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Practical method for assessing the vulnerability of the agricultural production system to the effects of climate change in rainfed areas "MEVSPA-CC"

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Abstract*— *According to the literature, various methods have been used to assess vulnerability to the effectof climate change, few of them have addressed the degree of vulnerability of agricultural production systems to climate change effects. In this paper we propose a new method appropriate to the Evaluation of theVulnerability of an Agricultural Production System to the effects of Climate Change in rainfed areas noted « MEVSPA-CC ».

This method refers to the concept of vulnerability to climate change as defined by the IPCC.This method builds on practical approaches and methods of climate change vulnerability assessment that have already been implemented in other contexts.This method consists of measuring the intensity of each component of vulnerability (sensitivity, exposure and adaptive capacity) of an agricultural production system based on the causal relationships between its internal and external factors (human, physical, financial, natural, economic, and social) and the potential effects of a climate event.

***Keywords*— Adaptation, Assessment, Climate, Exposure, Method, Sensitivity, Vulnerability.**

I. INTRODUCTION

Without a doubt, climate change has become a reality. Indeed, during the last 50 years, the world has experienced an increase in the frequency and intensity of extreme weather events, including droughts, floods, tsunamis, and storms (***EM-DT, 2014)***.

Thus, the evolution of the average temperature of our planet has recorded an upward trend and the precipitation regime has been modified with a downward trend, especially in arid areas. These climatic fluctuations have had adverse effects on all human activities and particularly on agriculture, since the latter is directly linked to the climate in most countries and particularly in poor countries.

In addition to these exogenous climatic factors, illiteracy, lack of support, supervision and awareness, the fragility of infrastructure and land fragmentation are among the main factors that hinder the adaptation of agricultural production systems to the effects of climate change and consequently increase the degree of vulnerability of these systems (***Laamari,A., and al., 2016)***.

Furthermore, according to the literature***(world Bank, 2013)***on vulnerability assessment, researchers and international organizations have developed several indicators and indices to assess vulnerability to climate change.

Thus, two classifications have been distinguished: the first classification consists of assigning the main general indicators according to the three components that define vulnerability to climate change, namely: sensitivity, exposure and adaptive capacity. The second classification borrows the nature and type of climate event as the main criterion for assigning indicators.

In addition, the Livelihoods Vulnerability Index (LVI), the Environmental and Climate Vulnerability Index (EVI), and Climate Change Vulnerability Mapping (CCVM) are among the most widely used methods for assessing ecosystem vulnerability to the effects of climate change. It should be noted that, despite this diversity of existing methods for assessing vulnerability to the effects of climate change, specific methods for measuring the degree of vulnerability of agricultural production systems to the effects of climate change are still little studied. Therefore, in order to master the main determinants of vulnerability to the effects of climate change, is it possible to measure the degree of vulnerability of an agricultural production system to the potential effects of a climatic event?

In order to contribute to the answer to this question, we try, in this article, to propose an appropriate Method for the Evaluation of the Vulnerability of an Agricultural Production System to the effects of Climate Change in rainfed areas, known as "MEVSPA-CC".

This method refers to the definition of vulnerability to climate change as put forward by the IPCC - "vulnerability is the degree to which a system is susceptible to, or affected adversely by, adverse effects of CC, including climate variability and extremes. Vulnerability depends on the character, magnitude and rate of CC to which a system is exposed, as well as its sensitivity and adaptive capacity"***(GIEC, 2001)***.And it draws on practical approaches and methods for assessing vulnerability to climate change that have already been implemented in practice in other contexts.

I- Conceptual framework of the "MEVSPA-CC" method

According to the literature***(Barbut, L. and al., 2004)***, the vulnerability can be evaluated, in a quantitative or qualitative way through the analysis of the sensitivity to the damage or through the characterization of the damage or through the capacity of response to the damage. Indeed, the assessment of the sensitivity to damage is essentially based on the study of the main factors (quantitative and/or qualitative) that can directly or indirectly influence the vulnerable system. The assessment of vulnerability through the capacity to respond to damage is often translated into an analysis of the effectiveness of the actions and means implemented to mitigate or reduce the damage. It is based on qualitative description and analysis tools (SWOT, Scorecard, GANTT chart, Evaluation sheets...). Vulnerability assessment through damage characterization is based on damage assessment.

Generally, the characterization of the damage is done according to a quantitative measurement. Vulnerability is expressed either by a potential damage coefficient that varies from 0 to 1, or by a potential loss rate that varies from 0 to 100%. Thus, "The risk corresponds to the mathematical expectation of damage or loss and its analytical expression is based on the product of the temporal component of the hazard (probability of occurrence), the values of the issues and the measure of their vulnerability. The damage or loss rates depend on the nature of the exposed elements (their resistance or resilience) and the magnitude of the natural phenomena involved (their effects). They are given in the best of cases by functions called damage (vulnerability) or losses***(LEONE, F. and al.,2006)***.

1-1- Presentation of the "MEVSPA-CC" method

The idea behind this new vision is that the degree of vulnerability of an agricultural production system to the effects of climate change can be calculated by measuring the ratio of weights between the components of vulnerability, i.e. exposure and sensitivity on the one hand and adaptive capacity on the other. Thus, if the adaptive capacity of an agricultural production system is greater than its exposure and sensitivity, we say that the system is not vulnerable, otherwise, we can say that the system is vulnerable. Thus, we can schematize this idea in Figure 1:

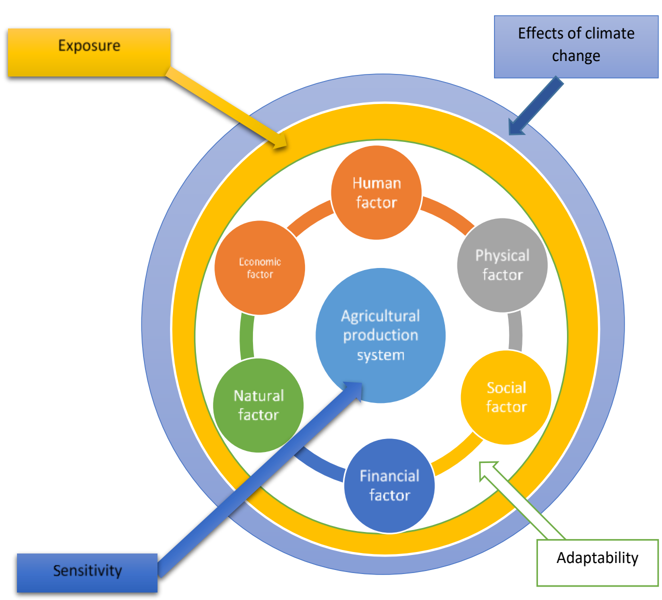


Figure 1: Representative diagram of the different vulnerability components of an SPA

This figure summarizes the key factors that determine the vulnerability of an agricultural production system.

Then, we analyse the causal relationships between the determining spheres of vulnerability in Figure 1, we obtain: The first sphere represents the sensitivity of the agricultural production system to climate change. The measure of the degree of sensitivity of an agricultural production system is a function of its specific internal characteristics. So, if the intensity of sensitivity is very high, this sphere grows while absorbing the sphere that represents the system's capacity to adapt. The second sphere represents the degree of adaptability of the agricultural production system to the effects of climate change.

This degree is measured in terms of the capacity of the production factors (human, physical, economic, social, natural and financial) to reduce or mitigate the adverse effects of climate change. If the degree of adaptive capacity is very important, the white sphere dominates the other spheres. The third sphere represents the degree of exposure of the agricultural production system to climate hazards. The measure of the degree of exposure of a system is a function of its external environment (the magnitude of the effects) and internal environment (the tolerance of its production factors).

The fourth sphere represents the magnitude of the effects of climate change. The degree of the magnitude of these effects depends on the type of climatic event itself (drought, floods, storms,...) and its duration of occurrence.

1-2- Rationale for the choice of factors

Referring to the literature(***MFACED(Zig),2017)***) on the assessment of vulnerability to the effects of CC, and like any other system, the analysis of the vulnerability of an agricultural production system requires us to study its interaction with its internal and external environment. In fact, there are six determining factors***(D'Ercole,R., and al., 1994)***) that can characterize the study of the assessment of each component of the vulnerability of an APS to the effects of CC.

a- Human factor

This factor is very important to assess the degree of vulnerability of an agricultural production system because human capital is the axis on which all other variables that can influence this system are articulated. Thus, an ecosystem can only be developed if great importance is given to this pivotal factor. So to measure the human factor of an agricultural production system, we analyze the following criteria: level of education, age, experience in agriculture, household size and immigration.

b- Social Factor

The social factor is an essential index for any evaluation of the socio-economic and demographic development of ecosystems. Thus, according to **Dugarova**,***(2014)***. "social factors here refer to structures (class, gender, ethnicity, religion and domicile), institutions (laws and norms) and social agency (the ability of individuals and groups to make their own choices and influence decisions that affect their lives) that are based on social norms and values and that determine the directions and modalities of change"**.** Thus, for our study, the criteria assigned to measure this factor are social stability, social membership, family relationship, social supports, and participation in decision making.

c- Physical factor

The physical factor informs us about the wealth of the system, the element or a group of elements to be evaluated. Thus, in our analysis, we have assigned the following criteria to this factor: the size of the farm, the number of livestock, the material and equipment.

d- Economic factor

The economic factor plays a very important role in the evaluation of agricultural production systems. Indeed, the expenses, costs and yields allow us to calculate the profits or benefits of an agricultural activity. And on the basis of these calculations, the decision of profitability of this activity can be taken in order to continue to exploit it, to stop it or to modify the exploitation techniques to improve it. Moreover, these calculations must take into account the potential losses and damages related to climatic risks.

e- Financial factor

The availability and diversification of financial resources are key indicators of an economic activity's ability to succeed.

f- Natural factor

The scarcity of natural resources, the degradation of fertile land and the lack of energy resources undoubtedly increase the vulnerability of an agricultural production system to the effects of climate change. Thus, we have assigned the following evaluation criteria to this factor: soil quality, availability of water resources and energy resources used.

II. PRESENTATION OF THE GRIDS FOR ASSESSING THE VULNERABILITY OF AN SPA

In order to contribute to the bank of tools for measuring the degree of vulnerability to CC, we have invented a specific grid for each component, to which we have assigned specific and quantifiable criteria and indicators to measure its contribution to the intensity of the component in question.

2-1- Evaluation grid for the sensitivity of an SPA to the effects of CC

For the constitution of the sensitivity evaluation grid, the choice of indicators for each criterion followed the following reasoning: For each factor, we asked the following starting question: For each factor, we asked the following starting question: What are the internal parameters related to this factor that can make it sensitive to climatic hazards? Thus, the answers to this question were summarized in the following grid:

Grid 1: Assessment of the degree of sensitivity of the SPA to CC						
Component	Factor	Criteria	S	MS	NS	Note
Sensitivity	Human factor	Level of education of the head of the household				
		Qualification, training				
		Immigration				
		Work availability				
	Physical factor	Size of the exploited area				
		Land tenure				
		Farmmaterials and equipment				
		Housing and storage				
		Livestocknumbers				
	Social Factor	Access to associations or cooperatives				
		Access to social assistance				
	Natural factor	Soilquality				
		Historicalprecipitation				
		Availability of water resources for irrigation				
		Energy resources				
	Financial factor	Self-financing				
		Access to financingcredits				
		Other sources of financing				
	Economic factor	Income				
		Savings/Agricultural product stock				
S: highly sensitive; MS: moderately sensitive; NS: not sensitive.			Total score = (1*S)+(0,5 *MS)+ (0*NS)			

2-2- Evaluation grid of the exposure of an agricultural system to climate change

In order to establish the evaluation grid for the exposure of an APS to CC, we proceeded as follows: the choice of indicators for each criterion is made through the answer to the question: What are the external parameters related to this factor and which can make it fragile to climatic hazards? Thus, the answers were summarized in the following grid:

2-1- Grid for assessing the capacity to adapt to climate change

For the construction of the evaluation grid of the adaptive capacity of an SPA to CC, we asked for each factor the following question: What are the internal and external parameters related to this factor that can make it resistant to climate hazards. Thus, the answers were summarized in the following grid:

Several authors have tried to concretize the function that links vulnerability to its components (sensitivity, exposure and adaptation). Indeed, Hahn et al. have put forward a formula attempting to express the relationship between these three components of vulnerability. Thus, the formula was presented as follows:

$$Vulnerability = (Exposure - Adaptation) \times Sensitivity$$

However, the reliability of this last formula requires an explanation of the mathematical operations linking the three components of vulnerability. Indeed, the difference, if possible, between "exposure" and "adaptive capacity" gives an incomprehensible measure and the multiplication of the latter with "sensitivity" makes the result difficult to interpret.

This ambiguity led us to consider two other alternative formulas for measuring the degree of vulnerability of an agricultural production system, namely a historical formula and a probabilistic formula.

3-1- Historical formula

This formula uses historical data for the three vulnerability components. It calculates the ratio of the degree of sensitivity and exposure to the degree of adaptive capacity. This formula is based on the comparison between the weights of the vulnerability components by putting them on two scales with one containing the weight of the adaptive capacity and the other tray carrying the other two vulnerability components (sensitivity and exposure). Thus, the concept of resilience has been introduced as a complement to vulnerability because "resilience is the ability of a body, organism, organization or system to recover its initial properties after an alteration"***(Wieland, A., and,Wallenburg, C.M. ,2013)***.

Furthermore, resilience can be conceptualized as both proactive and reactive capacity. It includes both the ability to prevent or resist an event and the ability to return to an acceptable level of performance after being affected by an external event.

Grid 3: Assessment of the adaptability of the SPA to CCs						
Component	Factor	Criteria	A	MA	NA	Note
Adaptability	Human factor	Local know-how				
		Local agricultural practices				
		Awareness of CC				
		Participation				
	Physical factor	Efficiency				
		Sustainability				
		Profitability				
		Resistivity				
		Compatibility				
	Social Factor	Laws, regulations, standards				
		Traditions, social culture,				
	Natural factor	Available				
		Accessible				
		Conservable				
		Renewable				
	Financial factor	Diversification				
		Liquid assets				
		Financingguarantees				
	Economic factor	Wealth/Savings				
		Permanent income				
A: Adaptable ; MA:Moderately Adaptable; NA: Not Adaptable.			Total score = (1*A)+(0,5 *MA)+(0*NA)			

Grid 2: Assessment of the degree of exposure of the SPA to CC						
Component	Factor	Criteria	E	ME	NE	Note
Exposure	Human factor	Illiteracy/non-education				
		Healthinsecurity				
		Unemployment				
		Technological innovation				
	Physical factor	Urbanization				
		Degradation of cultivated land				
		Deterioration of material and equipment				
		Deconstruction of dwellings and depots				
		Livestock diseases				
	Social Factor	Social conflicts				
		Social and political instability				
	Natural factor	Geographic location				
		Frequenthazards				
		Degradation of resources				
		Pests (viruses, diseases,..)				
	Financial factor	Financial crises				
		Financial charges				
		Insurancecosts				
	Economic factor	Variation in prices (seed, raw materials,...)				
		Variation of the selling prices of the products				
E: highly exposed; ME : moderately exposed; NE : not exposed.			Total score = (1*E)+(0,5 *ME)+(0*NE)			

III. PRESENTATION OF THE FORMULA FOR MEASURING THE DEGREE OF VULNERABILITY OF AN SPA TO CC.

So, we can borrow the definition put forward above and apply it to the behavior of an agricultural production system towards the effects of climate change by stating that the resilience of an agricultural production system to the effects of climate change is the capacity of this system to behave proactively and reactively towards a climate event in order to mitigate its effects, avoid them or transform them into opportunities.

So, this last definition allowed us to write the following formula:

$$Degree\ of\ Resilience = \frac{Adaptation}{(Exposure\ + Sensitivity)}$$

with

$$Degree\ of\ vulnerability\ = 1 - \ degree\ of\ resilience$$

If the ratio of the degree of resilience is close to 0, this implies that the sum of the weights of the sensitivity and exposure of the agricultural production system is very high compared to the weight of the capacity to adapt. This means that the degree of resilience of this system is very low and consequently its degree of vulnerability to climate change is very high. On the contrary, if the resilience ratio is close to 1, we say that the system is able to face the potential effects of climate change and therefore the system is not vulnerable.

3-2- Probabilistic formula for assessing the vulnerability of APS to CC

To measure the intensity of the potential vulnerability of an agricultural production system to climate change, we propose a second alternative formula. The latter calculates the probable degree of vulnerability of an APS to CC according to two conditional probabilities. The probability of the system's capacity to adapt to climate change knowing its degree of exposure and the probability of the system's capacity to adapt to climate change knowing its degree of sensitivity. Then this second formula is written as follows:

$$\pi(RSPA)_{/CC} = (P(Adaptation\_CC)_{/(Sensitivity)}) \cap (P(Adaptation\_CC)_{/(Exposre)})$$

With

- $\pi(RSPA)_{/CC}$: The probable intensity of resilience of the agricultural production system to climate change..
- $(P(Adaptation\_CC)_{/(Sensitivity)}$: the conditional probability of the capacity of an agricultural production system to adapt to climate change knowing its degree of sensitivity.
- $P(Adaptation_CC)_{/(Exposure)})$The conditional probability of an agricultural production system's capacity to adapt to climate change given its degree of exposure.

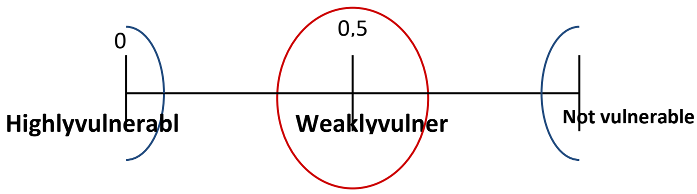
And since these two probabilities are independent, then we can write the said formula in this way:

$$\pi(RSPA)_{/CC} = (P(Adaptation\_CC)_{/(Sensitivity)}) \times (P(Adaptation\_CC)_{/(Exposure)})$$

With

$$Degree\ delaVulnerability = 1 - \pi_{RSPA/CC}$$

And since the result of this formula is always between 0 and 1, it can be interpreted as follows:



$$\begin{cases} If\ \pi_{\frac{RSPA}{CC}} iscloseto\ 0:\ thesystemis\ highlyvulnerabletoCC \\ If\ \pi_{RSPA/CC} iscloseto\ 0,5\ ;\ thesystemismoderatelyvulnerabletoCC \\ If\ \pi_{RSPA/CC} iscloseto\ 1\ :\ thesystemisadaptable\ (notvulnerable)\ toCC \end{cases}$$

IV. CONCLUSION

With this method we intend to contribute to the enrichment of the bank of existing methods related to the assessment of vulnerability to climate change. Thus, this method is the first specific method to assess the vulnerability of APS to the effects of CC. Moreover, this method allows to measure in a historical or preliminary way the intensity of the vulnerability of an agricultural production system to the effects of climate change, which will help, in advance, the clarification of the vision of the different actors in order to improve their interventions to strengthen the resilience of vulnerable systems and in particular the small farmers operating in countries where the climate is arid or semi-arid Thus, we plan to cooperate with national and international bodies operating in the field of vulnerability analysis of ecosystems to the effects of CC in order to develop this method through experimentation for other agricultural production systems in larger areas.

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