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XXIII SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS

VULNERABILITY AND ADAPTATION CAPACITY OF RIVER BASINS TO CLIMATE CHANGE: A Different Approach to Climate Vulnerability Index

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ABSTRACT - The impacts of climate change, such as floods, droughts, windstorms, and others are evident, and the surrounding issues, have been discussed all over around the world. However, the big challenge still on how to recover from those impacts, it means, the resilience of the systems. On the other hand, there is a consensus that the solution has to come from a long-term plan, which includes the improving of the assessment tools for climate vulnerability and reinforcement of the role of management institutions of climate change issues. Here, the Climate Vulnerability Index will be assessed, taking into account four main components; Exposure, Sensitivity, Adaptive Capacity, and Governance, the latter as a new component. The expected result shows that systems with a strong Governance component, become less vulnerable. This remark, as a scientific contribution, brings a new approach to Climate Vulnerability Index definition.

RESUMO - Os impactos da mudança climática, como inundações, secas, tempestades de vento e outros, são evidentes, e as questões a sua volta têm sido discutidas um pouco por todo o mundo. No entanto, o grande desafio continua sendo o processo de recuperação desses impactos, ou seja, a resiliência dos sistemas. Por outro lado, há um consenso de que a solução tem que vir de um plano de longo prazo, que passa pela melhoria das ferramentas de avaliação da vulnerabilidade climática e pelo fortalecimento do papel das instituições de gestão de assuntos relacionados a mudança climática. Neste trabalho, será avaliado o Índice de Vulnerabilidade Climática, tomando em consideração quatro componentes principais; Exposição, Sensibilidade, Capacidade Adaptativa e Governança, este último como uma nova componente. O resultado esperado mostra que sistemas que investem fortemente na componente de Governança, se tornam menos vulneráveis. Essa observação, como contribuição científica, traz uma nova abordagem para a definição do Índice de Vulnerabilidade Climática.

Keywords: Vulnerability; Adaptation; Governance.

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INTRODUCTION

Recently, the special report on global warming of 1.5 ^{0}C released by the Intergovernmental Panel on Climate Change (IPCC), showed that parties need to increase their efforts more than they expected to keep the temperature well below 2 ^{0}C (IPCC, 2018). They also show that different systems with the same risk exposure can have a different sensitivity according to their adaptive capacity. These statements reinforce the previous reports IPCC (2007), which showed that the impact of climate change can be more severe, mainly in the least developed countries. These means that even knowing the impacts of climate change on different levels, the frequency and magnitude of extreme events such as floods, droughts, windstorms, and others, still increase, and the recovery process still very complex (UNDP, 2007), requiring a huge structure of risk management (BANK, 2010).

As a solution, to better understand the systems affected by climate change, researchers have been using different approaches combining sensitivity, exposure, and adaptive capacity indicators to assess vulnerability in the context of adaptation to climate change (Majeed *et al.*, 2015). However, the question remains: how systems can adapt to climate change? To address this issue, we suggest a different approach to assess the impact of climate change, through the introduction of the new component (Governance) in climate vulnerability function. Therefore, the objective of this paper is to propose a method to build a Climate Vulnerability Index that explicitly considers the Governance component. Hereupon, in the following sections are introduced the necessary definitions.

Climate Vulnerability, Exposure, Sensitivity, and Adaptive Capacity

Based on the principle that these concepts have being defined by many researchers, for this study, by definition, climate vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change (IPCC, 2001). As a function, Climate Vulnerability (CV) can be expressed as $CV = f(E, S, AC)$, where E is the exposure, S is sensitivity, and AC the adaptive capacity (IPCC, 2001; Brooks *et al.*, 2005; Mendoza *et al.*, 2012; KC *et al.*, 2015). According to IPCC (2001), the Exposure is the nature and degree to which a system is exposed to significant climatic variations; Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli; and Adaptive Capacity, the flexibility of the system to adjust to climate change and cope with the consequences.

However, as an indicator, vulnerability is an aggregate measure which does not just depend on interactions between robustness of ecosystems and economic dynamism, but also, on response

capacity of the people and authorities (Bogardi, 2004). On the other hand, the suggested approaches support that there is no single definition of vulnerability that could cover all the contexts (Fussel, 2007). They support the idea that the concept is the consequence of a variety of policy contexts for different systems exposed to different hazards (Table 01). Thus, there are two largely independent dimensions to conceptualize vulnerability: (i) distinguishing internal from external factors and (ii) distinguishing socio-economic from biophysical factors.

Table 1 – Vulnerability conceptualization

	Domain	
Sphere	Socioeconomic	Biophysical
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea-level change

Source: Adapted from Fussel (2007).

Governance and Vulnerability

By definition, Governance is the means that power is exercised to manage the socio-economic resources of a country (Jubeh and Mimi, 2012). Therefore, Governance could be a political issue or a simple act of organization with abilities to pursuit for solutions. On the other hand, vulnerability is composed of a suite of environmental, socio-economic, and institutional or political variables. However, the factors which make vulnerable a rural community in developing countries, will not be the same which make vulnerable industrial countries. The difference remains on the efforts of the quality of infrastructures and the efficacy of the long-term planning, including Governance (Brooks *et al.*, 2005).

Thereby, to reinforce the role of management institutions (Governance), as a function, we advocate that climate vulnerability should take into account four main components: Exposure (E), Sensitivity (S), Adaptive Capacity (AC) and Governance (G): $CV = f(E, S, AC, G)$. This approach is also supported by Luers *et al.* (2003); Dasgupta *et al.* (2006); Oculi and Stephenson (2018); Weiler

et al. (2018). However, in these studies, governance is considered implicitly by means of Governance indicators as part of the Adaptive Capacity component.

Therefore, this proposal aims to introduce a different approach to assess climate vulnerability and assist decision-makers in identifying the needs in terms of more efforts to cope with the impacts of climate change.

BUILDING THE CLIMATE VARIABILITY INDEX

There are two more concepts which are considered to build Climate Variability Index (CVI), index and indicators. The indexes are an empirical tool used to quantify something which cannot be measured directly (e.g., how water-stressed a household is) or to measure changes (e.g., the impacts of economic growth). They provide information in an indirect way, giving a quantity or state that allows for comparison over time. However, some issues have to be addressed to construct any index: (1) choice of components, (2) sources of data, (3) choice of formula, and (4) choice of the base period (Sullivan, 2002; Mazziotta and Pareto, 2013). On the other hand, an indicator is a variable which indicates the magnitude (e.g., mean seasonal temperature) or variability (e.g., standard deviation seasonal rainfall) of a parameter, or the statistical relationship among variables (Anandhi and Kannan, 2018).

Therefore, knowing that vulnerability is a theoretical phenomenon that cannot be measured directly, here, it will be built according to the main goal, taking into account the four components: Exposure, Sensitivity, Adaptive Capacity, and Governance. To do that, are proposed the econometric and the indicator methods as suggested by different researchers, as the most common tools to assess vulnerability to climate change. The econometric method assesses the level of vulnerability in different social groups using socioeconomic survey data at household-level. On the other hand, the indicator method assesses the levels of vulnerability based on the combination of some selected indicators from the set of potential indicators (Hinkel, 2011; Maiti *et al.*, 2017). Thus, based on the same approach of the Human Development Index and Water Poverty Index Hahn; Riederer and Foster (2009), will be used the indicator method following the steps are given below:

I. Selection of Indicators

The indicators should be selected based on knowledge over elements which contribute to vulnerability such as exposure, sensitivity and adaptive capacity (Vincent, 2004; UNITED

NATIONS, 2007). Exposure measures how much the system is close and affected by extreme events, and Sensitivity, is the magnitude of the impact of the extreme events (Krishnamurthy *et al.*, 2014; Koutroulis *et al.*, 2018). The adaptive capacity component is the existence and the quality of the resilient infrastructures to extreme events. Therefore, focus on adjustments and institutional capacity (Marília *et al.*, 2018). Governance is the existing structure of institution management, on the affected area, measured by the number of existent organizations or policies approved and ongoing (Krishnamurthy *et al.*, 2014; Koutroulis *et al.*, 2018).

Finally, based on qualitative and quantitative criteria, to determinate the best indicators, we suggest the use of Analytic Hierarchy Process, a multi-criteria analysis based on a par comparison method which enables all combination of the criteria and indicators to choose the best alternatives (Saaty, 1989; Saaty, 1990).

II. Value Normalization

Indicators come in different scales or units. Therefore, they may be normalized to put on the dimensionless way and allow comparisons between them, avoiding disproportionalities when multiple indicators are combined (Anandhi and Kannan, 2018). First, it is very important to know the relationship between indicator and vulnerability index to ensure that the indicator values are always in positive correlation with vulnerability. Thus, if the indicator increase and the vulnerability also increase Pandey and Jha, (2012), is suggested the equation (01) (Kumar *et al.*, 2017). But, if the indicator increase and vulnerability decrease, should use equation (02) (Pandey *et al.*, 2017).

$$X = \frac{X_v - X_{min}}{X_{max} - X_{min}} \quad (01)$$

$$Y = \frac{X_{max} - X_v}{X_{max} - X_{min}} \quad (02)$$

where X_v is the value to be normalized, X_{min} and X_{max} are the minima and maximum values of the indicator on the impact area, X and Y are the normalized values.

Once normalized, the values of each component are averaged using equation (03).

$$C = \frac{\left(\sum_{i=1}^{n_I} W_{Ii}.X_i + \sum_{i=1}^{n_I} W_{Ii}.Y_i\right)}{\sum_{i=1}^{n_I} W_{Ii}} \quad (03)$$

where, C is each component value (E, S, AC or G), X_i and Y_i are indicators value of the i^{th} indicator in the respective component, W_{Ii} is the weight per indicator, and n_I is the number of indicators per component.

III. Weight Determination

Many researchers give equal importance to all indicators/components to have the overall vulnerability index (Sullivan, 2002; Mazziotta and Pareto, 2013; Pandey *et al.*, 2017). Others, give specific weight for each indicator/component, based on different methods (Iyengar and Sudarshan, 1982; Pandey and Jha, 2012; Mazziotta and Pareto, 2013). However, to ensure that the variation of one indicator would not incorrectly dominate the contribution of the rest of the indicators is suggest the Iyengar and Sudarshan's Method (equation 04), which is based on uncertainty aggregate on variance. Hence, the greater the variance is, the smaller will be the weight (Iyengar and Sudarshan, 1982).

$$W_i = \frac{NC}{\sqrt{var(X_i)}} \; ; \left(0 < W_i < 1 \;\; and \sum_{i=1}^{n} W_i = 1\right) \quad (04)$$

where W_i is the weight, X_i is the normalized score, n (i = 1, 2, …, n) indicators of vulnerability, and NC is a normalizing constant, determined by (equation 05):

$$NC = \left[\sum_{i=1}^{i=n} \frac{1}{\sqrt{var(X_i)}}\right]^{-1} \quad (05)$$

IV. Climate Vulnerability Index (CVI)

The overall index (CVI) can be determined by (equation 06):

$$CVI = \frac{W_E.E + W_S.S + W_{AC}.AC + W_G.G}{W_E + W_S + W_{AC} + W_G} \quad (06)$$

where, W_E, W_S, W_{AC}, and W_G are the weights determined for each major component, *E*, *S*, *AC*, and *G* are the values of each component.

The result value of this index (CVI), will give a state of the system such as, very low (0.0 – 0.3), low (0.0 – 0.4), little low (0.2 – 0.5), medium (0.3 – 0.7), little high (0.5 – 0.8), high (0.6 – 1.0), and very high (0.7 – 1.0), based on Fuzzy logic concept (Dasgupta *et al.*, 2006; Eakin and Bojórquez-Tapia, 2008; Krishnamurthy *et al.*, 2014).

FINAL CONSIDERATIONS

This work aims to suggest a different approach to assess the climate vulnerability and provide a strong tool to assist decision-makers on identification of the needs to cope with the impacts of climate change. According to previous research, to cope with the impacts of climate change, systems need an improvement in adaptive capacity (Pandey *et al.*, 2017). Perhaps, these conclusions might be related to different factors such as governance performance Jubeh and Mimi, (2012), which is likely to have a strong influence on vulnerability. However, there are more components such as Exposure, Sensitivity, and Governance which also defines the level of vulnerability. Therefore, the most exposed system is not necessarily the most vulnerable as suggested by logic taking into account the average occurrence of extreme events, when we are assuming that the most exposed systems should be the most vulnerable. The justification could be a less effort on adaptive capacity, but this does not mean that they are not working on adaptive capacity (infrastructure), it means that they are not working on governance (capacity building).

Hence, if results show a high score in governance component, more effort is needed in capacity building to coping to extreme events, but not exactly less effort in adaptive capacity, likely related to resilient infrastructures. Therefore, systems with less adaptive capacity might be highly vulnerable.

According to above mentioned, adaptive capacity component (Governance), is strongly related to climate vulnerability index. Thus, improving in adaptive capacity component introducing additional indicators related to governance, which involves approved and implemented specific policy, could reduce the climate vulnerability forcing a better organization of the institution to cope the impact of climate change. On the other hand, the introduction of governance component gives more sensitive to the climate vulnerability assessment tool and provide additional information to decision-makers in addressing the issues about climate change resilience. Thus, we could conclude

that governance is likely becoming the most important factor in adaptive capacity, mainly to provide more information about which part of adaptive capacity needs more improvement.

However, there is a slight inconvenience on this process related to subjectivity on some steps, due to human judgment. But this does not invalidate the contribution of this proposal to climate change issues, mainly to the Sustainable Development Goals (SDG), simplifying the method of evaluation climate vulnerability and became easily applied by any system or decision-makers.

In conclusion, taking into account the main goals, the following results are expected:

- Systems with less adaptive capacity might be highly vulnerable (infrastructure and capacity building).
- Governance is likely the most important factor on climate vulnerability index.

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