the assessment of current vulnerability, in order to take into account the different dynamics of climate and economic changes (2020-2030 and 2045-2065). But the dynamic view of the system is restricted to the comparison of these three snapshots of vulnerability states. A real dynamic conceptualization would imply a marginal approach of vulnerability quantification.

As a result, these four dimensions of Füssel's vulnerable situations nomenclature give a complete and precise answer to our first question *What are we talking about?*. Füssel's second step of his approach offers a terminology to identify and characterize vulnerability concepts. This additional description of vulnerable concepts allows answering to our second question *What are we exactly mea-*

suring as vulnerability?. Vulnerability concepts are described through a two dimensions matrix of vulnerability factors. These two dimensions are the *sphere or scale* of and *the knowledge domain.* Sphere is internal when referring to "properties of the vulnerable system" (income, soil quality, *etc.*) or external when referring to "something outside the system" (groundwater policies, market prices, pest attacks, bad monsoon). If the sphere of concern refers to both internal and external factors, then Füssel speaks of "cross-scale factors". Knowledge domain is split in two categories of vulnerability factors: socioeconomic factors and biophysical ones. Socioeconomic factors relate to "characteristics of social groups" (income, groundwater policies, market prices) whereas biophysical ones relate to "system properties investigated by physical sciences" (soil quality, bad monsoon). When factors are of both domains, Füssel speaks of "integrated vulnerability factors".

Going on our SHIVA example, internal sphere factors of vulnerability are identified through the description of the farming system itself with emphasis on its performance. In our approach, performance is assessed by farmers' capacity to adapt to changes which is itself based a Sustainable Livelihood Approach (SLA) (Orr and Mwale, 2001; Scoones, 1998). Thus, internal sphere factors refer to the five capital resources described by Scoones (see Section 2). Without going deeper in our conceptualization, we can already see that some capital resources are of the socioeconomic knowledge domain whereas others are from the biophysical knowledge one. On the other side, we use the Porter's diamond framework adapted from a firm to a farming system in the line of Vandermeulen framework (2009), in order to identify the external factors that influence the development of the farming structure. This conceptual framework allows a concise description of external forces, taking into account altogether the context of farming system strategy that can be natural (rainfall, temperature, altitude, water availability, *etc.*) or economic (agricultural policies, subsidies, investments, *etc.*); the evolution of farming products demand and consumption; the evolution of upstream and downstream industries (e.g. fertilizer or machinery industries, sales cooperatives, regional trade); and the factor conditions (land, labour, information, infrastructures, *etc.*). Again, factors that we take into account in our analysis are of both knowledge domains (socioeconomic and biophysical).

Füssel's matrix of vulnerability factors, in its basic conception, offers a set of factors combinations that is sufficient to depict any vulnerability approaches found in the literature (Füssel, 2007, p. 160). In the classical risk-hazard approach, for example, vulnerability concept is defined as the level of damage or loss due to the severity of the hazard of concern. Our project's geographers can then recognize their usual approach of vulnerability. It can also be denoted as dose-response or exposure-effect relationship. In this case, vulnerability is equivalent to sensitivity as in our hydrologists' conceptualization: the properties of the vulnerable system are only considered to estimate the impacts of the hazard and the vulnerable system is exclusively restricted to physical systems, natural or not (equipment, production assets like land). Vulnerability concept in risk-hazard approach is then denoted as internal biophysical vulnerability. In the second main approach, which is the political economy one, vulnerability concept focused on people livelihood and well-being and their ability to cope with and adapt to stresses. Here SHIVA economists will find their own traditional conceptualization of vulnerability. Internal as well as external factors are generally analyzed, but knowledge domain of concern is exclusively socioeconomic. This approach is classed as a cross-scale socioeconomic vulnerability approach. There exists cross-scale integrated approaches of vulnerability that takes into account all four kinds of vulnerability factors. They combine risk-hazard and political economy approaches as factors of vulnerability can come from the properties of the system as well as from its external environment. In addition, vulnerability factors can be both of socioeconomic (e.g. market failure) and of biophysical domain (e.g. storm). Our SHIVA study is in the line of these cross-scale integrated concepts of vulnerability as the above description of factors shows. That is why the IPCC definition totally fits with the context of vulnerability assessment within SHIVA study.

3 Passways to characterize the dynamics of vulnerability

Public decision makers as well as experts and scientific studies cannot avoid considering the general evolution of the system under consideration. In most cases, plan makers have limited their vision of the evolution to some perspective they wished to impose (e.g. 5 years plans in France, India and the USSR). This limitation has lead to many inabilities to adapt such plans to hazards, social movements or new instruments. Dynamics doesn't just mean we take the temporal reference into account. It amounts to describe in details different processes and their interactions (e.g. a hazard stressor and socio-economic processes). Furthermore, when decision makers are part of the system (as is our case), dynamics concerns decision making processes that respond to external hazards. This is why a prospective approach is needed in order to introduce flexibilities, options and more generally to integrate the possibility to adapt to new information. Even in the case of a well-known natural hazard, the ways to react to it may depend on other parallel processes such as new technology, social changes or other hazards. A prospective vision of the system evolution includes the different factors processes affecting the attributes, the different relevant hazards among the spheres (internal or external, and in our case, integrated). Obviously, the temporal reference is fundamental in a prospective approach as it limits the different dynamics that interact and are taken under consideration. Leichenko *et al.* (2002) suggest that

> "traditional vulnerability indicators may be insufficient in capturing the nature of global change, including its many dimensions and its diverse effects at different scales of analysis. [...] one possible strategy for addressing dynamic vulnerability via a multi-scale method of analysis would be to combine macro-level vulnerability mapping using dynamic indicators [...], with local-level survey-based investigations of how changing economic policies are affecting farmer and institutional response to climate variability."

The authors then proposed to assess *changes* in a set of vulnerability indicators during one period of time, but they didn't applied the methodology in a concrete case study. That's what we tried to do within SHIVA project (i) by downscaling global change effects, either climatic and economic, and (ii) by incorporating elements of dynamics in adaptive capacity and sensitivity indexes. However, dynamics is limited to some large time intervals.

First of all, in a pilot phase, we try to identify the major hazards to which a farmer has been exposed and is sensitive. Results show that droughts, bad monsoons, pest attacks, low groundwater table, input prices increase and output prices decrease were the major hazards encountered. Faced to them, farmers use to adjust their strategy (or take management decisions). As a matter of fact, these hazards perceived by farmers can easily be linked to climate and economic changes. Thus, we introduce a prospective vision of the hazards under concern, global change, with a particular attention to those hazards perceived locally (Belliveau et al., 2006). To forecast these changes, we use medium and long term IPCC scenarios of climate change. IPCC scenarios are derived from the future simulation of gas emissions which are themselves simulated according to hypotheses about countries' future behavior in terms of environmental concern and market exchanges (so-called SRES scenarios). These scenarios are the start of our prospective approach of global change hazards. Though, additional work was achieved to downscale SRES and IPCC scenarios over the SHIVA area of concern. Only to this condition, differentiate impacts of global change on farmers can be geographically observed. For the climate change part of downscaling, mathematical Global Climate Models (GCMs) exist and downscaling of models is now a common work in research projects dealing with climate change impacts assessment. From GCM time frames comes the temporal dimension of our study.

Besides, the downscaling of SRES/economic scenarios is clearly less "trivial". We consider one most probable scenario in India: the A2 scenario that is a continuation of what already happens, that is limited sustainable development and very moderate environmental consciousness. Then, the downscaling of this scenario in South India can be achieved through a prospective research on the economic factors that will influence the farming systems within the time frames considered (2020-2030; 2045-2045). These economic external factors are identified when describing the external sphere factors (according to Füssel's terminology, see section 2). National and regional plans, strategies and vision for these factors are then analyzed together with experts points of view in order to evaluate future trends. Within this economic prospective approach, we had to take into account some adjustment (or adaptation) made by government facing global change. Indeed, at national and likely regional scales, decision makers are informed of global change hazards and their potential impacts. Plans usually integrate general measures to limit negative effects of changes (collective adaptation capacity). As an example, water resource management plans include measures as increasing storage capacity, more efficient use of water or more efficient irrigation systems. Then, even if, at the very local scale, the farmers are not informed of hazards, they will be encouraged to change some elements of their system.

Though, the farmer (the decision maker) has to faced many other hazards than those derived from global change: health hazards, personal hazards, production hazards, institutional hazards, *etc.*. And finally, farmers' decisions are taken in this context of multiple hazards. That is why it is essential to describe farmers within a broadly environment and apply prospective analysis on the major driving forces influencing the system. As an example, food production is expected to remain a priority for Indian States with consequence such that a shift from subsistence to economic farming systems, and likely an important decrease of the farmers population. As a consequence, in Andhra Pradesh, farmers population in 2030 is expected to decrease by 30%. Livestock production won't be supported by government whereas more efficient irrigation will be subsidized and cash crops prices should be sustained by government. Energy price should grows up at international level with impacts on Indian farmers as local energy shouldn't remain free. The construction of new Hyderabad airport has impacts on farming systems and job opportunities. Analyzing farmers local and regional environment thus allows to built relevant hypothesis on national and regional economic hazards that are likely to impact farmers and farming local economies. These hazards are also described as "driving forces" within SHIVA study and we use Portal's diamond conceptual framework to identify main forces. The incorporation of some of these elements into vulnerability index (which combines sensitivity and adaptive capacity indexes) contributes to improve the dynamics of the concept. In the line of Leichenko *et al.* (2002) and Belliveau *et al.*(2006), we thus identified some indicators that could be "modeled" or "simulate" at future dates. As an example, sensitivity index includes indicators such as farming income evolution within the household, in order to grasp past trends; or the percentage of the cashcrops area, to get an idea of farmers' dependence to government support. Besides, adaptive capacity index incorporates indicators as education, health, infrastructure and information availability, operational area, production means, *etc.*, for which hypotheses can be done for their evolution in the future (see Figure 3 of adaptive capacity index). Indeed, future vulnerability not only relies on climatic or non-climatic conditions found to influence farmers. As we try to explain, farm-level factors are also likely to evolve and change the farmers' capacity to adapt to hazards. For some indicators, projection scenarios should bring more dynamics into the adaptive capacity concept.

4 Vulnerability concept observed from a decision-making approach

According of what we have described above, in order to better understand the dynamics of vulnerability, it might be helpful to analyze the system and its own dynamics. In our case where part of the system is a decision maker, that is an active entity, this dynamics is described by the decision process itself, which responds to hazard processes. In this context, the vulnerability concept could be approached by an analysis of decision makers ability/inability to react to hazards. Otherwise stated, vulnerability would amount to a limitation of the ability to take risks in order to mitigate and/or compensate the risks that are faced. It could be related to constraints that reduce the range of optimal decisions. It could be related as well to something much more difficult to grasp: a change in the decision makers preferences. This could be the case if, for instance in front of an unexpected hazard, family safety passed in front of the timing to plant. There is indeed a close relationship between factors of attributes that are integrated in the vulnerability measures and the variations of constraints limiting the decisions range. Following this point of view, it may be enlightening to integrate more questions about the decision process into the inquiries, assuming the decision maker is dynamically consistent (preferences are not assumed to change) in order to grasp the capacity to make up a prospective view (in opposition with the submission to habits), the relative importance of constraints (*e.g.* monetary *vs* working time), the relative importance of relevant events (subjective probability).

In August 2009, a survey of 153 farmers strati-

[1] Surveys and data management were piloted by the Center of Economic and Social Studies, CESS, Hyderadab.

fied by operating area size was carried out in a small pilot watershed[1]. The questionnaire aimed at characterizing the household composition and identity, the household sources of income and other financial determinants, the farming system in terms of cropping patterns, water uses and technical assets, plus additional questions about perceptions of climatic, political and economic events and shocks. Following IPCC definition of vulnerability as a function of exposure, sensitivity and adaptive capacity, but merging exposure and sensitivity on the basis that working at individual level exposure and sensitivity were intimately related, we built a composite index of vulnerability made of adaptive capacity and sentitivity/exposure indices. Adaptive capacity indicators identification is based on Scoones 1998 sustainable livelihood approach (SLA - 5 capital assets). The choice of indicators for each assets is based on a past research using SLA for watershed management in India (Reddy and Ready, 2004) plus discussions with local experts. Sensitivity indicators integrate components of hazards perception, natural or economic. Farmers are asked to assess the number of shocks that occurred during the last 5 years and if they suffered from these shocks the year just before the survey. This is to integrate the hypothesis that recent shocks are more likely to impact current farmers' decisions. Additionally, sensitivity index is composed of livelihood sensitivity indicators about past trends of farming income, irrigation costs, government programs participation, impacts of shocks on ability to buy food, and so on. Adaptive capacity and sensitivity indicators are then organized into a hierarchic matrix according to Analytic Hierarchic Process (AHP) method (Figures 3 and 4). After indicators are (i) valued through survey responses, and standardized to a single [0,1] scale, and (ii) weighted by experts through pairwise comparison of indicators, Compromise Programming (CP) is used to aggregate indicators value and weight (see, Eakin *et al.* 2006 for methodological development). Through CP, a distance to the anti-ideal point is calculated for each farmer and both indexes of adaptive capacity and sensitivity separately. Here, the anti-ideal point is represented by maximum vulnerability (the value of vulnerability score is then 1). The greater the distance to the anti-ideal point, the higher the capacity to adapt, and the lower the sensitivity. Formally, the distance to the anti-ideal point for a farmer is calculated as follows:

$$d_i = \left[\sum_j^J w_i^p (1 - x_{ij}^p) \right]^{1/p} \qquad (1)$$

where d_i is the distance to the anti-ideal point of the i^{th} farmer, w_j the weight of the j^{th} indicator, x_{ij} the standardized score of the i^{th} farmer for the j^{th} indicator, and p a constant metric indicating how compensated a decrease/increase in one indicator can be by the increase/decrease in another indicator. Here we took $p = 1$, meaning a perfect compensation.

Fuzzy logic is finally used to compile both distances and obtain a final vulnerability score per farmer[2]. At the end, farmers are ranked according to their vulnerability score. The closest to a score of one, the more vulnerable the farmer is; conversely, the closest to zero, the less vulnerable he is. We found 15% of Gajwel watershed farmers belonging to the high vulnerability class with average score of 0.652 and 56% belonging to medium vulnerability class (score of 0.484) (Figure 5). We found no farmer in the "very high vulnerability" class. Analyzing the origins of vulnerability from adaptive capacity point of view, we observe that[3]: (i) high vulnerable farmers particularly suffer from a lack of information on weather forecast and agricultural new practices and innovations; (ii) their sources of income are less diversified and their total income (household income) is lower; (iii) savings are less important; (iv) this category of farmers also suffers from the lack of public infrastructures (access to roads and urban facilities) (Figure 6). By the way, crop diversity does not seem to be a good strategy to ease farmers' adaptive capacity in this local context: indeed, this is not a significant variable to explain between classes vulnerability variability. Sensitivity indicators contribution to vulnerability is less trivial (Figure 7). What can be said is that some farmers who appears as more sensitive to market shocks, are yet attached to the "very low" vulnerability class. Their sensitivity is compensated by a high adaptive capacity score, showing their ability to take good decisions when faced to sensitive situations. Participation to government programs appears clearly as a sign of higher vulnerability. At last, the vulnerable farmers are those who are affected by hazards in such a way that it affects

[2] We use FisPro software developed by INRA and CEMAGREF, France.

[3] Most vulnerable farmers are located at the periphery of the star whereas less vulnerable ones are in the center.

their ability to buy food. Indicators on past hazards perceptions doesn't bring the expected contribution to vulnerability score, at least in the context of a small watershed as Gajwel one (80 km^2). This will be verified over larger basins (700 km^2). The results presented show the *current* farmers' vulnerability scores. Future vulnerability scores will be computed based on prospective simulation of a set of indicators. Particularly, hazards will be simulated in order to grasp their influence on future vulnerability. Then, perceptions will be replaces by corresponding simulated indicators. In the same way, hypotheses on irrigation costs trends, participation to government programs, *etc.* will be tested. On the adaptive capacity side, dynamics will be also introduced through the simulation of a number of indicators for which hypothesis can be made. This will be possible for indicators on infrastructures and services availability. This is all the more important that they are significantly contributing to vulnerability scores. Local experts' knowledge will be used to simulate these indicators. Among the ways we investigate to improve the dynamics of the vulnerability concepts, is the use of farmers' typology approaches: typologies are a way to study the system of concern and investigate its own dynamics. We first use official typology of Indian farmers based on operational land size. But we also built our own farmers' typology using again SLA to range farmers according to their current livelihood strategy[4]. We identify 6 groups of homogeneous farmers that were linked to 3 specific livelihood strategies. Farming strategies are then discussed with experts in order to forecast their evolution. Finally, we also study farmers according to their geographic location (rural/urban villages), as we find that infrastructures and services are significantly influencing farmers' vulnerability. Then, discussing with new experts, we hope to develop new hypotheses that could differentiate between and within farmers' strategies. Figure 8 shows an idea of farmers' current vulnerability according to the typology used. Variability already clearly appears between groups, and origins of vulnerabilities can be identified thanks to vulnerability indicators (in the same line of Figures 6 and 7).

5 Conclusion

The adaptive capacity figured out in Shiva, is a proxy for the Indian farmers' capacity to take risks. Indeed, the system we study is not limited to farmers only, but extends to parts of their environment as was explained in the previous sections. As a result, the vulnerability measures dynamics is constrained by the dynamic of the environment (bio-physical and socio-economical) and cannot grasp the much faster dynamic of the decision making processes. This is why our dynamic is limited to two periods, whilst farmers may adapt their behaviors to changes from year to year. Furthermore, information contained in the enquiries could let us follow the farmers dynamics but is integrated here in the indexes. Obviously, such a dynamic could only be described with some more information, notably the farmers attitudes toward risks. In our enquiries, these attitudes can be guessed from some answers, but were not sought for. Indeed, it would have not make sense to go further in details without a theory to rely on. Such a theory, relating vulnerability to risk attitudes, and hence its dynamic to the decision processes of farmers according the their attitudes toward risks, will be developed in a forthcoming paper.

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[4]The typology is based on statistical cluster analysis over the Gajwel farmers' sample.

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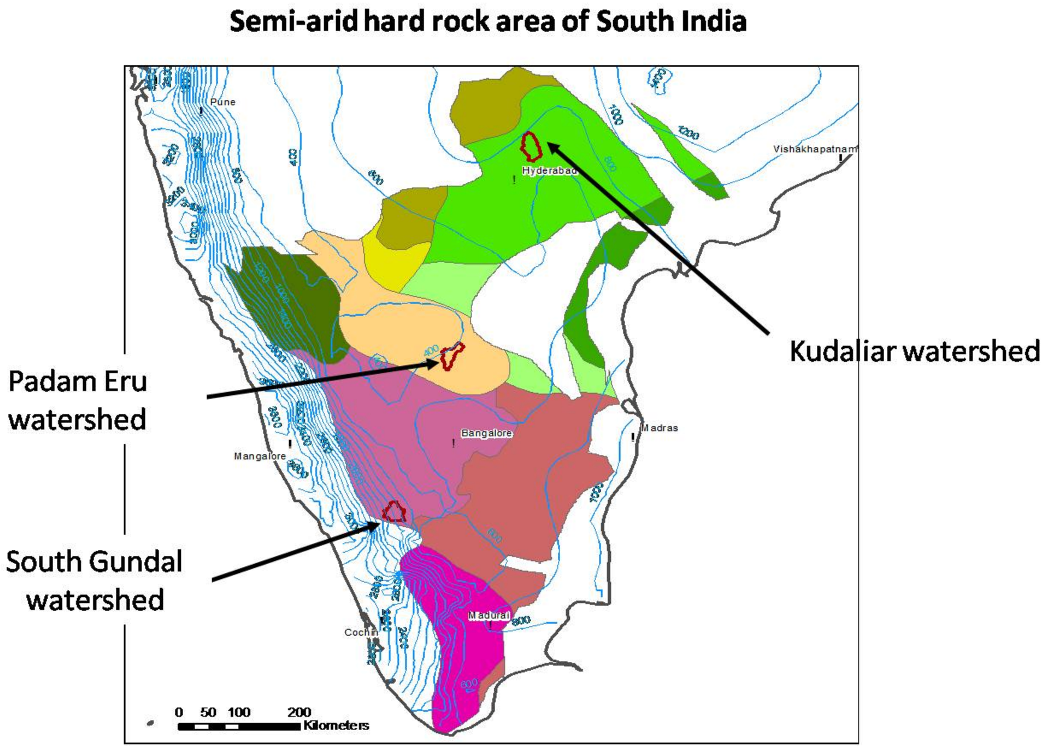

Figure 1: Location of the SHIVA project study area with 3 pilot watersheds.

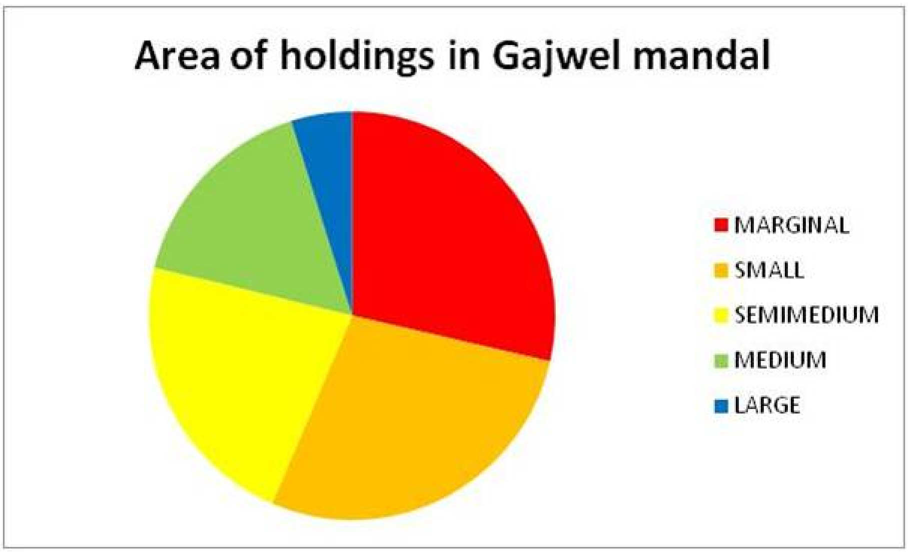

Figure 2: Distribution of holding area within the Gajwel mandal (small pilot watershed). *Marginal: lower than 1 ha; small: 1-2 ha; semi-medium: 2-4 ha; medium: 4-10 ha; large: above 10 ha.*

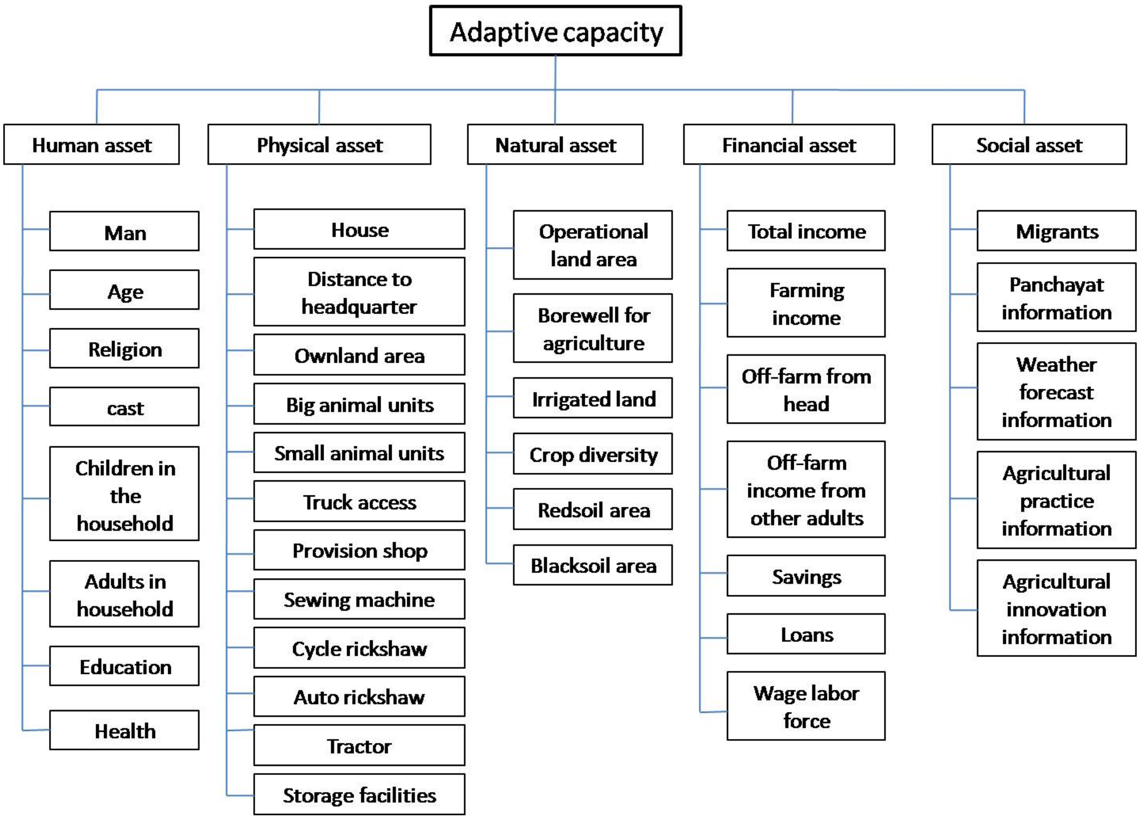

Figure 3: Matrix for farmers' adaptive capacity index.

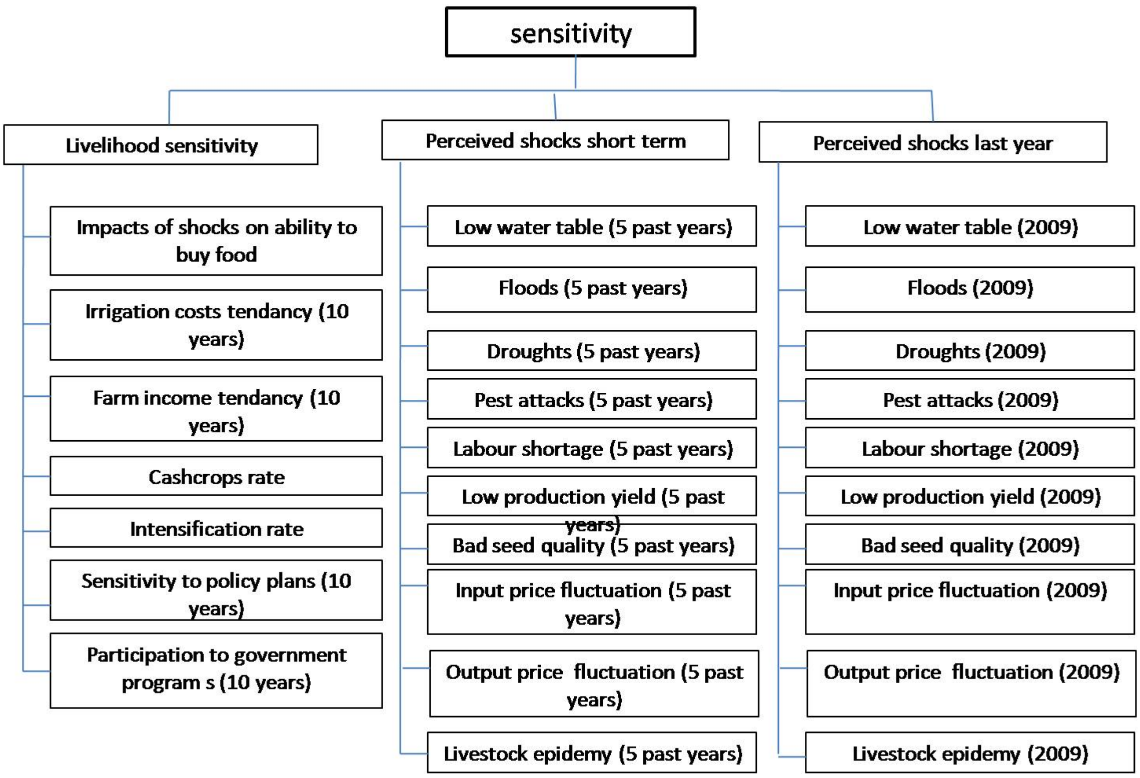

Figure 4: Matrix for farmers' sensitivity index.

Vulnerability class	Average score	Percentage of farmers sampled
High vulnerability	0.652	15%
Medium vulnerability	0.484	56%
Low vulnerability	0.306	22%
Very low vulnerability	0.126	7%

Figure 5: Results of farmers' vulnerability assessment.

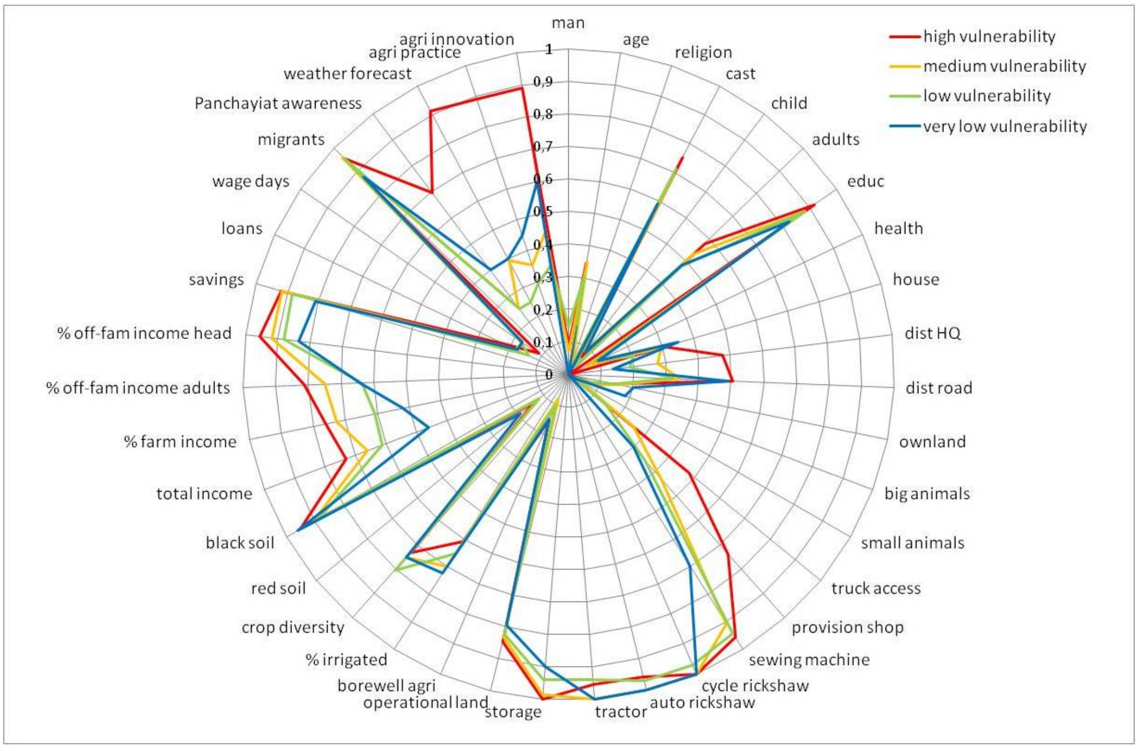

Figure 6: Origins of farmers' vulnerability: adaptive capacity indicators.

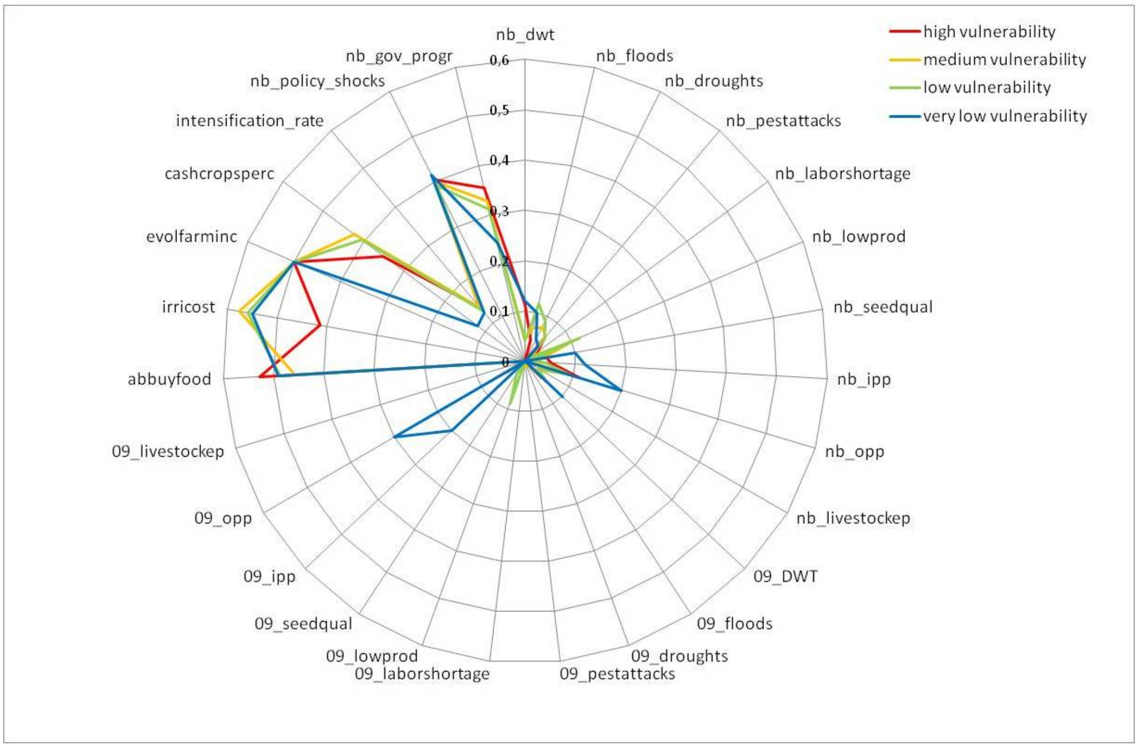

Figure 7: Origins of farmers' vulnerability: sensitivity indicators.

Typologies	Average score	Percentage of farmers sampled
Official farmers' categories		
Medium farmers (4-10ha)	*0,358*	5%
Semi-medium farmers (2-4ha)	0,451	14%
Small farmers (1-2ha)	0,455	35%
Marginal farmers (<1ha)	0,448	46%
Cluster farmers' groups		
Group 1	0,425	30%
Group 2	0,453	24%
Group 3	0,481	23%
Group 4	0,473	12%
Group 5	*0,303*	6%
Group 6	0,484	5%
Farmers' villages		
GAJWEL (urban)	*0,419*	49%
RANGAMPET (rural)	0,423	25%
VEERANAGAR (rural)	0,522	25%

Figure 8: Vulnerability results according to farmers' typologies.

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