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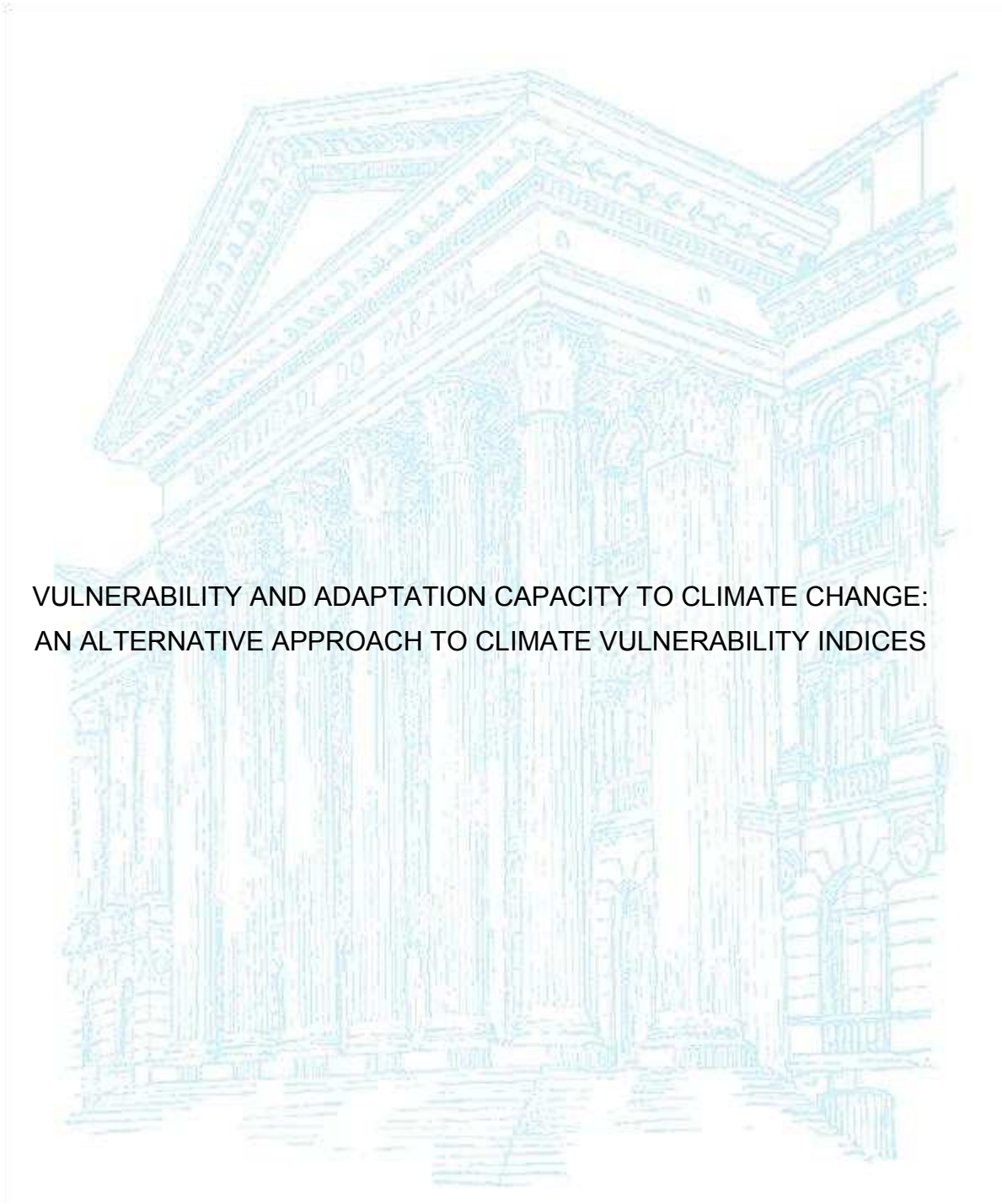

VULNERABILITY AND ADAPTATION CAPACITY TO CLIMATE CHANGE: AN ALTERNATIVE APPROACH TO CLIMATE VULNERABILITY INDICES

CURITIBA

2021

LUÍS MIGUEL SAMUSSONE TOMÁS BUCHIR

VULNERABILITY AND ADAPTATION CAPACITY TO CLIMATE CHANGE: AN ALTERNATIVE APPROACH TO CLIMATE VULNERABILITY INDICES

Tese apresentada ao Programa de Pós-Graduação em Engenharia de Recursos Hídricos e Ambiental, Setor de Tecnologia, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Recursos Hídricos e Ambiental.

Orientador: Prof. Dr. Daniel Henrique Marco Detzel
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APPROVAL MINUTE

The Examining Board is designated by the Faculty of the Graduate Program of the Federal University of Paraná in ENGENHARIA DE RECURSOS HÍDRICOS E AMBIENTAL where invited to argue the DISSERTATION of PHILOSOPHY DOCTOR by **LUIS MIGUEL SAMUSSONE TOMAS BUCHIR** , entitled: **Vulnerability and Adaptation Capacity to Climate Change: An Alternative Approach to Climate Vulnerability Indices**, under the supervision of Dr. DANIEL HENRIQUE MARCO DETZEL, which and after assessment of the candidate and the work, the Examining Board decided for the APPROVAL in the present rite.

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I dedicate this work to my lovely wife and son Joelma Nilza dos Santos Leão Buchir and Yuki dos Santos Tomás Buchir, my younger brother Orlando da Consolação Stanley Buchir and my parents, Tomás Stanley Buchir and Cecília da Consolação de Samussone Chilenge

(*both in memory*).

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Last but not the least, to one of the most precious riches of my life, my true friends, who directly or indirectly contributed to this finale, a special thanks for everything.

“O que verão provavelmente alguns gostarão e outros não,
mas ninguém dirá que já viu um igual”.

(Oscar Niemeyer)

RESUMO

De acordo com diversos relatórios de instituições internacionais como o IPCC, PNUD e o Banco Mundial, nos próximos anos, os impactos das mudanças climáticas continuarão a afectar o planeta e principalmente os Países Menos Desenvolvidos (LDC), devido a sua condição sócio-económica e o seu arranjo institucional. Por outro lado, regista-se um aumento da frequência e a magnitude dos impactos das mudanças climáticas, como inundações, secas, ciclones e outros, o que significa que os países menos resilientes, definidos pelo Índice de Vulnerabilidade Climática, serão os mais vulneráveis. No entanto, embora todas essas questões já sejam de conhecimento comum, os LDC's ainda são incapazes de lidar com o impacto de eventos extremos. Pois, ainda agem de forma reactiva. Como consequência dessas preocupações, a questão que se levanta é: Que parte da Capacidade Adaptativa precisa de mais investimento para lidar com os eventos climáticos extremos? Para abordar está questão e como contribuições no processo de avaliação do impacto das mudanças climáticas, este trabalho sugere o uso de uma ferramenta alternativa para avaliar a vulnerabilidade climática, considerando explicitamente a Governança como a quarta componente na função de vulnerabilidade climática agora definida por *CVI = f(E, S, AC, G)*. No final, as evidências mostram que com 04 componentes a ferramenta fica mais sensível, ao invés de 03 componentes como de costume. Em conclusão, como forma de atingir o estado de resiliência climática, a Governança é aceite como uma forte componente na definição do Índice de Vulnerabilidade Climática.

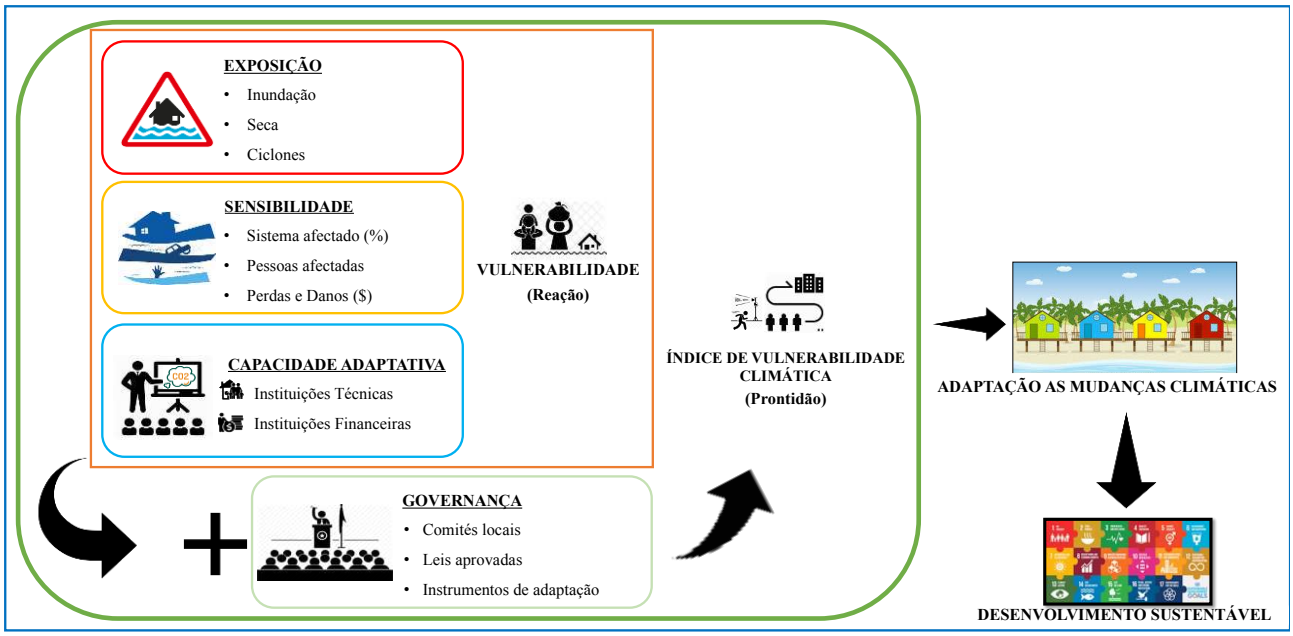
Palavras-chave: Vulnerabilidade. Adaptação. Governança.

ABSTRACT

According to many reports from international institutions such as IPCC, UNDP, and the World Bank, in the coming years, the impacts of climate change will continue affecting the planet, and mainly the Least Developed Countries (LDC) due to his social-economic condition and institutional arrangement. On the other hand, the frequency and magnitude of the impacts of climate change, such as floods, droughts, windstorms, and others, are still increase, meaning that the less resilient countries, defined by the climate vulnerability index, will be the most vulnerable. However, even though all these issues are already common knowledge, the LDCs are still unable to cope with the impact of extreme events. They are still reactive. As a consequence of these concerns, the main question is: Which part of Adaptive Capacity needs more effort to deal with extreme weather events? To address this issue and as a contributions into the process of climate change impact assessment, this work aims to suggest an alternative tool to assess climatic vulnerability, explicitly considering the Governance as a fourth component in the climate vulnerability function now defined by *CVI = f(E, S, AC, G)*. In the end, the evidence shows that with 04 components, the tool becomes more sensitive, rather than 03 components as usual. In conclusion, as a way to achieve a state of climate resilience, Governance is accepted as a strong component in the Climate Vulnerability Index definition.

Keywords: Vulnerability. Adaptation. Governance.

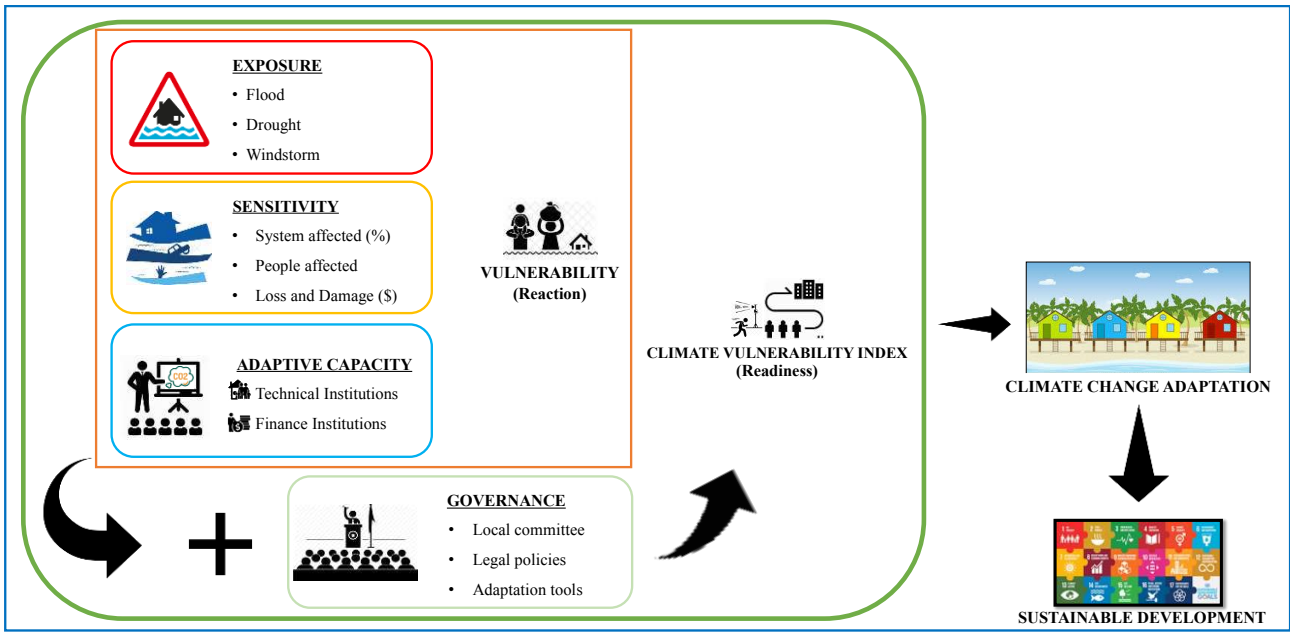
RESUMO GRÁFICO



Destaques

- Vulnerabilidade e Governança ou apenas Prontidão versus Desenvolvimento Sustentável.
- O impacto da componente Governança na adaptação à vulnerabilidade climática.
- O papel dos tomadores de decisão na avaliação do impacto das mudanças climáticas.
- Uma abordagem alternativa da ferramenta de avaliação de vulnerabilidade climática.

GRAPHIC ABSTRACT



Highlights

- Vulnerability and Governance or just Readiness versus Sustainable Development.
- The impact of Governance component on climate vulnerability adaptation.
- The role of decision-makers in assessing the impact of climate change.
- An alternative approach of climate vulnerability assessment tool.

LIST OF PAPERS

PUBLISHED

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

Luís Miguel Samussone Tomás Buchir, Miriam Rita Moro Mine, Regina Tiemy Kishi, Marcelo Rodrigues Bessa, Cristovão Vicente Scapulatempo Fernandes, Daniel Henrique Marco Detzel

Congress of Brazilian Association of Water Resources, July, 2019.

PAPER II - ARE THERE RIGHT INDICATORS FOR CLIMATE VULNERABILITY?

Luís Miguel Samussone Tomás Buchir, Miriam Rita Moro Mine, Regina Tiemy Kishi, Marcelo Rodrigues Bessa, Cristovão Vicente Scapulatempo Fernandes, Daniel Henrique Marco Detzel

Congress of Brazilian Association of Water Resources, July, 2019.

PAPER III - DEALING WITH SUBJECTIVITY IN WEIGHT DETERMINATION: CLIMATE VULNERABILITY INDICATORS

Luís Miguel Samussone Tomás Buchir, Miriam Rita Moro Mine, Regina Tiemy Kishi, Marcelo Rodrigues Bessa, Cristovão Vicente Scapulatempo Fernandes, Daniel Henrique Marco Detzel

Congress of Brazilian Association of Water Resources, July, 2019.

SUBMITED

PAPER IV – AN ALTERNATIVE APPROACH TO CLIMATE VULNERABILITY INDICES

Luís Miguel Samussone Tomás Buchir, Miriam Rita Moro Mine, Carolina Natel de Moura, Daniel Henrique Marco Detzel

SUBMITED

PAPER V - THE ROLE OF THE GOVERNANCE ON THE CLIMATE VULNERABILITY INDEX DEFINITION

Luís Miguel Samussone Tomás Buchir, Miriam Rita Moro Mine, Daniel Henrique Marco Detzel

TO BE SUBMITED

PAPER VI – CLIMATE CHANGE MAINSTREAMING INTO LOCAL PLANNING

Luís Miguel Samussone Tomás Buchir, Eduardo Muchamisse, Francisco Sambo, Miriam Rita Moro Mine, Daniel Henrique Marco Detzel

ACRONYMS

CAPES	Coordination of Higher-Level Personnel
CARE	Cooperative for Assistance and Relief Everywhere
CEPED/PR	University Center for Disaster Studies and Research
COP	Conference of the Parties
GIIMC	Inter-Institutional Group on Climate Change
LAP	Local Adaptation Plan
MITADER	Ministry of Land, Environment and Rural Development
NAP	National Adaptation Plan
QUALIS	Classification of periodicals
SABSTA	Subsidiary Body for Scientific and Technological Advice
SEMA	State Secretariat for the Environment and Water Resources

SIGLAS

ABRH	Brazilian Association of Water Resources
AC	Adaptive Capacity
AHP	Analytic Hierarchy Process
AR	IPCC Assessment Report
C	Component value
CI	Consistency Index
CR	Consistency
CV	Climate Vulnerability
CVCA	Climate Vulnerability and Capacity Analysis
CVI	Climate Vulnerability Index
DHS	Department of Hydraulics and Sanitation
E	Exposure
EM-DAT	Emergency Events Database
ENAMMC	National Strategy for Adaptation and Mitigation to Climate Change
FAR	First IPCC Assessment Report
G	Governance
GCM	Global Climate Model
GHG	Green House Gases
IBGE	Brazilian Institute of Geography and Statistics
IF	Impact Factor
INAM	National Institute of Meteorology
INGC	National Institute for Disaster Management
IPCC	Intergovernmental Panel on Climate Change
Km	Kilometre
LDC	Least Developing Countries
mm	Millimetre

MTA	Ministry of Land and Environment
N	Number
NC	normalizing constant
ND-GAIN	Notre Dame-Global Adaptation Index
PPGERHA	Program in Water and Environmental Resources
PR	Paraná
$R_{ead}V$	Readiness Value
RI	Tabled Consistency Index
S	Sensitivity
SAR	Second IPCC Assessment Report
SBI	Subsidiary Body for Implementation
TAR	Third IPCC Assessment Report
ToC	Theory of Change
UCL	Catholic University of Louvain
UFPR	Federal University of Paraná
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
Var	Variance
W	Weight
X	normalized value

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CHAPTER 1

GENERAL INTRODUCTION, MAIN GOAL, AND METHODS

HIGHLIGHTS

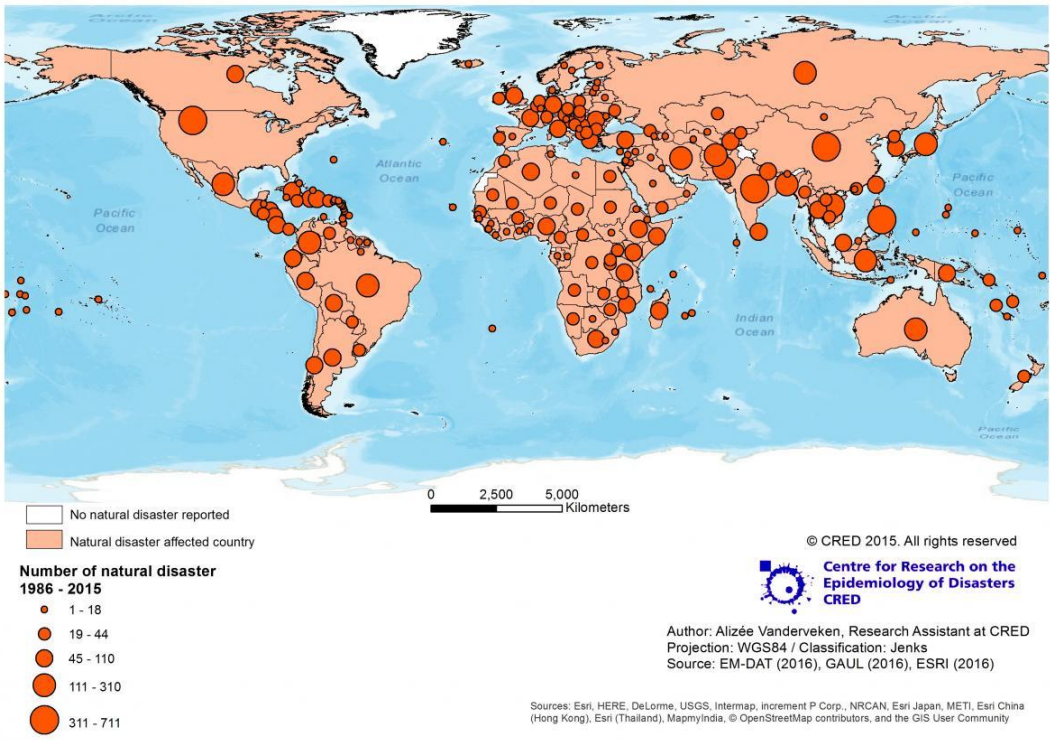
This chapter will present the introductory aspects that guided the elaboration of this thesis.

VULNERABILITY AND ADAPTATION CAPACITY TO CLIMATE CHANGE:
An Alternative Approach to Climate Vulnerability Indices

GENERAL INTRODUCTION

Research has shown that, although there is uncertainty about when and how climate change can impact systems and, consequently, the main sectors of production, there is no doubt about the risk impact (Schellnhuber et al., 2006). Therefore, climate change must be addressed as a cross-cutting issue, with direct implications for the development sectors (Vincent and Colenbrander, 2018). Mainstreaming climate issues into different planning sectors should be a priority for governments to adapt to climate change and become resilient. However, climate change is still seen as a problem. Because of that, countries have being prioritized disaster risk reduction actions rather than adapting to them (Aguiar et al., 2018; Lyles et al., 2018; and Woodruff et al., 2018). This shows that countries need to improve their abilities to deal with these challenges (Figure 01), understanding their limits and barriers, fill in the gaps, and then seek solutions that lead them to climate resilience.

Figure 01 - Worldwide coverage of the number of natural disasters



Source: Adapted from EM-DAT (2016)

On the other hand, due to these uncertain climate change impacts on social-economic issues, the decision-makers are forced to increase their demand for long-term strategies which resulted in most of the cases, on a specific group dedicated to managing the unpredictable effect of climate change (Doherty et al., 2016; and Vij et al., 2017).

Some researchers came up with the approach that countries have working in an ad hoc manner, in response to international positions. It seems that they have acted with no solid basis for scientific, economic, and political assessment. Therefore, they suggest that governments should approach climate change in a pragmatic way. They have to strengthen strategic capacity in climate change, integrating climate issues on decision-making, and showing institutional leadership (Governance) in these issues (Meadowcroft, 2009; Sarkodie and Strezov, 2019).

Therefore, according to Termeer et al. (2017), adaptation to climate change is not a matter of technical issues; it is also about governance. Because adaptation, in its true sense, requires adjustment and positive coordination actions between the actors (Huitema et al., 2016).

However, according to Aguiar et al., 2018; and Morgan et al. (2019), there is no classic way to plan climate change because there are multiple interests and motivations around. The solutions have to come from long-term planning (Wilby and Harris, 2006; Kundzewicz et al., 2018). Thus, the questions are: even with all this knowledge and efforts, why the recovery process from the impacts of climate change still uncertain for the Parties? How complex are the existent tools?

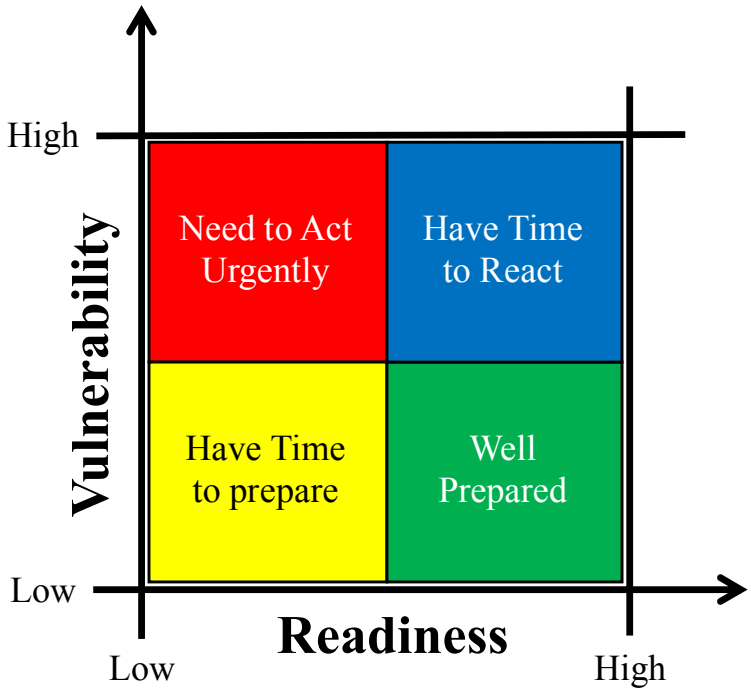
Therefore, due to these uncertainty scenarios, tools for climate vulnerability assessment, most based on indicators, have been developed to provide a better understanding of the facts. However, most of these models do not incorporate governance components, assuming that the existence of a public agency of environment will regulate all, which is why the World Bank committed itself to evaluated country policies and institutional capacity on environmental governance (Dasgupta et al., 2006). Therefore, this work introduces an alternative approach to climate vulnerability assessment, proposing an explicit consideration of Governance in the adaptation capacity issues to reinforce the role of management institutions to cope with extreme weather events.

Vulnerability and Governance

Vulnerability and Governance, or just readiness versus sustainable development, is one of the most interesting discussions among different organizations suggesting

vulnerability assessment as a tool to support decision-makers in the development planning process (Hussain, 2008). These concerns about the role of governance in climate change have led to different levels of society to seek improvements in the process of integrating climate change into development plans and strategies. In a similar context, Notre Dame University has developed a very useful tool (Figure 02), called The Notre Dame-Global Adaptation Index (ND-GAIN). It is a free open source tool that combines vulnerability and readiness to come up with a very stimulating value that can lead decision-makers to deal with climate change (Chen et al., 2015).

Figure 02 - Combination of vulnerability and readiness to obtain the current status of the system in terms of reacting to the negative impact of climate change



Source: Adapted from Chen et al., (2015) - https://gain.nd.edu/our-work/country-index/methodology/

In this context, analysts suggested that one of the main issues to be addressed to achieve this goal is the institutionalization of climate change, followed by synergistic actions between the government as a leader, the academy, and the private sector. However, to identify and align their priority actions to development needs, countries need specific tools (Drexhage, 2007; Sarkodie and Strezov, 2019).

On the other hand, in addition to readiness, analysts also discuss the issue of trust in decision-makers. Sandoval and Voss (2016), in their research, discuss how governments lead the post-disaster recovery process. Bringing the case of Chile, which resembles a top-down governance process, the weakness of communication, and coordination between different levels, were the main factors for the failure. The authors conclude by suggesting a more participatory approach, which allows a multiplicity of authors through a bottom-up process, highlighting the issue of leadership's commitment to its promises (Sandoval and Voss, 2016).

Some countries, such as the southern Africans, have been prioritizing the bottom-up process through rural development as a key to sustainable development. They have been improving their land use plans through the local adaptation plans, prioritize issues about community-based adaptation (Brown et al., 2013). Therefore, they develop mechanisms for sharing information that allows collaboration between different actors, which include civil society, private sector, and government at all levels. These mechanisms took us to learn from those countries in planning for adaptation strategies.

Thereby, responding in an ad-hoc manner to emergency issues cannot be a recurring practice. The governance process must bring a system and structure to support decision making. However, for decision making to be truly effective, it must also be legally binding and supported by a strong institutional arrangement, with sufficient capacity building and reliable sources of information (Edwards et al., 2017).

Vulnerability

Vulnerability is a multi-dimensional term, used in different contexts such as climate change, disaster risk reduction, economy, epidemic disease, social and poverty-relate issues. Therefore, it is frequently related to civil society in terms of socio-economic, health, political, and environmental development issues to describe the existing condition of the system. Thereby, there are many tools to assess vulnerability, such as the Human Development Index (HDI), Climate Vulnerability Index (CVI), Environmental Vulnerability Index (EnVI), and Economic Vulnerability Index (EconVI), implemented by different institutions to address specific needs. However, even know that vulnerability represents the system condition in terms of the capacity to disaster risk reduction, there is no common sense about the term definition (Box 1), due to the natural dynamic of environment and climate uncertainty (Hussain, 2008).

Box 1: See below some common views to understand vulnerability

- "… represents the degree of damage to which a system is susceptible, due to exposure to the hazard …"
- "… is something that shows defenselessness, which is, 'fragility' or 'susceptibility' to damage …"
- "… is the capacity to cope with the future event …"
- "… is the threat or general state of emergency preparedness to which a community is exposed …"
- "… is the degree to which different classes in society absorb hazard and, consequently, how they recover …"
- "… is the potential for loss due to threats hazards …"
- "… is the ability or inability of individuals or social groupings to respond, recover, or adapt to external events …"
- "… is the degree of preparedness to damage originating from external forces …"
- "… is the capacity to anticipate, cope with, resist, and recover from the impact of a hazard…"
- "… is a condition, which determines the probability and degree of damage due to the impact of a determinate hazard …"
- "… is the potential to lose and damages, related to the capacity to cope with a hazard and recover from its impact …"
- "… is the degree of contingencies to cope with extreme events without huge loss or damage…"

However, the factors which make vulnerable a rural community in developing countries will not be the same, which makes vulnerable, industrial countries. The difference remains on the efforts of the quality of infrastructures, human resources, and the efficacy of long-term planning, which includes Governance (Brooks et al., 2005).

Governance

Governance is a multifaceted term, which means different things depending on the context (Hussain, 2008). The term governance represents a range of processes that involve governance in its true sense. Therefore, it is a process that requires the creation of policies and institutions that give stability to communities (Huitema et al., 2016). Thus, it is clear that governance is not synonymous with the government. The Government refers to a functional body that designs and implements policies, while governance is the system of rules that involves everyone's interest in a state (Hussain, 2008).

In the context of climate adaptation, governance represents the effort of various actors in society, nationally and internationally, in search of joint solutions to circumvent the negative impacts of climate change (Huitema et al., 2016). Therefore, a scenario which includes the formal and informal decision-making undertaken by different actors at different levels, including civil society and the private sector (Keskitalo, 2009).

The issue of governance in climate change gained more space on the global political agenda, with the adoption of the 2015 Paris Agreement, which established a global goal leading countries to a joint effort (Persson, 2019). On the other hand, globalization has powerful influences on the governance process of the least developed countries, which affects the definition of the interests of local communities (Keskitalo, 2009). However, the multilevel complexity of climate change requires governance systems capable of managing conflicts of interest at different levels (Di Gregorio et al., 2019). For this reason, since the first World Bank reports on governance in the 1990s, the concept of governance has been continuously redefined (Box 2). However, it is important to mention that the governance indicators used by different organizations change according to their particular interests.

Box 2: See below some common views to understand governance

- "… is the method or system by which particular society is governed …"
- "… is the description of the process of governing …"
- "… are standards by which public power can be exercised in a given social context …"
- "… is a system of rules that are approved by a majority …"

- "… is the way that countries exercised power to manage their socioeconomic resources …"
- "… is orientation …"
- "… is a formal or informal arrangement in which a group of people or institutions agree and consider it to be of interest …"
- "… is the economic, political, and administrative authority exercise to manage a country's affairs at all levels …"
- "… is the process of training people and strengthening public institutions to build climate resilience …"

Therefore, by definition, Governance is the means that power is exercised to manage the socio-economic resources of a country (Jubeh and Mimi, 2012). It aims to encourage and improve the institutional capacity of the government, as a way of strengthening coordination between partners, at different levels of society (Meadowcroft, 2009). Thereby, Governance could be a political issue or a simple act of organization with the ability to pursuit solutions. On the other hand, vulnerability is a set of environmental, socio-economic, institutional, or political variables. Therefore, governance is the primary condition for vulnerability reduction, meaning that governance and vulnerability are interconnected phenomena (Hussain, 2008).

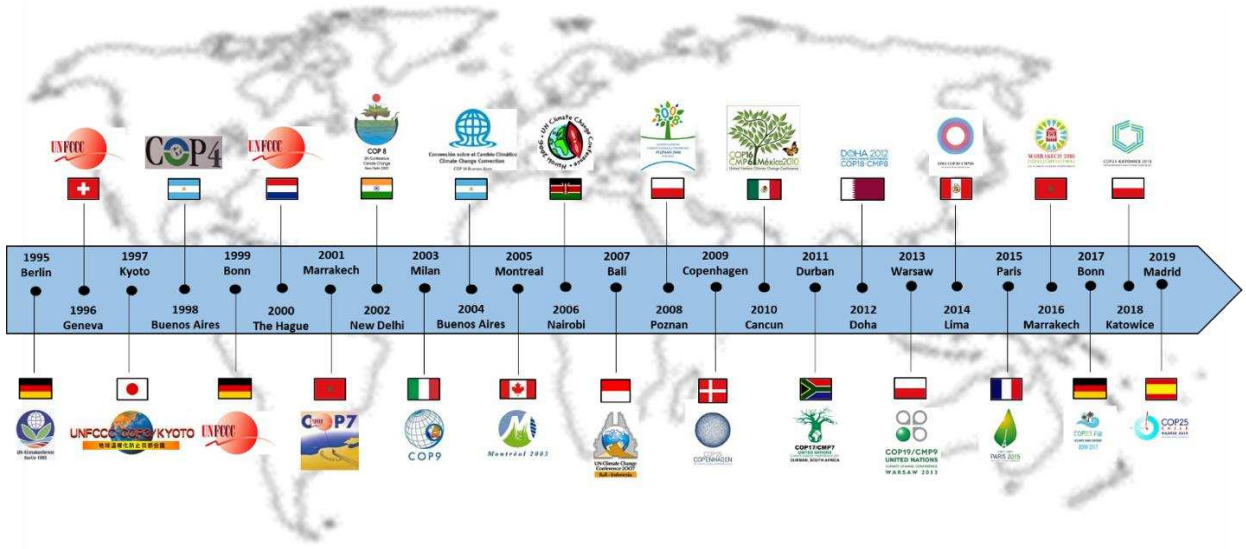
The Conference of Parties (COP)

The Conference of the Parties (COP), with 197 representatives of the parties, is a participatory, high-level government meeting established by the United Nations Framework Convention on Climate Change (UNFCCC), a United Nations body responsible for assessing issues on climate change through scientific support from the Intergovernmental Panel on Climate Change (IPCC). The IPCC is a United Nations body which provides scientific evidence and specific tools, to support the policymakers and decision-makers, with the current knowledge state about climate change (IPCC, 1989, 2001, 2007, 2014, 2018).

These governance meetings (Figure 03), where scientists and decision-makers come together to discuss improvements and consolidate new approaches to climate change, came to align climate strategies. There are two main strategies to be considered. One is

the Kyoto Protocol, adopted at the Conference of Parties 03 (COP3), which was unsuccessful, by establishing, through a precise timetable, legally binding targets for all parties. Second is the Paris Agreement, adopted at Conference of Parties 21 (COP21), bring a different approach of climate international governance model, which seeks to accountability, and transparency to achieve the goal of keeping warming well below 2°C or efforts to limit it to 1.5°C, through the Nationally Determined Contributions (NDC) (Worker, 2016).

Figure 03 – Conference of the Parties since the 1995



Source: The author (2021)

Thus, 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), Jubeh and Mimi (2012), Pandey et al. (2017), Oculi and Stephenson (2018), and Weiler et al. (2018), in their studies where they conclude that Vulnerability is influenced by climate change, and government performance, through its adaptation policies and strategies. They add saying that both the policy and academic communities should work together to apply the approved tools and be able to receive external support, reinforcing the idea of synergies, and the need to improve governance issues.

Therefore, the use of composite indicators allows the systematization of information, and provide the necessary information of adaptation to become a resilient system. Here, it is important to mention that the use of indicators as a policy tool became useful since the 1920s, and the climate vulnerability index as a function, was first presented in 2002 by

Sullivan (2002), years later after Albinet (1970) and Margat (1975), first presented the concept of vulnerability. Since then, many researchers have been used this function as a way to evaluate the level of vulnerability of the communities (Luers et al., 2003; Dasgupta et al., 2006; Jubeh and Mimi, 2012; Pandey et al., 2017; Oculi and Stephenson, 2018; Weiler et al., 2018). These led the IPCC to propose a framework to assess climate vulnerability (IPCC, 2007a).

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), Exposure is the 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. For more information, please find details in chapter 2 (Buchir et al., 2019a).

However, as an indicator, vulnerability is an aggregate measure that does not just depend on interactions between the robustness of ecosystems and economic dynamism, but also, on the 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 01 – 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)

Indices and Indicators

The indices could be defined as a statistical concept to quantify something which cannot be measured directly or to measure changes (Mazziotta and Pareto, 2013). On the other hand, an indicator can be defined as any variable that indicates the magnitude, variability or statistical relationship between variables. Therefore, a direct measure used to operationalize the indices (Anandhi and Kannan, 2018). According to Sullivan (2002), there are hundreds of global indicators around the world, selected by too many ways and put forward by many institutions. This selection could be by a deductive framework, theoretically or physical relationship-based, an inductive framework based on a statistic or based on judgment value, which is a normative framework, besides their combination (Anandhi and Kannan, 2018). Furthermore, indicators could be tangible, which include physical existence that can be express in monetary values, or intangible, which referring to attitudes and believes of people that influence their actions, such as risk perception (Marília et al., 2018).

However, according to some researchers, most indices have substantial weaknesses in methodology and conceptual framework, which include lack of clarity in their conception, sensitivity in aggregating other methods, limited quality of available data, and difficult adjustment to current policies (Eakin and Bojórquez-Tapia, 2008).

Climate Vulnerability Index

Climate vulnerability index (CVI) is a measure that provides the state of the system, allowing comparison over time. However, to construct an index, some issues have to be addressed: (1) choice of components, (2) sources of data, (3) choice of formula, and (4) choice of the base period, beside of many others (Sullivan, 2002; Mazziotta and Pareto,

2013). Therefore, these are some concepts to be able to prepare a climate report that supports decision-makers.

Climate Change Reports

Concerns about climate change have been discussing for years in the last decades by the governments (SBA - Subsidiary Body for Implementation), including the scientific community (SABSTA - Subsidiary Body for Scientific and Technological Advice), as a task force to cope with the adversities of his impacts. These efforts became better with the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC is a United Nations body which assesses the climate change issues and supports the policymakers and decision-makers, with scientific evidence and specific tool, providing the current state of knowledge about climate change (IPCC, 1989, 2001, 2007, 2014, 2018).

Since then, six main reports were already produced (Figure 04), where we had the First IPCC Assessment Report (FAR) in 1990, focused on international cooperation to cope with the challenges of climate change. Five years later (1995), the Second Assessment Report (SAR), was released as scientific support to the governments on his discussions about an international agreement which commits Parties to set internationally binding emission reduction targets — the Kyoto Protocol in 1997.

Figure 04 – The Intergovernmental Panel on Climate Change (IPCC) Report

Source: The author (2021)

In 2001, due to the negative increase of the impact in climate change, the Third Assessment Report (TAR) was finished with the intention to work more on the needs of adaptation. However, those efforts were not enough, as presented in 2007 through the Fourth Assessment Report (AR4), bring up the attention on limiting global warming in 2^0C. This concern became the focus of the Parties, and in 2014, the IPCC release the Fifth Assessment Report (AR5) as scientific support to bring these discussions in the Paris Agreement — an international treaty to keep the global temperature well below 2^0C above pre-industrial levels and pursue efforts to limit the temperature increase in 1.5^0C. Currently, the IPCC is on his Sixth Assessment Report, and they already provided the first Special Report (SR15), focus on issues about the 1.5^0C of Global Warming.

Therefore, it is notable the some commitment on these issues, and according to those reports, one of the primary effects of climate change is on the water cycle, which has a direct effect on all if we take into account that a river basin is a unit of planning for territorial development (Pietrapertosa et al., 2018).

QUESTION

Assuming that solutions to reduce climate vulnerability are widely known, why is the post-extreme event recovery process still complex and inefficient?

ASSUMPTION

The existing tools for assessing climate vulnerability are also complex or, there is a weak technical and institutional capacity to cope with extreme weather events.

MAIN GOAL

This thesis aims to introduce an alternative approach of climate vulnerability assessment proposing simple tools that can assist decision-makers on the identification of the needs to adapt to climate change.

Specific Goals

- Propose a methodology for identifying climate indicators.
- Propose a methodology for assigning weights to climate indicators.
- Define the role of governance in the process of reducing climate vulnerability.

Social and Scientific Contribution

Scientifically, this research fits into academic studies to formulate simplified mechanisms for assessing climate vulnerability. It will support the decision-making process at different levels of execution. Therefore, it is proposed the formulation of the climate vulnerability function based on four components, bringing the role of governance in defining adaptation needs for climate change.

How to read this document

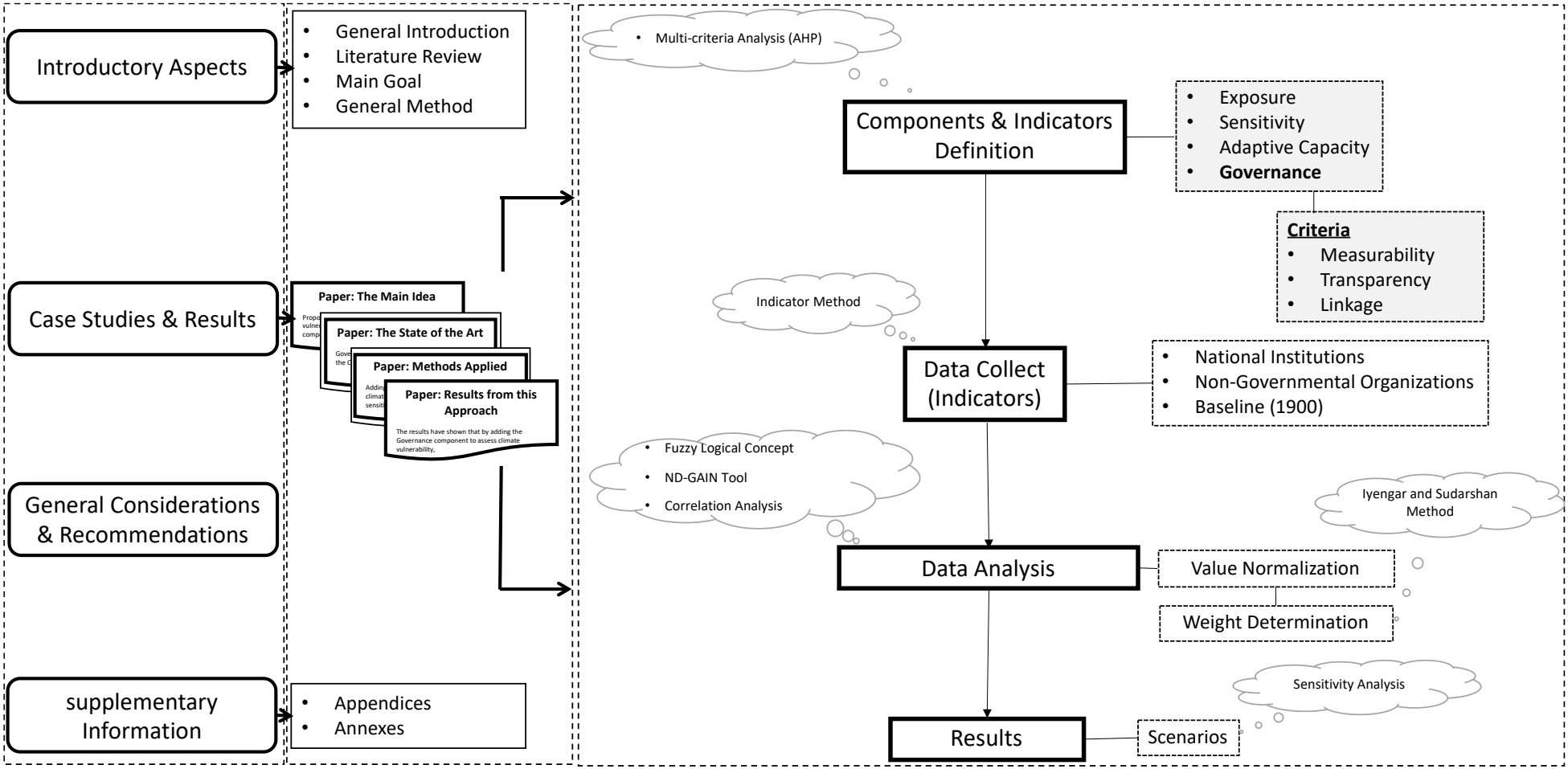
Starting from Chapter 2, are sequentially presented a series of papers to lead the reader to understand the methodology and criteria used in this topic on **Climate Vulnerability and Adaptation to Climate Change**. Therefore, this first paper focuses on the questions that led to the preparation of this study bringing the current scenario of the recovering process of the negative impact of climate change. This paper, entitled **Vulnerability and Adaptation Capacity of River Basins to Climate Change: A Different Approach to Climate Vulnerability Index**, advances a proposal on how this study can take place and what kind of tools are necessary, making references to the Climate Vulnerability Index. However, assessing climate vulnerability using indexes are based on indicators. Therefore, moving forward, the elaboration of the second article entitled **"Are There Right Indicators for Climate Vulnerability?"** was led by the need to define climate indicators. The idea is to lead the reader to understand the complexity of the process of defining indicators. However, a new challenge has arisen regarding the weight attributed to each indicator, and the question is: They must be equal or differentiated, according to their influence? Thus, the third paper entitled **Dealing with Subjectivity in Weight Determination: Climate Vulnerability Indicators**, comes to justify the adopted approach in this document. Therefore, after presenting the idea (Paper 01), defining the indicators (Paper 02), and assigning the appropriate weights to each component (Paper 03), the next step was to test the tool. Thus, was proposed the fourth paper entitled **An Alternative Approach to Climate Vulnerability Indices**, which is consists of a comparative analysis of the reduction of climate vulnerability process, based on the technical and institutional capacity of each system to face climate change. And because it is a tool for decision-making, the fifth paper, entitled **The Role of the Governance on the Climate Vulnerability Index Definition**, became the main motivation of this research. Here it is intended to highlight the role of decision-makers in the process of climate resilience. After that, to strengthen the idea

of the governance role into long-term planning was proposed the sixth paper entitled **Climate Change Mainstreaming into Planning**. This paper brings details of the process of integrating climate change into strategical development plans. Therefore, the idea of explicitly bringing the governance component into the role of climate vulnerability is a way of showing that the organizational form and the defined policies are the keys for a fragile system to become resilient to the negative impact of climate change.

METHOD

This project idea was developed based on a real situation of facing the challenge of recovering process and adapting to the impact of climate change. Therefore, we first set the main goal and the components to be used. Next, using the Analytic Hierarchy Process Method (AHP) we established the criteria to select the necessary main indicators to reach the goal. These indicators were collected from public institutions that have a responsibility to manage climate change and disaster risk reduction issues. Once collected, the data were normalized and analyzed based on specific methods from the literature review. In the end, based on a fuzzy set logic concept and ND-GAIN approach, we present the results in different scenarios of resilience (Figure 05).

Figure 05 - The four parts of the document



Source: The author (2021)

Analytic Hierarchy Process Method (AHP)

There are several methods that can be used to determine, which are the best indicators. However, in this work, we suggest the AHP Method, a multi-criteria analysis to choose from several, the main indicators. The AHP is a pair comparison method that enables all possible combinations, based on defined criteria, eliminating similarities or duplications to choose the best alternatives. (Saaty, 1989; Saaty, 1990). It converts human judgment on numerical value (Table 02), based on human perception, and combining psychology and math (Saaty, 1990). Therefore, it compares qualitative and quantitative criteria to determine the preferred alternative, based on available criteria.

Table 02 - Numerical value proposed by Saaty (1990)

Numerical Value	Judgment	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity ***j***, then *j* has the reciprocal value when com pared with ***i***	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Source: Adapted from Saaty (1987)

Determine the Consistency of the judgment

Based on the Consistency value (CR), it is verified the confidence of the judgment by the consistency analysis (equation 01). The calculated Consistency Index (CI) with tabled Consistency Index (RI) are compared, based on the number of elements considered (Table 03).

$$\mathrm{CR} = \left[\left(\frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1}\right)/\mathrm{RI}\right] = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (01)$$

Where *CR* is the consistency value, λ_{max} is the eigenvalue, and *n* is the number of the criteria.

Table 03 - Consistency Index for randomly

n	**RI**
1	0
2	0
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,54
13	1,56
14	1,57
15	1,58

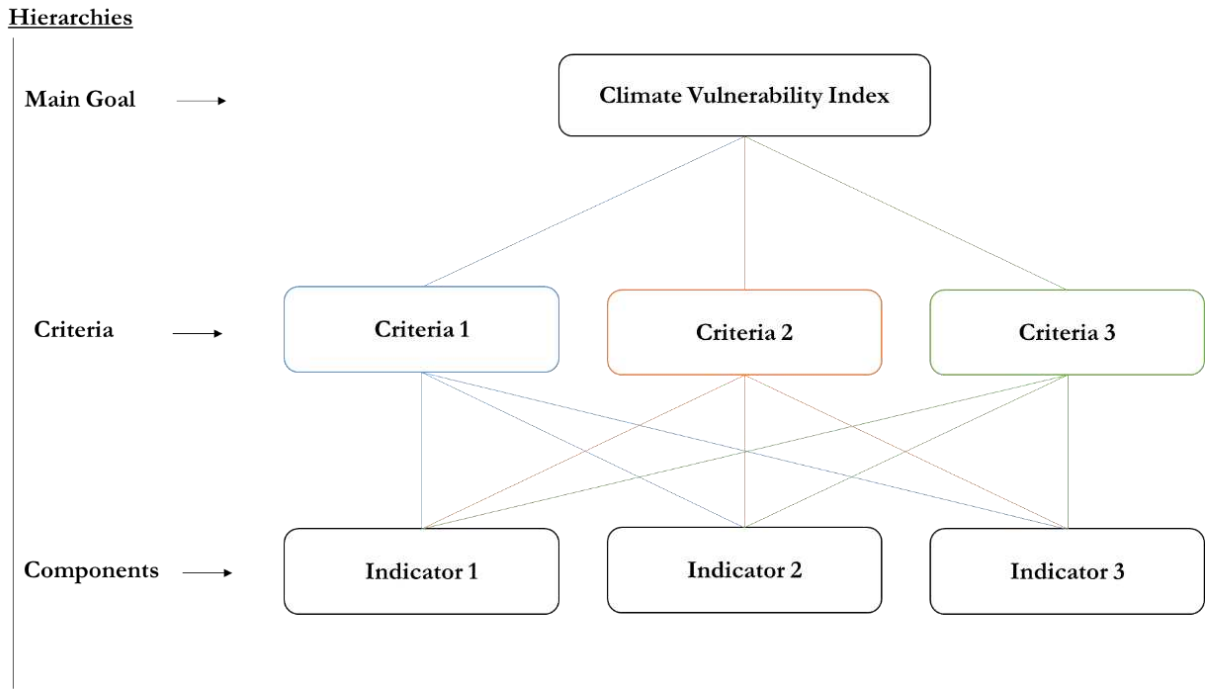
Source: Adapted from Saaty (1990)

According to Saaty (1990), if the CR is less or equal to 0.1, the inconsistency is rejected, it means judgment acceptable. However, if the CR is greater than 0.1, we have an inconsistency, suggesting a judgment revision.

Selection of Indicators

The indicators are defined according to the main goal, taking into account a set of criteria, and components (Appendix A, D and E). Therefore, based on the main goal (Climate Vulnerability Index), we defined, criteria 1, 2, and 3, which provided alternatives per component (Indicators 1, 2, and 3), to address the main goal (Figure 06).

Figure 06 - Hierarchy of the problem



Source: The author (2021)

However, according to Neset et al. (2018), good indicators need to be aligned with the main goal. Therefore, for more details, find in Buchir et al. (2019b), chapter 3, and also see Appendix A, an example of using the AHP Method to define the main indicators.

Data Normalization

Indicators used to come in different scales or units (Appendix F). Therefore, they must be normalized to put on the dimensionless way and avoid disproportionalities when multiple indicators are combined or compared (Anandhi and Kannan, 2018). However, it is very important to know the relationship between the indicator and main goal (Climate Vulnerability Index) to ensure that the indicator values are always in a positive correlation (Appendix E). Thus, according to Pandey and Jha (2012); Kumar et al. (2017); and Pandey

et al. (2017), if the indicator increase and the main goal also increase, equation (02) is suggested, otherwise, if the indicator increase and main goal decrease, equation (03) is recommended.

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

$$X = \frac{X_{max} - X_v}{X_{max} - X_{min}} \quad (03)$$

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 is the normalized value. Once normalized, equation (04) was used to average the values of each component.

$$C = \frac{\left(\sum_{i=1}^{n_I} W_{Ii}.X_i + \sum_{i=1}^{n_I} W_{Ii}.X_i\right)}{\sum_{i=1}^{n_I} W_{Ii}} \quad (04)$$

where, C is each component value (E, S, AC, or G), X_i is indicator 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.

On the other hand, it is very important to ensure that the variation of one indicator would not incorrectly dominate the contribution of the rest of the indicators. However, according to Mazziotta and Pareto (2013), even knowing that some methods are based on subjectivity understanding, though some research gives specific weight for each indicator Iyengar and Sudarshan (1982); Pandey and Jha (2012); and Mazziotta and Pareto (2013), many others used to give equal importance to all (Sullivan, 2002); Mazziotta and Pareto, 2013; Pandey et al., 2017). Therefore, we suggested the Iyengar and Sudarshan's Method (equation 05), which is, based on uncertainty aggregation on variance, meaning that as the greater the variance is, the smaller the weight will be (Iyengar and Sudarshan, 1982).

$$W_i = \frac{NC}{\sqrt{var(X_i)}} \; ; \left(0 < W_i < 1 \text{ and } \sum_{i=1}^{n} W_i = 1\right) \quad (05)$$

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 06:

$$NC = \left[\sum_{i=1}^{i=n} \frac{1}{\sqrt{var(X_i)}}\right]^{-1} \quad (06)$$

This approach is supported by the peculiarities of each region, reflecting the actual situation, which defines the weight of the indicator. In chapter 4, more details are given on these issues (Buchir et al., 2019c). Thus, the overall index can be determined by equation (07), as climate vulnerability index (CVI):

$$CVI = \frac{W_E.E + W_S.S + W_{AC}.AC + W_G.G}{W_E + W_S + W_{AC} + W_G} \quad (07)$$

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. After having the climate vulnerability index (CVI), is combined with the readiness value ($R_{ead}V$) to identify the country stage (Figure 02). This $R_{ead}V$ can be expressed by equation 08:

$$R_{ead}V = \frac{W_{AC}.AC + W_G.G}{W_{AC} + W_G} \quad (08)$$

where, W_{AC}, and W_G are the weights determined for each major component, *AC*, and *G* are the values of each component. The result value of this index (CVI and $R_{ead}V$), gives the 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), according to a fuzzy set logic concept (Dasgupta et al., 2006; Eakin and Bojórquez-Tapia, 2008; Krishnamurthy et al., 2014).

Fuzzy Logic Concept

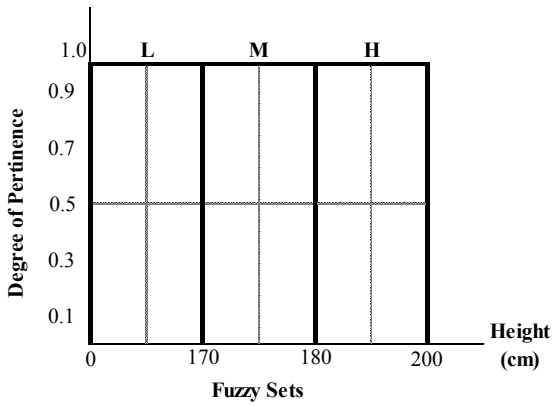
The fuzzy concept can be understood as a situation where it is not possible to simply answer "Yes" or "No". Even if you have all the information you need, saying something like "maybe" or "almost" becomes more appropriate. Therefore, unlike Boolean logic (classical), which only admits boolean values (true or false), fuzzy logic, admits the existence of a half-truth, almost true or almost false (Rignel et al., 2011).

Fuzzy logic was first proposed in 1930 by Jan Lukasiewicz, through a study using terms like tall, old and hot, where he proposed the use of a range of values [0,1] that would indicate the possibility of a statement being true or false. A few years later, in 1937, Max Black, continuing the initial idea, defined the first fuzzy set, providing some basic ideas of fuzzy set operations. Years later, in 1965, Lofti Zadeh published the paper entitled Fuzzy Sets, which became known as the origin of fuzzy logic, becoming also known as the "Master" of Fuzzy Logic (Rignel et al., 2011).

Fuzzy sets

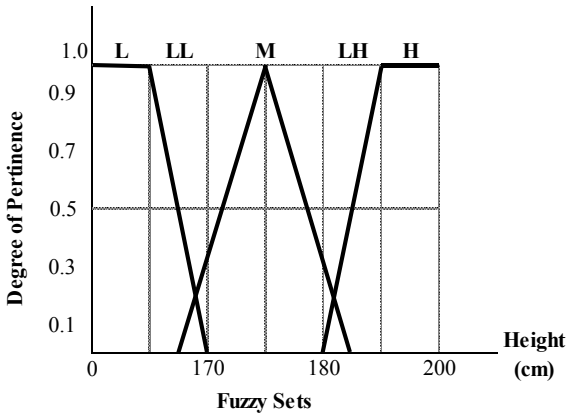
According to Zadeh et al., (1965) explanation, in Classical Logic, sets are well-defined, so that a certain element belongs to only one set (Figure 07a), avoiding ambiguity. It requires an exact definition as "he is a man" or "he is mortal". It means, there is no answer other than true or false, different the fuzzy logic that has no exact definition. Thereby, an individual of 1.69 m would be considered a person of low height and belonging only to the set of short people. However, this difference is minimal and is difficult to separate, which is why the fuzzy theory is born. Then, from the perspective of fuzzy logic, through a certain degree of pertinence ranging from 0 to 1, the same 1.69 m individual belong to two different sets (Figure 07b). As you can see, the answer has a degree of veracity that selects between "totally false (0)" and "totally true (1)", such as "he is tall" or "he is young". Therefore, this logic allows the variables to have degrees of pertinence ranging from [0,1] (Figure 07b), not allowing precise values such as 0 or 1 (Figure 07a), were L is low, LL is little low, M is medium, LH is little high, and H is high.

Figure 07a – Classic Logic



Source: The author (2021)

Figure 07b – Fuzzy Logic



Source: The author (2021)

Thus, through partial degrees of relevance, the Fuzzy Logic, allows representing the common knowledge, which is mostly of qualitative linguistic type and not necessarily quantitative. Therefore, it is a tool capable of capturing vague information, generally described in natural language and converting it to a numeric format and vice versa, so that it is easy to manipulate (Tran and Duckstein, 2002; Azadi et al. 2009).

Thereby, a linguistic variable is understood as one whose values are fuzzy set names based on words such as low, medium, and high, and not numbers, expressing numerical values. Therefore, fuzzy sets are functions that map in three basic steps, the degree of relevance of the elements from a scalar value between 0 and 1, according to the following steps:

Fuzzification: the stage where the linguistic variables are subjectively defined and assigned to a pertinence degree through class intervals, converting the linguistic values to numerical values. Each input value will have a degree of relevance in each of the fuzzy sets (Table 04).

Table 04 – Fuzzification process

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]
Very High	[0.7 - 1.0]

Source: The author (2021)

Combination: the stage where the propositions (rules) are defined, representing the relationship between variables. Therefore, how the rules will be triggered and combined to determine a specific condition (Table 05).

Table 05 – Combination process

Sensitivity	Adaptability	Vulnerability
Low	Low	Medium
Low	High	Low
High	Low	High
High	High	Medium

Source: The author (2021)

Defuzzification: the step where the numeric values between [0,1] are select and converted to linguistic values (low, medium, high). The inverse of the Fuzzification process (Table 06).

Table 06 – Defuzzification process

0.36	Little Low
0.38	Little Low
0.44	Medium
0.46	Little High
0.47	Little High
0.53	High
0.54	Very High

Source: The author (2021)

In conclusion, the fuzzy logic is the ability to handle uncertainties and ambiguous terms, something which cannot be done by classical logic Eakin and Bojórquez-Tapia, (2008); (Silvert, 1997), and the first step to represent the fuzzy sets are choosing the pertinence function, take into account the problem to be modeled.

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CHAPTER 2

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

HIGHLIGHTS

This part aims to provide some references to illustrate the process of the construction of the Climate Vulnerability Index (CVI). It also brings the role of the main components of the CVI and the impact of climate vulnerability assessment.

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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 the world. However, the big challenge is 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, we will assess the Climate Vulnerability Index, 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 the 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 the 1.5 0C global warming 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). Further, they also show that different systems with the same exposure hazard can have 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. This means that even knowing what are the impacts of climate change on different levels, the frequency, and magnitude of the extreme events, such as floods, droughts, and windstorms, still increasing, and according to UNDP (2007), the recovery process still also very complex, requiring a huge structure of risk management (World 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 02 – 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 VUNERABILITY INDEX

There are two more concepts which are considered to build Climate Vulnerability 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 collect data to 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 must 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).

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

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

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 is the normalized value.

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

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

where, C is each component value (E, S, AC or G), X_i is indicator 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 an alternative approach to assess the climate vulnerability and provide a robust tool to assist decision-makers on the 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 to improve 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 powerful influence on vulnerability. However, there are more components such as Exposure, Sensitivity, and Governance which also define 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 (institutional arrangement - infrastructure), but this does not mean that they are not working on adaptive capacity, 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 the 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 can 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 the 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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CHAPTER 3

ARE THERE RIGHT INDICATORS FOR CLIMATE VULNERABILITY?

HIGHLIGHTS

This part aims to provide elements to determine climate vulnerability indicators. Here there are presented some methods and criteria to be followed for the definition of the main indicators to climate vulnerability assessment.

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ARE THERE RIGHT INDICATORS FOR CLIMATE VULNERABILITY?

Luís Miguel Samussone Tomás Buchir[1], *Miriam Rita Moro Mine*[2], *Regina Tiemy Kishi*[3], *Marcelo Rodrigues Bessa*[4], *Cristovão Vicente Scapulatempo Fernandes*[5], *Daniel Henrique Marco Detzel*[6]

ABSTRACT – Probably not. This paper aims to contribute to the assessment of climate change impact at the river basins. Here we propose some criteria that can be easily followed to decide on the choice of climate indicators. Based on the Indicator Method, were collected a set of indicators take into account some previously defined criteria over four main components, Exposure, Sensitivity, Adaptive Capacity, and Governance. The result shows that good indicators need to be aligned with the main proposal and take into account a set of criteria to achieve the main goal.

RESUMO – Provavelmente não. Este trabalho visa contribuir para a avaliação do impacto das mudanças climáticas em bacia hidrográficas. Aqui são propostos alguns critérios que podem ser facilmente adoptados na escolha de indicadores climáticos. Com base no Método dos Indicadores, foram coletados um conjunto de indicadores que tomam em consideração alguns critérios previamente definidos, envolvendo quatro componentes principais: Exposição, Sensibilidade, Capacidade Adaptativa e Governança. O resultado mostra que bons indicadores precisam estar alinhados com a proposta principal e acima de tudo ter em conta um conjunto de critérios que visam atingir o objetivo principal.

Keywords: Climate; Vulnerability; Indicators.

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INTRODUCTION

Research shows that indicators are a critical starting point for a good assessment tool because they reflect the measurability of the main goal. Therefore, if the criteria to choose them are not transparent and comprehensive, the results can be seriously affected (Neset et al., 2018). In the context of climate change, using indicators is one of the most common ways to measure climate vulnerability, because vulnerability is a theoretical phenomenon which cannot be measured directly (Hinkel, 2011). On the other hand, as is well-known, most of the vulnerability measures to climate change are affected by different policies and international agreements, such as the Sustainable Development Goals (SDG). Therefore, to adapt them to a local level, and create indicators of vulnerability, must be taken into account some major characteristics of measurement, such as scale issues, dynamism, and understanding (Posey, 2009).

However, even knowing all these issues, there are some concerns about the criteria to choose vulnerability indicators. According to some researchers, most indices have substantial weaknesses in methodology and conceptual framework, which include lack of clarity in their conception, sensitivity in aggregating other methods, limited quality of available data, and difficult adjustment to current policies (Eakin and Bojórquez-Tapia, 2008).

Therefore, it is clear that the validation of international indicators to the national-scale is a big and very important challenge, mainly if we take into account the weight issues due to the difference between systems, and the quality of the available data. Therefore, the question is, what is the right indicator? To address this issue, we propose a set of indicators based on Indicator Method and Analytic Hierarchy Process (AHP), assuming the importance and the role of decision-makers on the ownership of the process.

Indices and Indicators

The indices and indicators became useful since the 1920s, and today there are hundreds of global indicators around the world, put forward by many institutions (Sullivan, 2002). The index could be defined as a statistical concept used to quantify something which cannot be measured directly or to measure changes (Mazziotta and Pareto, 2013). On the

other hand, an indicator can be defined, as any variable which indicates the magnitude or variability of a parameter, therefore, a direct measure (Anandhi and Kannan, 2018).

In general, they are too many ways to select an indicator. It could be by a deductive framework, theoretically or physical relationship based, an inductive framework based on statistic, or based on judgment value which is a normative framework, besides their combination (Anandhi and Kannan, 2018). Furthermore, indicators could be tangible which include physical existence that can be express in monetary values, or intangible which referring to attitudes and beliefs of people that influence their action, such as risk perception (Marília et al., 2018).

The Role of Indicators

The indicators have a crucial role in the context of managing big strategies or agreements. Because, through the periodical assessment of the activities based on a set of indicators, they monitored the progress of the implementation of those strategies. The Sustainable Development Goals and Human Development Index, led by the United Nations, are a good example of that. They use a set of indicators to propose the improvement on the livelihood in different regions taking into account the peculiarities of each locality. Hence, the indicator is a mean of evaluation.

Climate Vulnerability Indicators

Climate vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change (IPCC, 2001; Brooks et al., 2005). However, as an indicator, vulnerability is an aggregate measure which not just depends on interactions between ecosystems and economic dynamism, but also, on response capacity of the people and authorities (Bogardi, 2004).

Indicators Measurement

One of the most common methods to assess vulnerability to climate change are the Econometric Method, based on socio-economic survey data at household-level, assessing the level of vulnerability in different social groups, and the Indicator Methods, based on

selecting some indicators from the whole set of potential indicators, and then combine systematically, those indicators to indicate the levels of vulnerability (Maiti et al., 2017). Although the econometric method is more transparent and easy to use in the political context, they are unable to identify risks in the medium and long term (Yohea et al., 2006).

On the other hand, the indicator method based on generic measures such as climate factors, physical and institutional infrastructure, education, and technology, can give us the possibility to consider the present and future potential vulnerability (Yohea et al., 2006).

These possibilities, added to sophisticated models, can provide much more information about the future climatic vulnerability. However, the mechanism is less transparent, and can likely be more contested. Thus, to minimize the uncertainty, most of the climate indicators are selected based on knowledge over elements which contribute to vulnerability such as exposure, sensitivity and adaptive capacity (UNITED NATIONS, 2007). Thereby, in this context, Exposure and Sensitivity indicators are mainly related to countable or the density of exposed assets. Therefore, exposure is the number of events, which affect directly the system, and Sensitivity, the quantity of loss and damages in the system (Krishnamurthy et al., 2014).

On the other hand, the adaptive capacity, which includes governance, is focused on adjustments and institutional capacity (Marília et al., 2018). Thus, it is the number of resilient infrastructures, and the number of existent institutions or organizations to support and with a structure to cope with extreme events (Krishnamurthy et al., 2014).

In summary, Indicators are used to operationalise theoretical concepts (Birkmann and Ã, 2011; Hinkel, 2011). Thereby, this paper aims to contribute to the assessment of the climate change impact, proposing a set of criteria and climate indicators, which can operationalize the initiatives of climate actions.

MATERIAL AND METHOD

Material

The indicators were collected from national institutions and non-governmental organizations, which provide data and conduct research on these issues.

Method

Due to the possible elevated number of indicators, we suggest the use of Indicator Method coupled with the Analytic Hierarchy Process (AHP), a multi-criteria analysis to choose the main indicators. The AHP is a par comparison method which done all available criteria combination Saaty (1990), and most used to eliminate similar or duplicate criteria.

It converts human judgment on numerical value (Table 01), based on human perception, and combining psychology and math (Saaty, 1990). Therefore, it compares qualitative and quantitative criteria to determine the preferred alternative, based on available criteria.

Table 01 - Numerical value proposed by Saaty (1990)

Numerical Value	Judgment	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity ***j***, then *j* has the reciprocal value when com pared with ***i***	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Source: Adapted from Saaty (1987)

Determine the Consistency of the judgment

The consistency analysis helps to verify the confidence of the judgment. Using equation 01, we compared the calculated Consistency Index (CI) with tabled Consistency Index (RI) propose by Saaty (1990), which based on the number of elements compared (Table 02).

$$CR = \left[\left(\frac{\lambda_{max} - n}{n - 1}\right)/RI\right] = \frac{CI}{RI} \qquad (01)$$

Where *CR* is the consistency value, λ_{max} is the eigenvalue, and *n* is the number of the criteria.

Table 02 - Consistency Index for randomly

n	RI
1	0
2	0
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,54
13	1,56
14	1,57
15	1,58

Source: Adapted from Saaty (1990)

According to Saaty (1990), if the CR is less or equal to 0.1, the inconsistency is rejected, it means judgment acceptable. But, if the CR is greater than 0.1, we have an inconsistency, suggesting a judgment revise.

Selection of Indicators

The indicators are defined according to the main goal, taking into account a set of criteria and components. Therefore, based on the main goal (Climate Vulnerability Index), we defined the criteria 1, 2 and 3, which provided alternatives per component (Indicators 1, 2 and 3), to address the main goal (Figure 01).

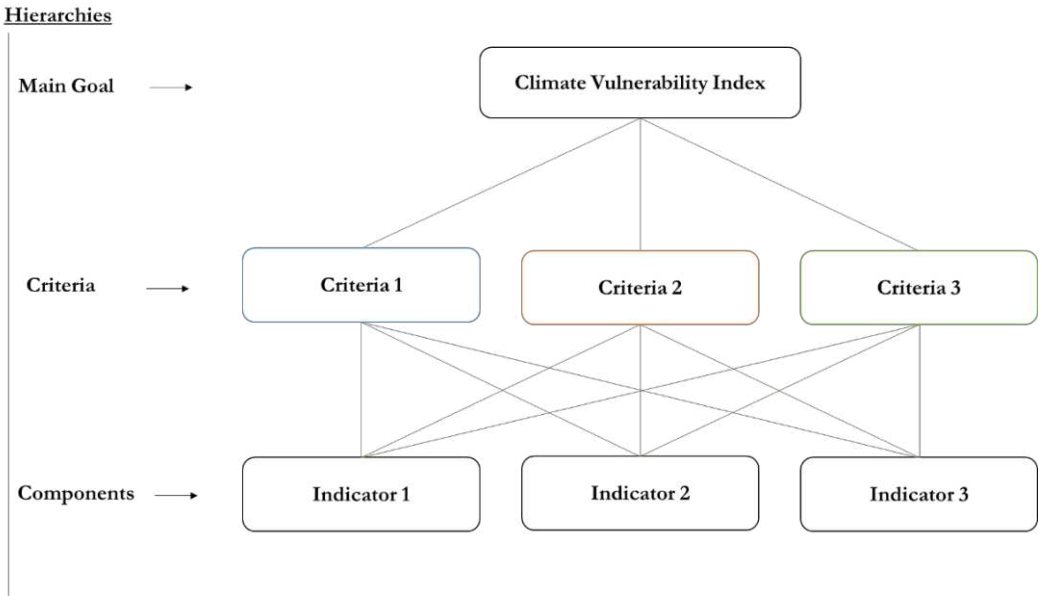

Figure 01 - Hierarchy of the problem

Indicator Definition

Good indicators need to be aligned with the main goal (Neset et al., 2018). Here, they were identified based on three main criteria aligned to the main goal, over the four components – exposure, sensitivity, adaptive capacity, and governance. The criteria were previously selected take into account five main suggestions (Table 03).

Table 03 – Criteria definition

CRITERIA	Measurability	Transparency	Tangibility	Comprehensiveness	Linkage	WEIGHT
Measurability	**1.00**	3.00	5.00	5.00	0.50	**0.3072**
Transparency	0.33	**1.00**	3.00	2.00	0.33	**0.1401**
Tangibility	0.20	0.33	**1.00**	3.00	0.20	**0.0886**
Comprehensiveness	0.20	0.50	0.33	**1.00**	0.20	**0.0585**
Linkage	2.00	3.00	5.00	5.00	**1.00**	**0.4056**
SUM	4	8	14	16	2	**1**
$\mathbf{l_{max}}$ =	5.3566	**CI =**	0.0891	**CR =**	0.0803	**ACCEPTABLE**

Based on par comparison, three criteria were elected – Linkage, Measurability and Transparency (Table 03). The Criteria of Linkage has 40.56% of the influence in the main goal, 1.32 (40.56/30.72) times more important than Criteria of Measurability, and 2.90 (40.56/14.01) times more important than Criteria of Transparency. The CR (0.0803) is less than 0.1, meaning that the judgment is acceptable and consequently the criteria chosen as priorities are also acceptable.

RESULTS

Comparing 32 alternatives indicators based on the criteria given to select the best option that attends the main goal (Table 03), we identified the priority indicators for each component through the Matrix of Decision (Tables 04). These matrices present all the indicators collected from selected institutions, and based on AHP Method, defines the main indicators, according to the tables (04).

Those with a high score in the result column, are defined as priorities indicators. Nevertheless, it is important to note that these indicators were adjusted to evaluate climate vulnerability on the system.

Table 04.1 - Exposure Component

INDICATOR | CRITERIA WEIGHT	Measurability 0.3072	Transparency 0.1401	Linkage 0.4056	Result
Extreme events of floods per year	0.1796	0.1530	0.1737	0.1471
Extreme events of droughts per year	0.1796	0.1530	0.1737	0.1471
Extreme events of windstorms per year	0.1796	0.1530	0.1610	0.1419
Frequency of heavy winds	0.0753	0.0505	0.0806	0.0629
Frequency of heavy rain	0.0926	0.0963	0.1140	0.0882
Frequency of rainfall below average	0.0926	0.0963	0.1206	0.0908
Frequency of high-temperature	0.1506	0.2223	0.1127	0.1231
Frequency Low-temperature	0.0500	0.0756	0.0448	0.0441
SUM	1	1	1	1

Table 04.2 - Sensitivity Component

INDICATOR | CRITERIA WEIGHT	Measurability 0.3072	Transparency 0.1401	Linkage 0.4056	Result
System affected by extreme events per year	0.2511	0.2399	0.2525	0.2132
Loss and damages in the system per year	0.1947	0.2004	0.2248	0.1791
Population Density	0.1613	0.1706	0.1359	0.1286
System cover by ecosystems	0.0777	0.0814	0.0729	0.0649
Economic incomes	0.0600	0.0541	0.0707	0.0547
Ecosystem diversity	0.0908	0.0937	0.0859	0.0759
Investment in the system	0.0449	0.0385	0.0582	0.0428
Infrastructures in the system	0.1195	0.1213	0.1157	0.1006
SUM	1	1	1	1

Table 04.3 - Adaptive Capacity Component

INDICATOR | CRITERIA	Measurability	Transparency	Linkage	Result
WEIGHT	0.3072	0.1401	0.4056	
Institutions providing financial support	0.2203	0.1806	0.0938	0.1310
Institutions providing technical support	0.1925	0.2164	0.2076	0.1737
Human capital (literature rate)	0.0478	0.0563	0.0738	0.0525
Physical capital (quality of insfrastructure)	0.0708	0.0626	0.1138	0.0767
Community training per year (Community-based preparedness)	0.1062	0.0957	0.1123	0.0916
Early warning sytems instaled	0.1170	0.1355	0.1484	0.1151
Research institutions involved on climate vulnerability	0.1603	0.1398	0.1681	0.1370
Published on the system (priority)	0.0851	0.1131	0.0468	0.0610
SUM	1	1	1	1

Table 04.4 - Governance Component

INDICATOR | CRITERIA	Measurability	Transparency	Linkage	Result
WEIGHT	0.3072	0.1401	0.4056	
Local management committee	0.2151	0.2505	0.2430	0.1997
Legal policies aproved	0.1771	0.1478	0.1579	0.1392
Specialized members on the committee	0.0731	0.1009	0.1414	0.0940
Climate change adaptation plans and strategies	0.1632	0.1637	0.0915	0.1102
Community participation (local priority)	0.0570	0.0958	0.1310	0.0841
Climate change issues integrated into different sectors	0.0474	0.0758	0.0962	0.0642
Border agreements on areas of shared extreme events	0.1549	0.0581	0.0903	0.0924
Periodic reports	0.1122	0.1075	0.0485	0.0692
SUM	1	1	1	1

DISCUSSION AND FINAL CONSIDERATION

This paper aims to propose a set of climate indicators based on some criteria and contribute to the process of the assessment of the climate change impact. According to the results, it is clear that the definition of the criteria is crucial to identify the priority indicators. They give a clear direction to target the main goal and defines the scale of measurement as suggested by Neset et al. (2018) in his analyses about the role of indicators. On the other hand, the AHP method proposed by Saaty (1990), also adopted by many others, was shown to be a very helpful tool to deal with subjectivity and eliminate similarities (Tables 04).

These results are acceptable because they are linkage to the main goal, and can be widely comprehensive to any user. Therefore, taking into account different researches, we reinforce the idea that, the most important step on the process to construct the indicators to become widely acceptable is identifying them in collaboration with those who are likely to use it and try to be as inclusive as possible (Sullivan, 2002; Mazziotta and Pareto, 2013).

In conclusion, there are no right indicators (Mazziotta and Pareto, 2013). They must be defined according to the main goal and identified through to the participatory process, take into account particular aspects of each area, as reinforced by (Adger, 2004). To be widely accepted the process must be driven by the decision-makers as ownership and based on a strong conceptual framework to guarantee the transparency.

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CHAPTER 4

DEALING WITH SUBJECTIVITY IN WEIGHT DETERMINATION:
Climate Vulnerability Indicators

HIGHLIGHTS

This part aims to discuss subjectivity in the validation of indicators of climate vulnerability, mainly in the determination of the weight of components. Here is presented a valid method to be used to avoid subjectivity in the climate vulnerability assessment.

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DEALING WITH SUBJECTIVITY IN WEIGHT DETERMINATION: Climate Vulnerability Indicators

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ABSTRACT - This paper aims to propose an appropriate method to dealing with the subjectivity in weight determination of the indicator in the context of climatic vulnerability assessment, where the weight of each one plays a very important role due to the difference in their impact on the system. The weight can be determinate assuming that each indicator contributes evenly or unevenly. Thus, here the Iyengar and Sudarshan method is proposed as an option to deal with this subjectivity. This method will aid the validating the indicators at the national level, having in mind the difference between systems and quality of the data available. The method is acceptable since the results of their respective indicators do not interfere incorrectly in the maintenance of the remaining indicators. Therefore, it is a useful tool to deal with issues of subjectivity in climate vulnerability assessment.

RESUMO - Este trabalho tem como objetivo propor um método apropriado para lidar com a subjetividade na determinação de pesos dos indicadores no contexto da avaliação da vulnerabilidade climática, onde o peso de cada um desempenha um papel muito importante devido à diferença do impacto dos mesmos no sistema. O peso pode ser determinado assumindo que cada indicador/componente contribui de igual forma ou de maneira desigual. Assim sendo, aqui é proposto o método de Iyengar e Sudarshan como resposta para lidar com essas subjetividades. Este método ajudará a validar os indicadores globais a nível nacional, tomando em conta a diferença entre os sistemas e a qualidade dos dados disponíveis. O método é aceitável, pois, os resultados mostram que a variação de um indicador não interfere incorretamente na contribuição dos restantes indicadores. Portanto, é uma ferramenta de bastante utilidade para lidar com questões de subjetividade na avaliação da vulnerabilidade climática.

Keywords: Vulnerability; Indicators; Weights

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INTRODUCTION

The weight determination for the indicators of the impact of extreme events on natural resources is one of the most critical points for a good assessment of resilience level. These pieces of evidences are notable on the validation of the global indicators to the national level, mainly if we take into account the weight issues due to the difference between systems, and the quality of the available data. Therefore, if the attribution of the weight is not transparent, on the way to reflect the main goal, the results also could not reflect the reality (Neset, 2015; Neset et al., 2018). As know, the weight can be determinate assuming that each indicator contributes evenly or unevenly. Many researchers give equal importance to all indicators to have the overall vulnerability assessment (Sullivan, 2002; Mazziotta and Pareto, 2013; Pandey et al., 2017). Others, give specific weight for each indicator, based on different methods (Iyengar and Sudarshan, 1982; Pandey and Jha, 2012; Mazziotta and Pareto 2013). However, some of these methods are based on the subjectivity understanding (Mazziotta and Pareto, 2013). Therefore, to deal with this and ensure that the variation of one indicator would not incorrectly dominate the contribution of the rest of the indicators/component, here we propose the alternative way to attribute the weight.

The Role of Weights on Climate Indicators

The weight determination of the climate indicators has a crucial role in the context of vulnerability assessment due to the fact that the indicators are used to monitor a set of activities and analyse the progress of established strategies over time (Birkmann and Ã, 2011; Hinkel, 2011; Martin and Becker, 2015). However, according to the situation or main goal, those indicators have different importance because each region takes into account its peculiarities. These peculiarities will define the weight of the indicator, reflecting the real situation and improves the process of vulnerability assessment.

Climate Vulnerability Indicators

Climate vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change (IPCC, 2001; Brooks et al., 2005; Hahn et al.,

2009; Mendoza et al., 2012; KC et al., 2015; Pandey and Bardsley, 2015). Is also an aggregate measure which brings us the response capacity of the people and authorities to cope with climate change (Bogardi, 2004).

Definition and Selection of the Indicators

The indicators are defined taking into account a set of criteria and components to reach the main goal (Climate Vulnerability Index). Here, we identified and selected twelve indicators based on three criteria over the four components: exposure, sensitivity, adaptive capacity, and governance (Table 01).

Table 01 – Selected indicators per component based on three criteria

Component	N.	Indicator			Interpretation
		Measurability	Transparency	Linkage	
Exposure	E1	Extreme events of floods per year (#)			The exposure of the system to this event due to his geographic location (risk level).
	E2	Extreme events of droughts per year (#)			The exposure of the system to this event due to his geographic location (risk level).
	E3	Extreme events of windstorms per year (#)			The exposure of the system to this event due to his geographic location (risk level).
Sensitivity	S1	System affected by extreme events per year (%)			The impact over the system in terms of expansion/size (coverage area).
	S2	Loss and damages in the system per year ($)			The economy and physical impacts over the system. Existence of resilient (necessary budget).
	S3	Population Density (#)			People affected around the system.
Adaptive Capacity	AC1	Institutions providing financial support (#)			Organizations with willingness to invest on adaptation over the System (funding).
	AC2	Institutions providing technical support (#)			Operated institutions to cope with the negative impact on the system (knowledge and human resource).
	AC3	Research institutions involved on climate vulnerability (#)			Investment on researchers to cope with climate issues (universities and others).
Governance	G1	Local management committee (#)			The existence of management institutions in operation. Level of the organization to cope the climate issues.
	G2	Legal policies approved (#)			Specific legislation on climate issues in the system (approved statutes).
	G3	Climate change adaptation plans and strategies (#)			Commitment. Influence of the committee on management process over the System.

As data to collect, Exposure is the number of events which affect directly in the system. Sensitivity is the quantity of loss and damages in the system (Krishnamurthy et al., 2014; Koutroulis et al., 2018). The adaptive capacity will be the number of existent institutions or organizations to support the system, and Governance the existent structure or mechanism to cope with extreme events (Marília et al., 2018; Krishnamurthy et al., 2014; Koutroulis et al., 2018).

Therefore, this paper aims to contribute to assess the climate change impact, proposing the Iyengar and Sudarshan's Method, as the appropriated method to determinate the weight of each climate vulnerability indicators.

MATERIAL AND METHOD

Material

In this paper, we used the Barigui river basin data in Curitiba-Paraná (Table 02). Were collected data from the national institutions such as Secretary of State for the Environment and Water Resources, and also the State Coordination of Protection and Civil Defence of Parana. It was selected, the main 11 state-level indicators (Table 01), and collected 81 data from 1981 to 2017. According to defined criteria, were identified the eligible extreme events and based on that, were composed 11 years' time-series.

Table 02 – Data of the Barigui river basin

Component	N.	Data 1	Data 2	Data 3	Average
Exposure	E1	2.20	2.00	0.77	1.66
	E2	0.00	0.00	0.00	0.00
	E3	3.27	2.17	1.08	2.17
Sensitivity	S1	50.00	50.00	50.00	50.00
	S2	5,145.93	416.67	7,730.77	4,431.12
	S3	31,058.80	1,336.50	225.15	10,873.48
Adaptive Capacity	AC1	0.33	0.42	0.38	0.38
	AC2	0.73	0.92	0.85	0.83
	AC3	0.73	0.92	0.85	0.83
Governance	G1	0.93	1.17	1.08	1.06
	G2	1.33	1.67	1.54	1.51
	G3	0.27	0.33	0.31	0.30

Method

The weight Determination (equation 01), is based on the principle that weight is defined by uncertainty aggregate on variance, meaning that as the greater the variance is, the smaller the weight will be (Iyengar and Sudarshan, 1982).

$$W_i = \frac{NC}{\sqrt{var(X_i)}} \; ; \left(0 < W_i < 1 \;\; and \sum_{i=1}^{n} W_i = 1 \right) \qquad (01)$$

where W_i is the weight, X_i is the normalized score, n (i = 1, 2, …, n) indicators of main goal, and NC is a normalizing constant, determined by (equation 02):

$$NC = \left[\sum_{i=1}^{i=n} \frac{1}{\sqrt{var(X_i)}} \right]^{-1} \qquad (02)$$

However, it is very important to know the relationship between the indicator and main goal to ensure that the indicator values are always in positive correlation with the main goal (Kumar et al., 2017). Therefore, before using the data to determinate the weight, they have to be normalized to put on the dimensionless way and allow comparisons between them (Anandhi and Kannan, 2018). It means, we recommend applying the equation (03) when the indicator increase and the main goal also increase Pandey and Jha, (2012), and apply the equation (04), when the indicator increase and the main goal also decrease (Pandey et al., 2017).

$$X = \frac{X_v - X_{min}}{X_{max} - X_{min}} \qquad (03)$$

$$X = \frac{X_{max} - X_v}{X_{max} - X_{min}} \qquad (04)$$

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 is the normalized value.

RESULTS

According to the principle of the uncertainty on variance Iyengar and Sudarshan, (1982), we determinate the weight of each indicator (Table 03).

Table 03 - Weight determination of each indicator

INDICATOR	VAR	SQRT VAR	1/SQRT VAR	NC	WEIGHT
E1	0.293	0.542	1.847	0.043	0.0793
E2	0.295	0.543	1.842	0.043	0.0790
E3	0.250	0.500	2.000	0.043	0.0858
S1	0.254	0.504	1.982	0.043	0.0851
S2	0.257	0.507	1.972	0.043	0.0846
S3	0.322	0.567	1.763	0.043	0.0757
AC1	0.254	0.504	1.983	0.043	0.0851
AC2	0.254	0.504	1.983	0.043	0.0851
AC3	0.254	0.504	1.983	0.043	0.0851
G1	0.254	0.504	1.983	0.043	0.0851
G2	0.254	0.504	1.982	0.043	0.0851
G3	0.254	0.504	1.982	0.043	0.0851

With these results and using the same approach as for indicators, were defined the weight of each component (Table 04).

Table 04 – Weight determination of each component

COMPONENT	VAR	SQRT VAR	1/SQRT VAR	NC	WEIGHT
E	0.003	0.051	19.621	0.004	0.0801
S	0.000	0.018	54.204	0.004	0.2213
AC	0.000	0.008	118.949	0.004	0.4857
G	0.000	0.019	52.123	0.004	0.2128

The adjustments on the system through the Adaptive Capacity has the highest value (0.4857), compared with the Governance (0.2128), and Sensitivity (0.2213), representing the magnitude of the impact on the system. Exposure (0.1473) has the lowest value, supposing less confidence in the data due to the significance of the dispersion measure, resulting from the quality of data, mainly the gaps such as having 0.0 for no data in five consecutive years and 1,750 or more in the next years.

DISCUSSION AND FINAL CONSIDERATION

This paper aims to propose the Iyengar and Sudarshan's Method, as the appropriate method to determinate the weight of each climate vulnerability indicators and dealing with the subjectivity in weight determination. The results show that using this method the variation of one indicator does not interfere incorrectly in the contribution of the remaining indicators, as proposed by Iyengar and Sudarshan, (1982), adopted by Pandey and Jha, (2012), suggested by Mazziotta and Pareto, (2013) and many others, on the previous discussions. Therefore, the Iyengar and Sudarshan's Method showed as a very acceptable and helpful tool to deal with subjectivity mainly if we take into account the difference on the impact of each component in the system, and the quality of available data. However, it is very important to pay attention to the gaps in data. Otherwise, the process will be based on a strong conceptual framework and led by expertise and decision-makers to be widely accepted, which used to be very questionable due to the controversial subjectivity of the judgments.

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CHAPTER 5

AN ALTERNATIVE APPROACH OF CLIMATE VULNERABILITY INDEX

HIGHLIGHTS

This chapter aims to present the implication of the Governance component in the climate vulnerability assessment, through a sensitivity analyses bringing different scenarios of adaptation.

AN ALTERNATIVE APPROACH OF CLIMATE VULNERABILITY INDEX

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ABSTRACT - According to many reports, the impacts of climate change will continue to be severe, mainly in the Least Developed Countries (LDC), and the less resilient countries, defined by the climate vulnerability index, will be the most vulnerable. The same reports state that the solutions addressing the impacts of climate change must come from long-term planning led by government management institutions. Therefore, this index, defined as the susceptibility degree of the system to the adverse effects of climate change IPCC (2001), is a tool to assist decision-makers in identifying country-specific needs. However, even though all these issues are already common knowledge, the LDCs are still unable to cope with the impact of extreme events. So, the question is, which part of adaptation capacity is in needs of more effort to deal with extreme weather events? To address this issue, we suggests a new approach to assessing climate vulnerability at 03 municipalities of Parana State, Brazil. Here, the Climate Vulnerability Index will be evaluated, consider four main components; Exposure, Sensitivity, Adaptive Capacity, and Governance, the latter as a new component to reinforce the role of management institutions at the climate change issues. Therefore, explicit consideration of Governance it is proposed to be added in the Climate Vulnerability function. The results have shown that by adding the Governance component to assess climate vulnerability, the function becomes more sensitive. Conclusion, Governance is accepted as a strong component in the Climate Vulnerability Index definition.

Highlights

- Which part of the adaptation capacity, needs more effort to deal with extreme weather events?
- The impact of Governance component on climate vulnerability adaptation.
- An alternative approach of climate vulnerability assessment tool.

Keywords: Climate Vulnerability; Adaptive Capacity; Governance.

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INTRODUCTION

According to the earlier reports from the IPCC (2007a, b), year after year, the impacts of climate change such as floods, droughts, windstorms, and others, can be more severe in the Least Developed Countries (LDC), instead of developed countries. On the other hand, and taking into account the average occurrence of extreme events, by logic the most exposed systems will be the most vulnerable ones (UNDP, 2007; World Bank, 2010; IPCC, 2018). However, evidence has shown that the most exposed system is not necessarily the most vulnerable, because there are several components such as Adaptive Capacity which can also define the level of vulnerability (IPCC, 2001; Adger, 2006; Eakin and Bojórquez-Tapia, 2008; and Maiti et al. 2017). Therefore, systems exposed to the same hazard could have different sensitivity, according to their efforts, such as quality of infrastructures and the system organization, which includes the long-term planning to adapt to climate change (Brooks et al. 2005; Pandey and Jha, 2012).

On the other hand, according to Weiler et al. (2018), the aid normally goes to the most exposed countries, mainly to Small Island Developing States (SIDS) and less to Least Developed Countries (LDC). Therefore, an opportunity for management institutions to play a very important role in the definition of adaptive capacity and the identification of the specific needs (Adrianto and Matsuda, 2002; Berman et al. 2012; Scandurra et al. 2017). However, it is very important to note that several tools have already been developed for assessing vulnerability. Hahn et al. (2009), in their approach to constructing the index using household parameters and includes eight major components, such as socio-demographic profile, livelihood strategies, social network, health, food, water, natural disaster, and climate variability. They presented an alternative method for assessing the vulnerability of communities to climate change impacts. The results show that this approach of Livelihood Vulnerability Index (LVI), helps to avoid missing data problems, which could affect many secondary data sources. Years later, Pandey and Jha, (2012), proposed an index (Climate Vulnerability index) for mountainous regions, which consist of three dimensions of vulnerability; Exposure, Sensitivity, and Adaptive Capability. This index also used primary household survey data, and in the end, they proved that this approach is very useful for assessing and monitoring vulnerability under different stress conditions, as well as evaluating the effectiveness of policies in various data-poor regions, comparing different scenarios. Later on, Pandey et al. (2017), at the same mountainous regions households, assessed the vulnerability of communities, and their potential to adapt to climate change,

bases on the counter-reactions. They concluded that both the policy and academic communities should collaborate to make the methodologies applied in the context of climate change vulnerability and adaptation more explicit, because the burden is on the government, in order to provide support to those who are most disadvantaged in terms of infrastructure, and public amenities.

Following the same approach of livelihood, Luers et al. (2003), in their paper on the vulnerability quantification method, proposed a new approach based on four concepts: Exposure, Sensitivity, Adaptability, and the State of the System. The latter, by means of introducing a human-environment system, that brings the measure of human welfare. In the end, in order to define system vulnerability, they show the necessity to understand the sensitivity of the system to different factors and identify the limit of well-being. A similar approach, assessing the vulnerability of populations and territories using an index, was also developed by Dos Santos et al. (2019), and based on the three basic dimensions of vulnerability - Exposure, Sensitivity, and Adaptive Capacity. They focus on micro region issues such as the local poverty index and the disease-associated to climate change. They concluded that the use of composite indicators allows the systemization of a series of information that, represented by a single number, provide the identification of vulnerability hotspots on a given system.

On the other hand, Dasgupta et al. (2006), in their vulnerability assessments, studying the EKC Model, provided new evidence that two important factors were excluded from the research in question, mentioned governance and vulnerability to environmental damage. They concluded that they are hard to quantify, particularly for developing countries, but governance has strong independent effects on environmental quality, suggesting policy reform to reduce air pollution significantly. However, Jubeh and Mimi, (2012), in their research on vulnerability in the Middle East region, assessed the effects of climate change and political regime, on water resources through the new index denominated, Governance and Climate Vulnerability Index (GCVI), and the findings show that vulnerability is influenced by climate change, and government performance, through its adaptation policies and strategies.

Furthermore, from a distinct perspective, Weiler et al. (2018), present a different approach to vulnerability, assessing the influence of adaptation and good governance, on donor allocation decisions. They suggest that physical vulnerability strongly influences both if a country receives adaptation assistance and how much adaptation assistance it receives. Therefore, they show that well-governed countries are significantly more likely to receive

external support and more funds per capita because they are better able to make good use of aid inflows.

These considerations make sense if we take into account that Governance is a simple act of organization with abilities to pursuit for solutions (Jubeh and Mimi, 2012). Hence, climate vulnerability (CV), is the susceptible degree of the system to adverse effects of climate change IPCC, (2001); Oculi and Stephenson (2018), and as a function, is expressed as *CV = f(E, S, AC)*, where *E* is the Exposure, expressing how close the system is too significant climatic variations, *S* is Sensitivity, the impact on the system after being affected by the extreme events, such as floods, droughts, windstorms, and others, and AC is the Adaptive Capacity, it means, the system flexibility to adopt measures adjusted to climate change (IPCC, 2001; Mendoza et al. 2012; Krishnamurthy et al. 2014; KC et al. 2015; Koutroulis et al. 2018; Marília et al. 2018).

Thus, according to the above mentioned, the adaptive capacity component, is the main component to evaluate climate vulnerability. However, even known all these issues, and taking as an example the SIDS and LDC where there is a strong investment in adaptive capacity, but they are still unable to cope with the impact of extreme events. Thus the question remains: which part of the adaptation capacity, needs additional effort to deal with extreme weather events?

Therefore, to understand this issue, we suggest a different approach to climate vulnerability, proposing an explicit consideration of Governance in the adaptation capacity issues to reinforce the role of management institutions to cope with extreme weather events. Thereby, as a function, we support 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).* Thus, this work aims to propose an alternative approach to assess climate vulnerability, introducing the Governance component in climate vulnerability function, and then assist decision-makers in identifying the needs in terms of more efforts to adapt to climate change.

The following sections will present the different stages of this work, which includes the used method, the study area, the data collection, and the analysis process. Once the data are collected, from determined indicators, they were normalized using the Indicator Method to in order to allow comparison between them. After that, will be presented the results, and discussion, given the degree of vulnerability according to the Fuzzy Logic concept. Here, the most important thing is to show that the values can change according to the sensibility of the function or the effort given on the system. Finally, we concluded, showing the needs for climate resilience to adapt to climate change.

METHODS

Four (04) stages composed this study. First was the component definition and data collection. Second, normalization and weight determination. Third, data analysis, and fourth, the results through the scenario proposal of climate vulnerability based on different sensitivity (Figure 01). Furthermore, were identified Curitiba, Araucária, and Almirante Tamandaré, as a sample field to collect data.

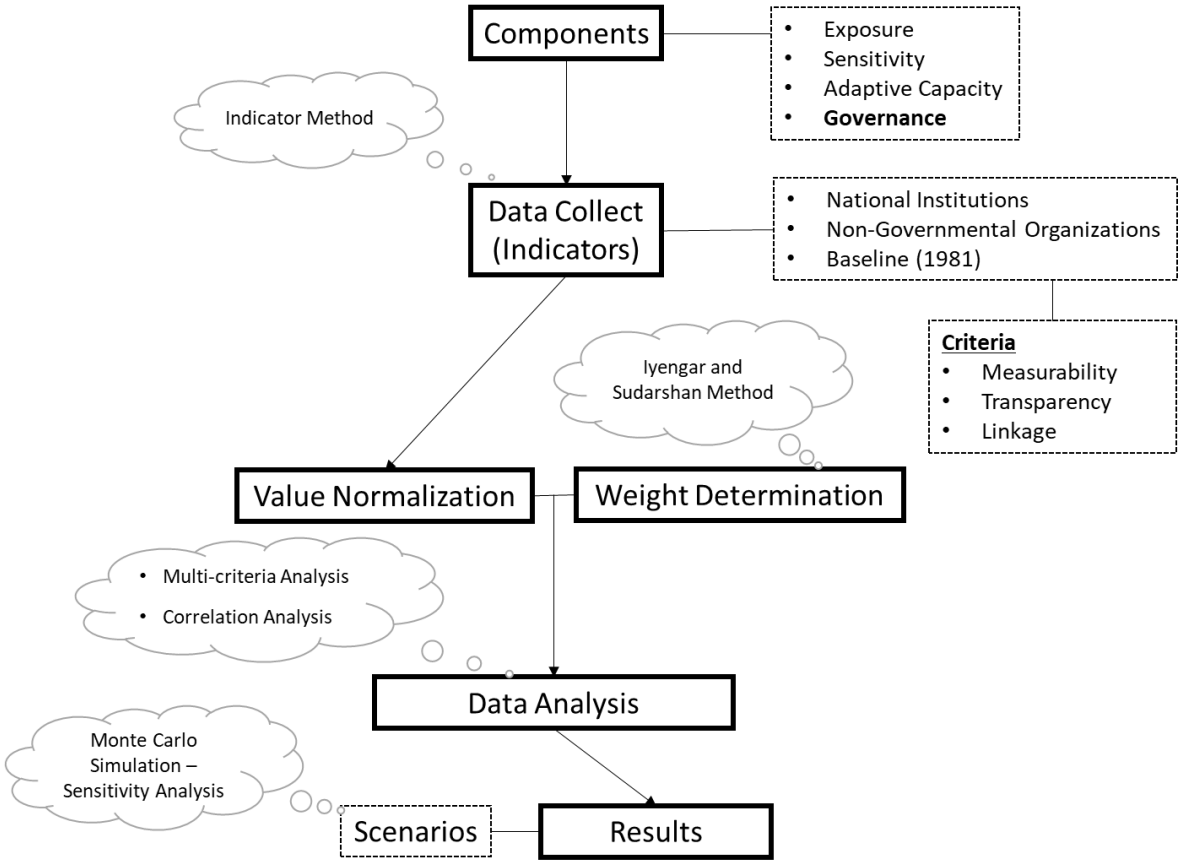

Figure 01 - The phases of the work

Study Area

According to Jubeh and Mimi (2012), to get a resilient system, it is necessary to promote development strategies, which include social-economic and climate change issues, through consistent assessments of vulnerability, integrating a wide range of relevant factors. Therefore, in this work, were selected three municipalities, considering the impact of climate change in the social-economic dynamic of the system, in this case, of the Barigui river basin, with around 267 Km^2 of the drained area, with 67 km of extension, direction North-South, representing the main metropolitan watercourse in three municipalities (Almirante

Tamandaré 36.2%, Araucária 8.3%, and Curitiba 54.7%). Thus, it was selected Curitiba (1,933,105 inhabitants; 435 km^2), Araucária (143,843 inhabitants; 469 km^2), and Almirante Tamandaré (118,623 inhabitants; 194 km^2). The three municipalities are located in the Eastern part of the state of Parana, southern Brazil (Figure 02). Parana is Brazil's fifth economy, and those three municipalities added to 26 more municipalities, represent the Curitiba Metropolitan Region, which is the second most populous in the South of Brazil (IBGE; IPARDES, 2011; CURITIBA, 2016; and Silva et al. 2016).

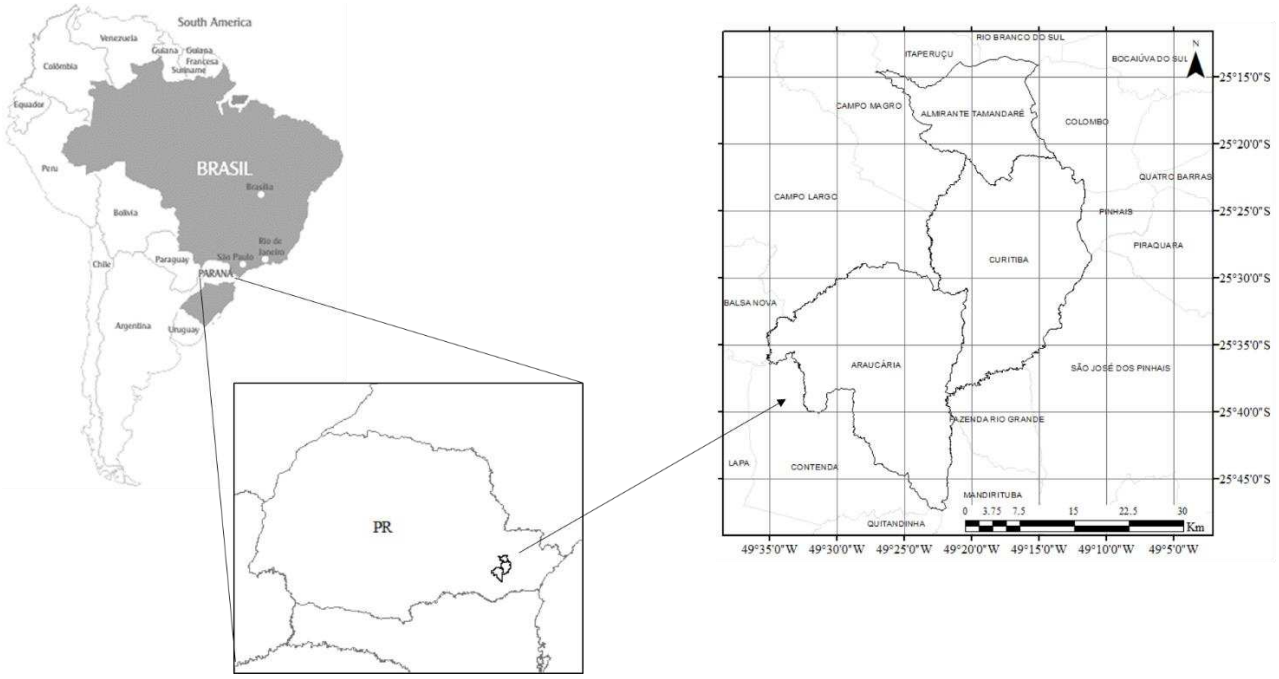

Figure 02: Municipalities of Curitiba, Araucária, and Almirante Tamandaré

This region is ranked as one of the best cities to invest in South America, considered one of the most relevant economic poles for business, highlighting the industrial park, which has already attracted large multinational companies, becoming one of the main and most developed industrial centers in the state of Parana (OECD, 2011; FIEP, 2018). Additionally, the forest, agriculture, pasture, and urban areas, also characterize the land use in this region (Leithold et al. 2017; Kozak et al. 2019).

However, this region is severely affected by extreme events such as floods and storms that impact local investment Marengo et al. (2001); FBDS (2009) and MMA (2016), and according to research, in urban areas, unusual risks can be generated due to the average increase of the frequency and magnitude of the extreme events, combined with the lack of normative tools that include climate change in development strategies (García et al. 2018). Thereby, as a way to ensure the progress of this proposal, beyond those risks, these municipalities were also chosen, taking into account the accessibility and available data.

Indicator Determination

According to Sullivan (2002), Mazziotta and Pareto (2013), and Anandhi and Kannan (2018), Climate Vulnerability is an empirical tool defined based on the main goal (Figure 03). However, it is important to mention that vulnerability is a positive function of the system's exposure and sensitivity, and a negative function of the system's adaptive capacity (Ford and Smit, 2004). Thus, based on some criteria, the indicators were identified through the four components: Exposure, Sensitivity, Adaptive Capacity, and Governance. Therefore, they were collected using the Indicator Method, which bases on choosing the main indicators from the set of potential national indicators (Vincent, 2004; UNITED NATIONS, 2007; Hinkel, 2011; Maiti et al. 2017).

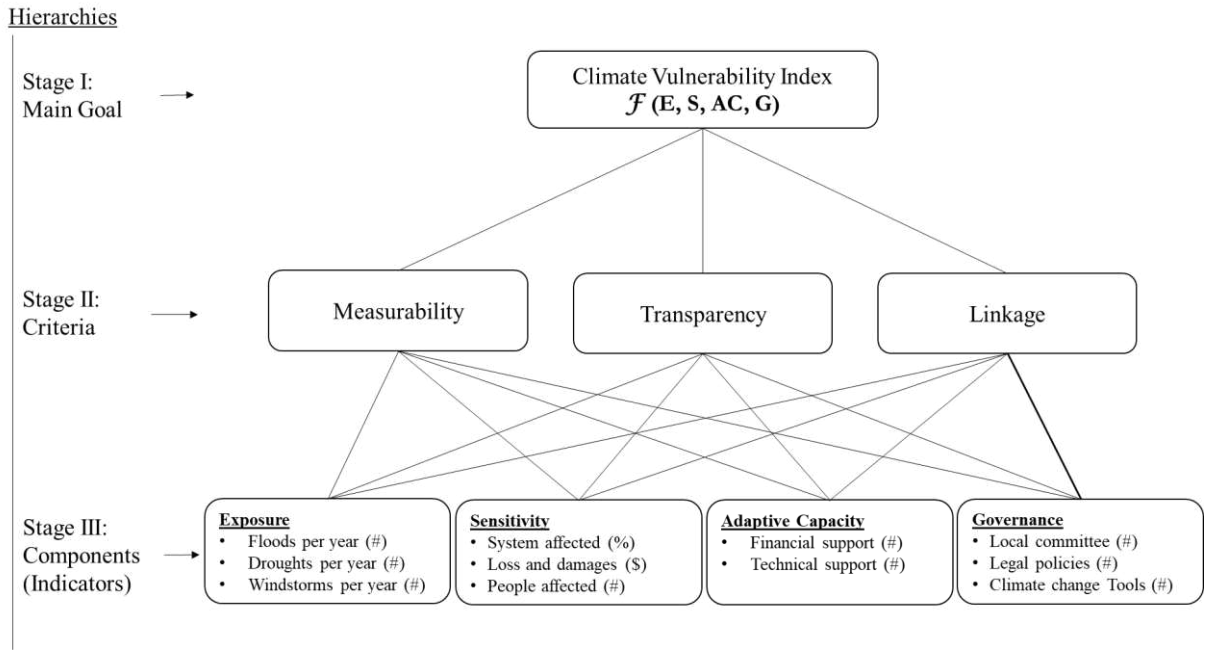

Figure 03 - Hierarchy of the problem

Furthermore, through the Analytic Hierarchy Process (AHP), which bases on human perception, converting human judgment on numerical value, the best indicators were chosen. AHP is a multi-criteria analysis, which makes a pair comparison of all possible combination, used to eliminate similarities or duplications (Saaty 1989a; 1990b; Russo and Camanho, 2015). Thus, were selected 11 indicators, based on the principle of the smaller the amount of data to be collected, the greater the chance of the tool be used. Therefore, they have to be accessible and easy to use by decision-makers (Table 01).

Table 01 – Four Main Components and their Indicators

Component	N.	Indicator			Interpretation
		Measurability	Transparency	Linkage	
Exposure	E1	Extreme events of floods per year (#)			The exposure of the system to this event due to his geographic location (risk level).
	E2	Extreme events of droughts per year (#)			The exposure of the system to this event due to his geographic location (risk level).
	E3	Extreme events of windstorms per year (#)			The exposure of the system to this event due to his geographic location (risk level).
Sensitivity	S1	System affected by extreme events per year (%)			The impact over the system in terms of expansion/size (coverage area).
	S2	Loss and damages in the system per year ($)			The economy and physical impacts over the system. Existence of resilience (necessary budget).
	S3	People affected around the system (#)			Population Density.
Adaptive Capacity	AC1	Institutions providing financial support (#)			Organizations with willingness to invest on adaptation over the System (funding).
	AC2	Institutions providing technical support (#)			Operated institutions to cope with the negative impact on the system (knowledge and human resource).
Governance	G1	Local management committee (#)			The existence of management institutions in operation. Level of the organization to cope the climate issues.
	G2	Legal policies approved (#)			Specific legislation of climate issues. Influence of the committee on management process over the System.
	G3	Adaptation tools for climate change (#)			Strategies and plans elaborated and in operation in the system.

Data Available

The data were collected from national institutions, such as the State Secretariat for the Environment and Water Resources, and the State Coordination for Civil Protection and Defense of Paraná state. For that, were defined 1981-2018, as a time-serial database to collect data at municipalities. After that, based on defined criteria, were collected information, and identified the extreme eligible events, according to main indicators (11), previously defined (Table 01).

Data Normalization

Data often come in different units making difficult, comparisons between them. Because of that, they are normalized based on two main equations: equation (01), when the indicator increase and the vulnerability also increase, and equation (02), when the indicator increase and vulnerability decrease (Pandey and Jha, 2012; Kumar et al. 2017; Pandey et al. 2017; Anandhi and Kannan, 2018).

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

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

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 is the normalized value.

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

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

where C is each component value (E, S, AC or G), X_i is indicator 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.

Weight Determination

The weight can be determined based on different methods. But basically, we have given equal importance to all indicators (Sullivan, 2002; Mazziotta and Pareto, 2013; Pandey et al. 2017), or given specific weight for each indicator (Iyengar and Sudarshan, 1982; Pandey and Jha, 2012; Mazziotta and Pareto, 2013). In this paper, was adopted the Iyengar and Sudarshan's Method (equation 04), which give specific weight for each indicator (Table 02), based on the uncertainty aggregate on variance, giving the smaller weight, where it has greater variance (Iyengar and Sudarshan, 1982).

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

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):

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

Table 02 –Average occurrence of the extreme event and each component weight

Component	Weight	N.	Indicator			Curitiba	Araucária	Almirante Tamandaré
			Measurability	Transparency	Linkage			
Exposure	**0.0355**	E1	Extreme events of floods per year (#)			2.00	1.86	0.77
		E2	Extreme events of droughts per year (#)			0.06	0.00	0.00
		E3	Extreme events of windstorms per year (#)			2.88	1.86	1.08
Sensitivity	**0.0473**	S1	System affected by extreme events per year (%)			90.64	28.53	50.00
		S2	Loss and damages in the system per year ($)			243,094.35	1,867.86	36,115.38
		S3	People affected around the system (#)			30,452.35	966.29	360.85
Adaptive Capacity	**0.4586**	AC1	Institutions providing financial support (#)			0.06	0.07	0.08
		AC2	Institutions providing technical support (#)			0.06	0.07	0.08
Governance	**0.4586**	G1	Local management committee (#)			0.59	0.00	0.15
		G2	Legal policies approved (#)			0.00	0.00	0.00
		G3	Climate change adaptation plans and strategies (#)			0.00	0.00	0.00

Climate Vulnerability Index (CVI)

The overall index (CVI) was 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.

Thus, the value result of the above index (CVI) can be grouped in classes to give the state or condition 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 (Figure 04) (Dasgupta et al. 2006; Eakin and Bojórquez-Tapia, 2008; Krishnamurthy et al. 2014).

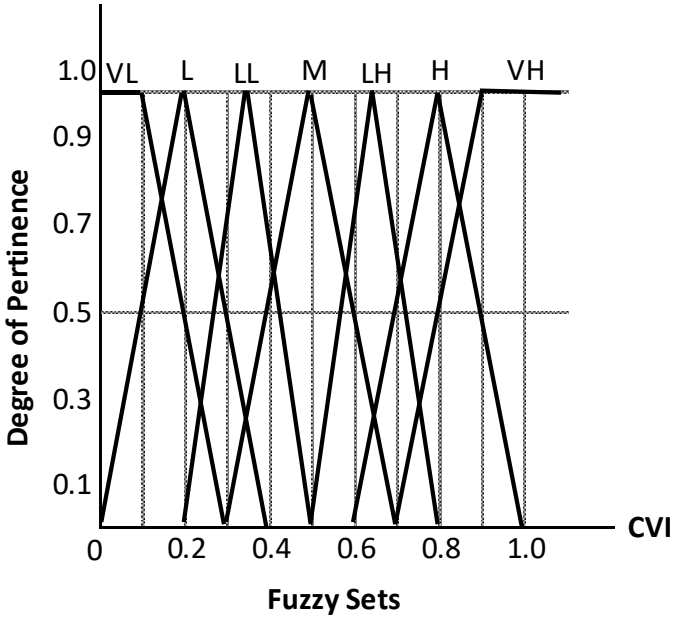

Figure 04 – Fuzzy logic concept

RESULTS

In terms of climate change impact, the three municipalities present Medium Vulnerable, with Curitiba ($CVI_{Curitiba}$ = 0.42), Araucária ($CVI_{Araucaria}$ = 0.42), and Almirante Tamandaré ($CVI_{Almirante\ Tamandare}$ = 0.43), based on three (03) main components (Figure 05),

and taking into account the Fuzzy Logic concept (Figure 04). However, if were taken into account four (04) components (Table 02), rather than three (03), the municipalities will be considered Little High Vulnerable, with ($CVI_{Curitiba}$ = 0.53; $CVI_{Araucaria}$ = 0.53, and $CVI_{Almirante\ Tamandare}$ = 0.54), which is more than 20% of the difference, suggesting a different approach to climate vulnerability function (Figure 05).

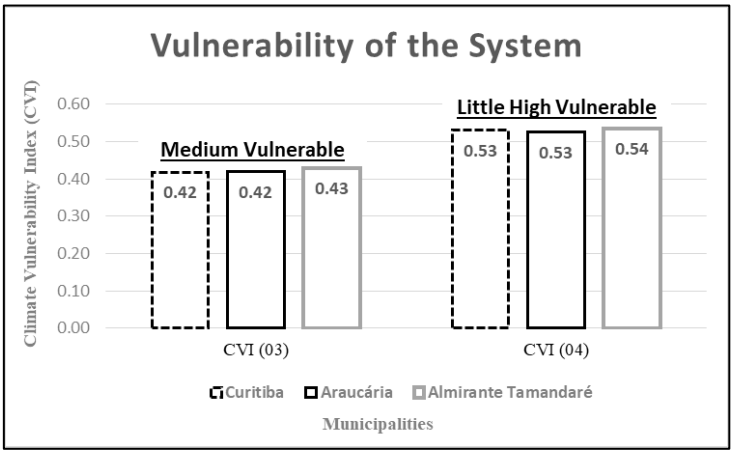

Figure 05 – Climate vulnerability index of each municipality, According to the number of components

On the other hand, in both situations (Figure 06.1), adaptation capacity is the most vulnerable part of the municipalities although, it is not clear which part of the adaptation capacity (infrastructure, or capacity building), they need more effort. However, adding the Governance component (capacity building) in the climate vulnerability function, it is easy to find specific indicators that allow us to identify where they need more effort (Figure 06.2).

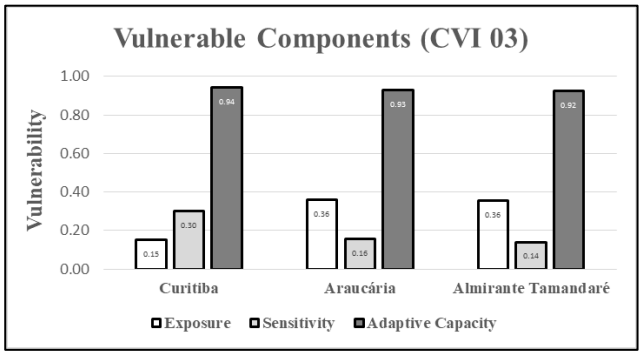

Figure 06.1 - Most vulnerable component of each municipality (03 Components)

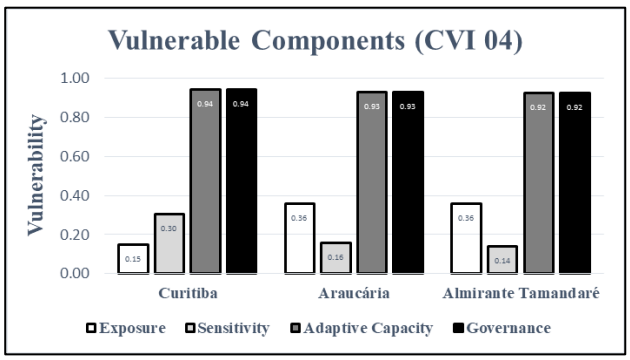

Figure 06.2 - Most vulnerable component of each municipality (04 Components)

Thus, we analyzed the factors that put the municipalities in those conditions (Figure 05), and take into account that there are several components which define the level of

vulnerability (Figures 06). It is observed that, in this case, Curitiba is the most exposed (Figure 07.1) and sensitive (Figure 07.2), compared with the other two, which is accepted, if we consider the frequency of extreme events, the structure of the city, and population density.

Furthermore, in terms of adaptive capacity (Figure 07.3), compared to the others, Curitiba has a high score in financial and technical support institutions, which means that they need to increase the number and quality of this type of support institution. In the governance component (Figure 07.4), Curitiba needs less effort to create local committees, assuming it has enough representatives in local communities, but, on the other hand, much more effort in approving legal policies and local adaptation plans, due to your coverage area.

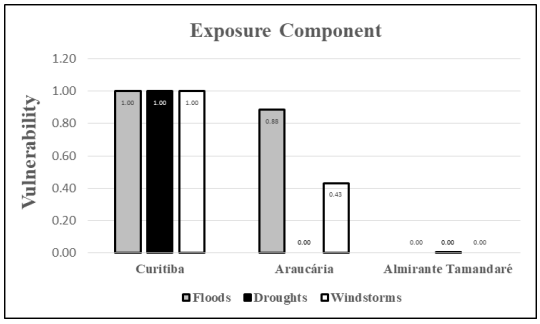

Figure 7.1 – Most vulnerable indicator

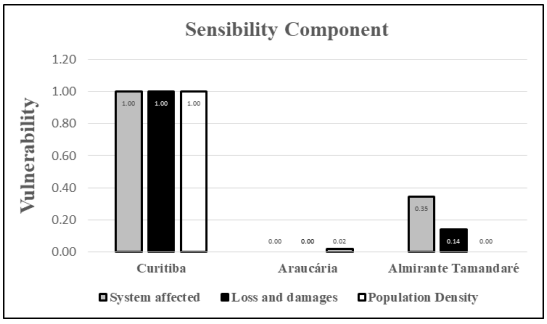

Figure 7.2 - Most vulnerable indicator

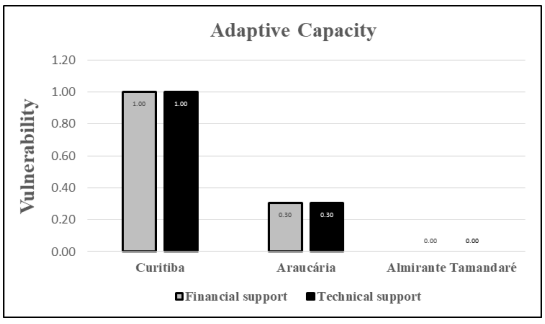

Figure 7.3 - Most vulnerable indicator

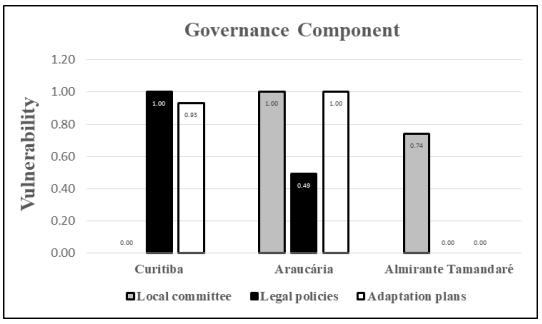

Figure 7.4 - Most vulnerable indicator

However, this does not mean less attention to one or another because, even though that they are not the most exposed municipalities, neither the most sensitive still, they need to improve their actions on adaptation to reduce climate vulnerability. Therefore, if we propose a different analysis according to their effort in the system (sensitivity analysis), suggesting scenarios of adaptation, the results showing that municipalities can present different levels of resilience (Figures 08).

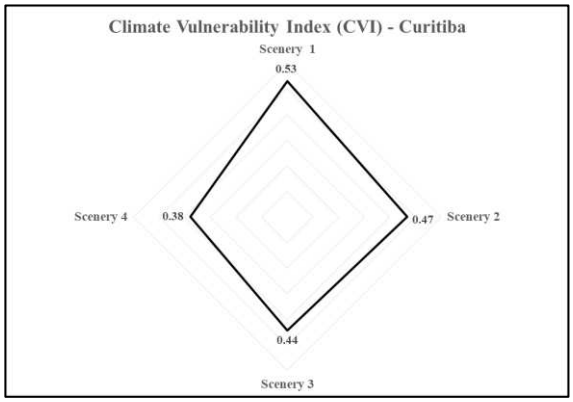

Figure 08.1a - Less vulnerable scenario

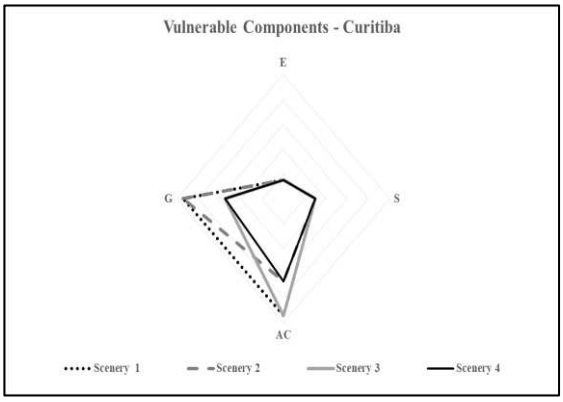

Figure 08.1b - Components to be reinforced per scenario

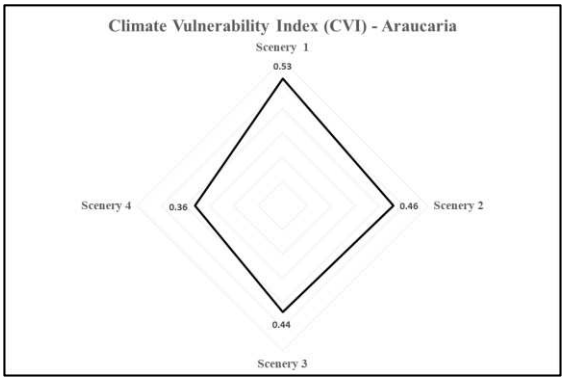

Figure 08.2a - Less vulnerable scenario

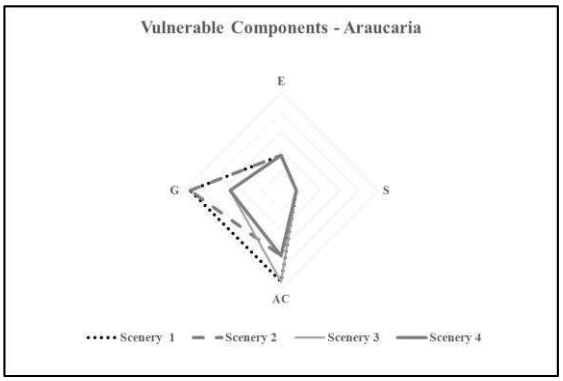

Figure 08.2b - Components to be reinforced per scenario

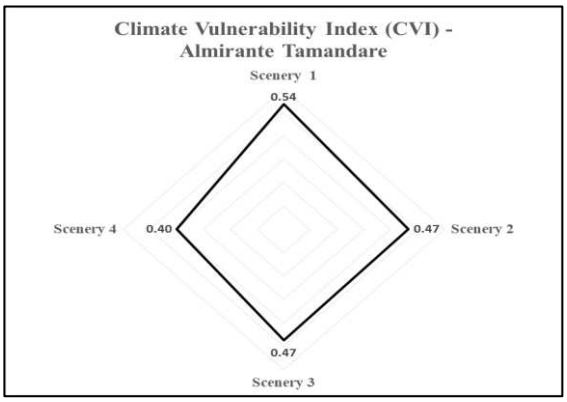

Figure 08.3a - Less vulnerable scenario

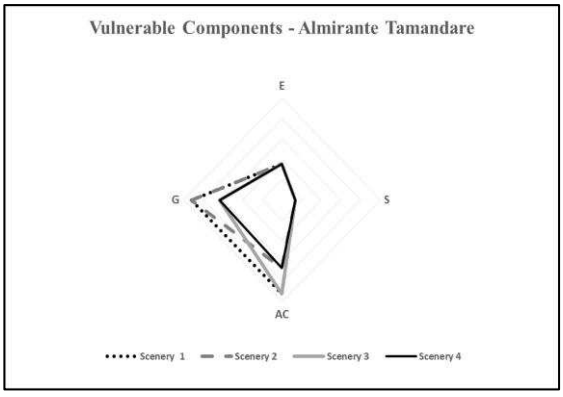

Figure 08.3b - Components to be reinforced per scenario

Analyzing these results, and taking into account that all scenarios 01 are the current scenario (Figure 08.1a, 08.2a and 08.3a), it's seen that in all municipalities the best scenarios is scenario 04 ($CVI_{Curitiba.4}$ = 0.38, $CVI_{Araucaria.4}$ = 0.36, $CVI_{Almirante\ Tamandare.4}$ = 0.40), because of the improvement in all adaptation components (Figure 08.1b, 08.2b and 08.3b).

However, analyzing the scenarios 03 and 02 in all municipalities, is interesting to note that, improving the governance component (scenario 03), the climate vulnerability decrease more ($CVI_{Curitiba.3}$ = 0.44, $CVI_{Araucaria.3}$ = 0.44, $CVI_{Almirante\ Tamandare.3}$ = 0.47), than when are improving on adaptive capacity component, as are observed in scenario 02 ($CVI_{Curitiba.2}$ = 0.47, $CVI_{Araucaria.2}$ = 0.46, $CVI_{Almirante\ Tamandare.2}$ = 0.47).

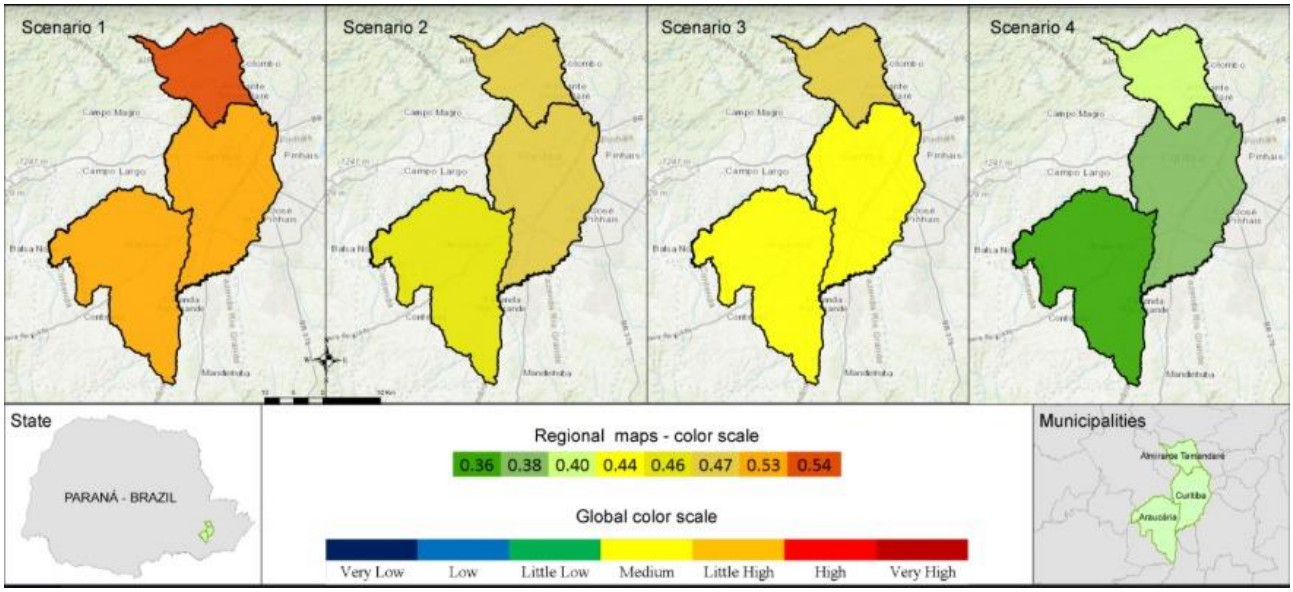

Figure 09 – Different scenarios of adaptation efforts

Therefore, remembering that scenario 01 (Figure 09) is the current scenario ($CVI_{Curitiba.1}$ = 0.53, $CVI_{Araucaria.1}$ = 0.53, $CVI_{Almirante\ Tamandare.1}$ = 0.54), presenting a Little High Vulnerable state (CVI = 0.5), and the following scenarios are the efforts made, is obvious that scenario 04 will be the best scenario, showing that with almost equal efforts on both components (adaptation and Governance), they can decrease to a Little Low Vulnerable state (CVI = 0.4).

DISCUSSION

Taking into account that systems need to improve their adaptive capacity to cope with the impacts of climate change Jubeh and Mimi, (2012); and Pandey et al. (2017), this work aims to suggest a new approach to climate vulnerability assessment, proposing an explicit consideration of the Governance component in the climate vulnerability function, and to provide a strong tool to assist decision-makers in assessing the impact of climate change. However, those improvements need to be adjusted to own reality, demanding more effort from the management institutions, including governance performance, as suggested by

Brooks et al. (2005); Dasgupta et al. (2006); Jubeh and Mimi, (2012); Oculi and Stephenson (2018); and Weiler et al. (2018). These findings reinforce the above results, giving the idea that countries must first know their gaps and barriers, such as the quality of infrastructure, and capacity building to effectiveness long-term vision.

Thus, as mentioned above, improving the climate vulnerability index by introducing a new component (governance component) could provide additional information to decision-makers to address climate change resilience issues, which include arrangements on management institutions and additional work in specific policies. Therefore, the difference between adaptation effort needs (Figure 07), may be related to human resource capacity, or local economy characteristics, according to Boero et al. (2015), which point out that the local economy has strong effects on vulnerability, and vice-versa. This evidence can be proven in the field if we consider that these municipalities have no other technical and financial resources than their own. However, even with a high score on the adaptive capacity component (Figure 06), which means more efforts are needed in the institutional arrangement to build resilient infrastructure, they need to continue working on capacity building-related governance component, involving the academic institutions.

CONCLUSION

Considering the main goal of this paper - identify the needs of the adaptation capacity to deal with extreme weather events - it was shown that the introduction of the Governance component gives more sensitivity to climate vulnerability function. Furthermore, it also has been demonstrated that systems with less effort in the adaptive capacity component are considered more vulnerable to the impact of climate change. However, the lack or unclear representation of one of these components (Adaptive capacity and Governance), may lead to an improbable outcome on climate vulnerability assessment (Marques et al. 2018). Therefore, it is clear that there is no single measure that can fully capture the multiple dimensions of vulnerability, it means, a set of metrics analyzed will be necessary to explain vulnerability across different systems (Luers et al. 2003). Thus, the most effective metrics will be those that can be collected and transparent enough to be applied to a wide range of systems, as also suggested by many researchers. However, due to human judgment, there are some inconveniences in this process related to subjectivity in decisions, but this does not invalidate the contribution of this proposal in the process of climate vulnerability assessment. Therefore, additional comparative studies are recommended focusing on the impact of Governance on climate vulnerability adaptation.

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CHAPTER 6

THE ROLE OF THE GOVERNANCE ON THE CLIMATE VULNERABILITY INDEX DEFINITION

HIGHLIGHTS

This chapter aims to present the application of specific indicators of adaptability in assessing climate vulnerability. We present an ongoing strategy for integrating climate change adaptation actions.

THE ROLE OF THE GOVERNANCE ON THE CLIMATE VULNERABILITY INDEX DEFINITION

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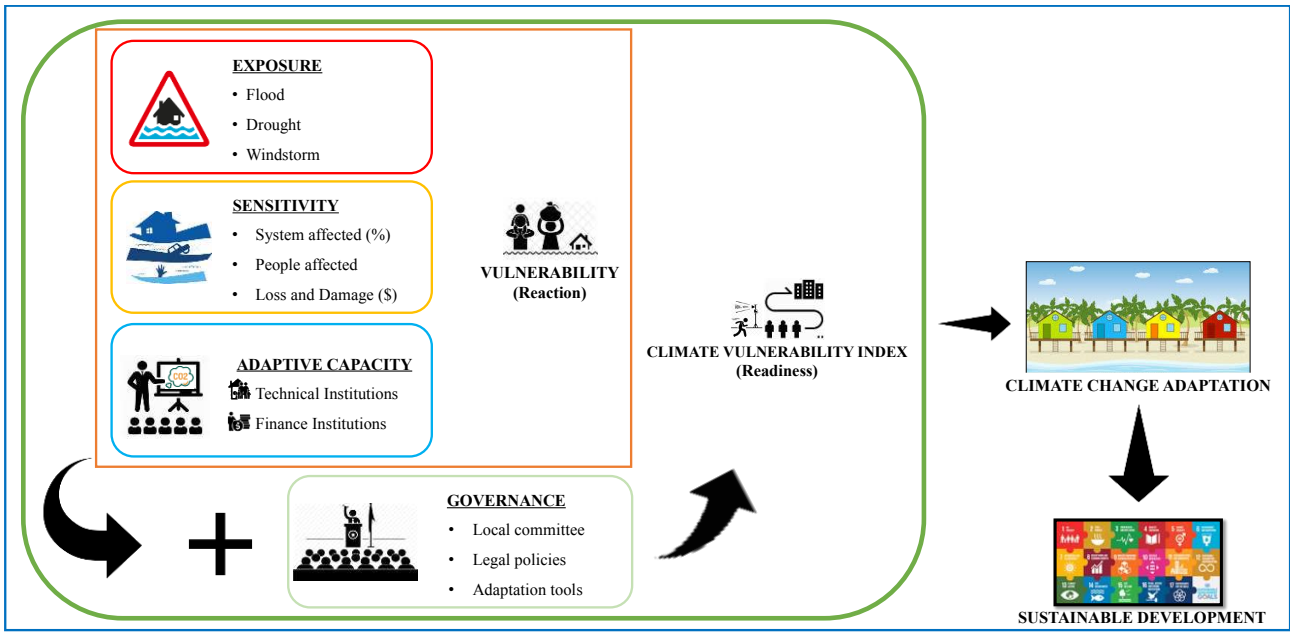
GRAPHIC ABSTRACT



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ABSTRACT

According to reports from international institutions such as IPCC, UNDP, and the World Bank, in the coming years, the impacts of climate change will continue affecting the planet, and mainly the Least Developed Countries (LDC). Such reports also state that the less resilient countries, defined by the climate vulnerability index (CVI), will be the most vulnerable, and the solutions to address the impacts of climate change must come from long-term planning leading by government management institutions. In general, the CVI is presented as a wide and well-accepted tool for assessing the susceptibility degree of a system by adverse effects of climate change. The CVI relates the Exposure, Sensitivity, and Adaptive Capacity for a specific Hazard, offering feasible supports for decision-makers in identifying country-specific needs to adapt to climate change. However, even given the general framework offered by CVI, the LDCs are still unable to cope with the impact of extreme events. This situation raises some questions about the tools used in evaluating climate change. As a consequence, the main question is, which part of Adaptive Capacity needs more effort to deal with extreme weather events? To address this issue, this paper discusses the governance role in the CVI definition, which suggests an alternative approach to assess climate vulnerability. Overall, we propose a tool to evaluate climate vulnerability, consider four main components: Exposure, Sensitivity, Adaptive Capacity, and Governance. In this case, the Governance component represents, government and non-government organizations, policies, and qualified human resources that could improve the planning and management of a specific system. Looking for a more specific approach we explicitly considered the Governance component in the climate vulnerability function, by adding the specific indicators. As a study case, we consider Mozambique, a highly vulnerable country to the adverse impact of climate change. The results have shown that by adding the Governance component to assess climate vulnerability, the function becomes more sensitive. In conclusion, Governance is accepted as a strong component in the CVI definition.

Highlights

- We discuss which part of the adaptation capacity, needs more effort to deal with extreme weather events;
- The impact of Governance component on climate vulnerability adaptation;
- The role of decision-makers in assessing the impact of climate change;
- An alternative approach of climate vulnerability assessment tool.

Keywords: Climate Vulnerability; Adaptive Capacity; Governance; Decision-makers.

INTRODUCTION

According to Brooks et al. (2005); Dasgupta et al. (2006); Jubeh and Mimi, (2012); Pandey et al. (2017); Oculi and Stephenson (2018); and Weiler et al. (2018), to get resilient, countries need to be improved to deal with the negative impacts of climate change. However, these improvements require more effort. It means that they have to be planned, dynamic, and adjusted to the countries realities. Therefore, countries must understand their gaps and barriers for effective long-term planning and then reduce vulnerability.

On the other hand, evidence has shown that more effort on adaptation capacity defines the level of vulnerability (IPCC, 2001; Brooks et al. 2005; Adger, 2006; Eakin and Bojórquez-Tapia, 2008; Pandey and Jha, 2012; Maiti et al. 2017). This means that more effort given on adaptation capacity can reduced vulnerability. Therefore, the most exposed system is not necessarily the most vulnerable.

Having all this knowledge, the above considerations make sense if we consider the relevance of the governance issues in management institutions. Therefore, the questions are: why the Least Developed Countries (LDC), including the Small Island Developing States (SIDS), still unable to cope with the impact of extreme weather events? Are their efforts on adaptation capacity not enough? How countries can play their role? All these questions can be answered by the time we really understand what governance on climate vulnerability assessment is and what is the role of the management institutions.

Previous studies have already mentioned the role of management institutions and, in particular, Governance on climate vulnerability (Dasgupta et al., 2006; Pandey and Jha, 2012; Jubeh and Mimi, 2012; Le and Chang, 2017; Pandey et al., 2017; Weiler et al., 2018). However, most of them focus on the political regime. They do not mention clearly how countries can play their governance role and what types of institutions or policies need to be improved. It appears that there is no explicit consideration of governance in assessing climate vulnerability. This apparent scenario leads this study to an evident demonstration of the Governance component role in assessing climate vulnerability.

Therefore, to address this issue, this work aims to propose an explicit consideration of the Governance component in the climate vulnerability function. We suggest that climate vulnerability function should take into account four main components: Exposure, Sensitivity, Adaptive Capacity, and Governance.

Governance and climate vulnerability

Vulnerability is a multi-dimensional term, used in different contexts and frequently related to civil society to assess socio-economic, health, political, and environmental development issues and describe the existing condition of the system. On the other hand, Governance is a multifaceted term, which can have different meanings, depending on the context. In the present context, the term governance means policies and institutions arrangements, based on the climate adaptation context, where governance represents the effort of various actors in society, nationally and internationally, in search of joint solutions to circumvent the negative impacts of climate change (Huitema et al., 2016).

In turn, the United Nations Framework Convention on Climate Change (UNFCCC) describes institutional arrangements regarding adaptation as a framework or approach established by stakeholders at different levels, with a view to guiding adaptation and vulnerability reduction actions (Worker, 2016). However, these approaches could be different according to the efforts of the quality of infrastructures, human resources, and the effectiveness of long-term planning, which include Governance. Therefore, the factors which make vulnerable communities in developing countries are not the same that makes vulnerable industrial countries. (Brooks et al., 2005; Le et al., 2017).

These concerns about the role of governance in climate change have led to seeking improvements in the institutional arrangements and in the process of integrating climate change into development plans and strategies. The findings suggested that synergies between sectors at all levels and institutionalization of climate change are the main issues to be addressed to achieve this goal. However, countries need specific tools to take this step (Drexhage, 2007; Chen et al., 2015; Sarkodie and Strezov, 2019).

Therefore, by definition, Governance will be a simple act of organization with the ability to pursuit solutions (Jubeh and Mimi, 2012). In this sense, climate vulnerability (CV) is defined as the susceptible degree to which a system is unable to deal with the adverse effects of climate change, expressed as a function of $CV = f(E, S, AC)$, where E is the Exposure, expressing the degree to which a system is close to significant climatic variations, S is Sensitivity, the degree to which a system is affected by the extreme events, and AC is the Adaptive Capacity, the flexibility of the system to adjust to climate change (IPCC, 2001; Mendoza et al. 2012; Krishnamurthy et al. 2014; KC et al. 2015; Oculi and Stephenson, 2018; Koutroulis et al. 2018; Marília et al. 2018).

Thus, analyzing the above approach, it becomes necessary to assign responsibilities in the process of adapting to climate change through an institutional arrangement. Therefore, the explicit consideration of the Governance in the adaptability component will bring an alternative approach to climate vulnerability problems, and not just information about the system's vulnerability status.

The following sections will present the different stages of this work, which includes the study area, method, the data collection, and the analysis process. After that, we present the results and discussion, given the degree of vulnerability according to the Fuzzy Logic concept. Here, the most important thing is to show that the values can change according to the sensibility of the function or the effort given on the system. Finally, we conclude combining the climate vulnerability index with the readiness value to show the need for climate resilience.

Study Area

Our analysis is applied in Mozambique, a country located in the extreme south of Africa (10-27º S, 30-41º E). Mozambique has a coverage area of about 799,380 km² and a population of approximately 28,000,000 inhabitants (Figure 01). In addition to its long coastline of just over 2,700 km, the 9 river basins with international characteristics stand out, giving the country a privileged position in terms of water resources exploration.

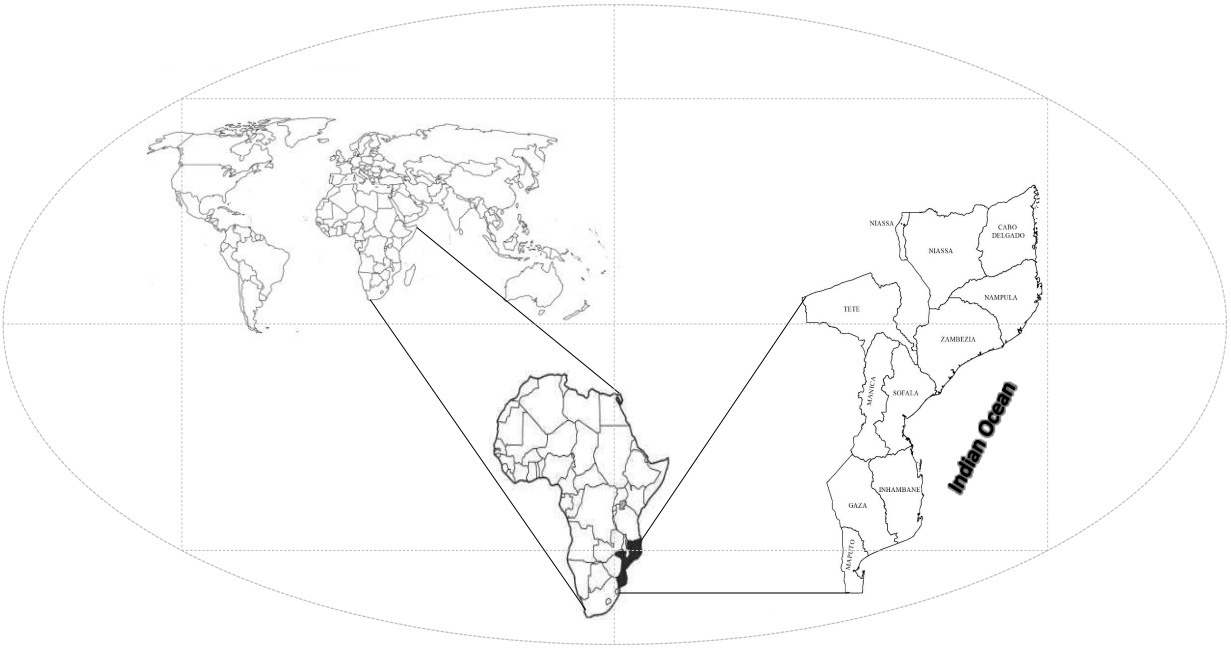


Figure 01 - Republic of Mozambique in southern Africa.

Mozambique morphology has a large part of its territory below 400 m above average sea level. These lands, characterized by coastal plains extending to the inland, cover almost 50% of the national territory. As for climatology, the country is considered semi-arid and subtropical in the south and tropical in the north. Temperatures range from 22 ºC to 27 ºC in the hottest months and 14 ºC to 18 ºC in the coldest months. On the other hand, annual levels of precipitation vary from 500 to 2000 mm, with 1000 to 1500 mm in the rainy season (October – April) and 600 to 800 mm in the dry season (May – September) (Uele et al., 2017). On the other hand, due to its socio-economic situation coupled with its geographical profile, Mozambique is considered a highly vulnerable country to the adverse impact of climate change (Figure 02).

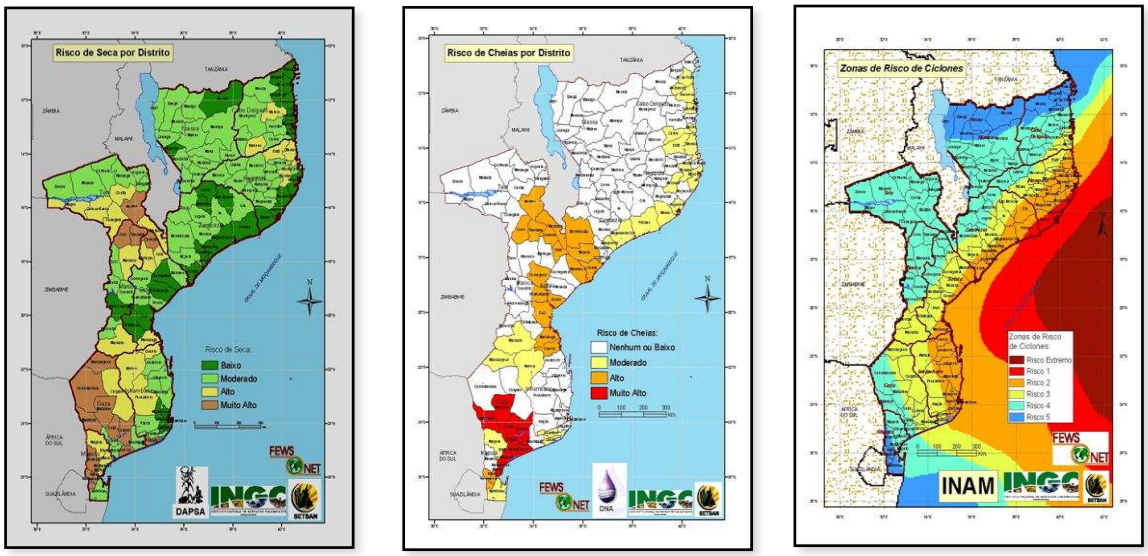


Figure 02 - The main extreme weather events in Mozambique are floods, droughts, and windstorm (INGC, 2006).

Parallel to this condition, records show that in the last 20 years, at least 14% of the national population has been affected by an event, such as drought, flood or windstorm (Figure 02), and over half of them (53%) having resulted in disaster (Figure 03). These findings, reinforced by the frequent increases of extreme weather events in recent years, and with increasingly alarming magnitudes, put the country on a scenario of readiness where the demands for solving problems resulting mainly from extreme rains are the main concern to decision-makers. These actions make sense if we take into account that agriculture, the most vulnerable sector, is the main economic sector in the country, and about 70% of the Mozambican population lives in coastal areas, which are mostly rural. Therefore, this may result in negative impacts when hit by an extreme event such as the dramatic case of the 2000 floods that affected around 500,000 Mozambicans in the south of the country, and the

2019 IDAI cyclone that affected around 600,000 Mozambicans in the center and north of the country.

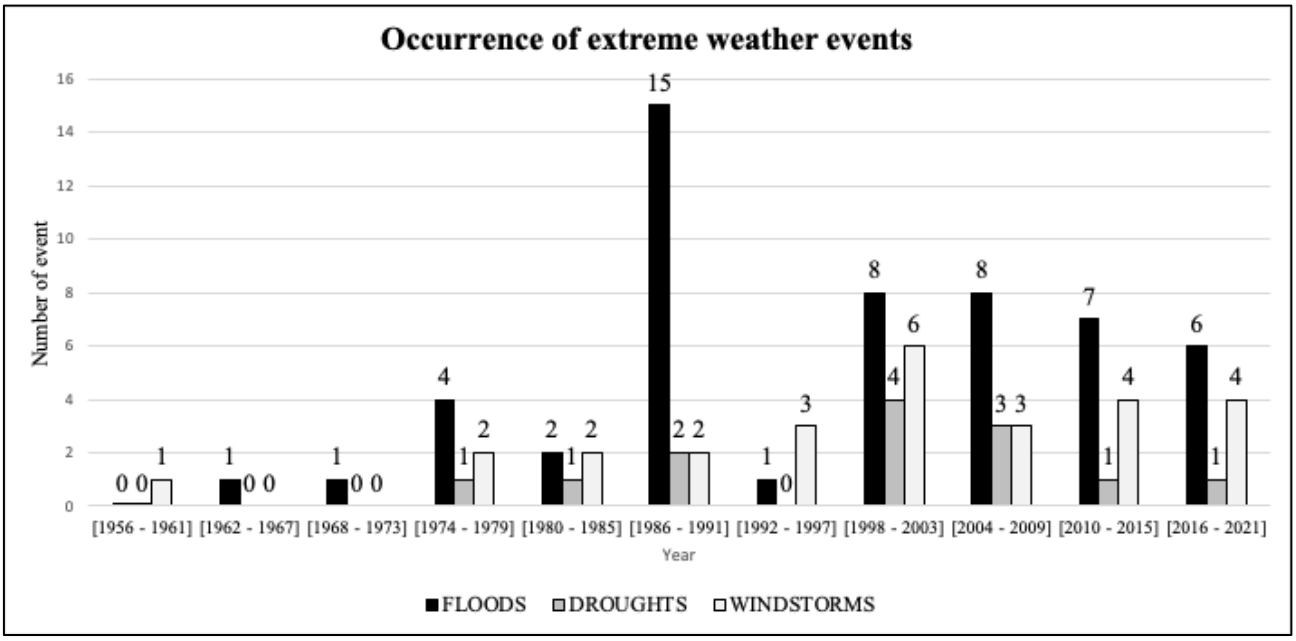


Figure 03 – Frequency of extreme weather events (1956 – 2020)

This scenario led the Government to look for more effective solutions that started with the approval of the National Strategy for Adaptation and Mitigation to Climate Change (ENAMMC) in 2012, and, more recently, the definition as a priority within the Government's Five Year Plan “Ensuring Sustainable and Transparent Management of Natural Resources and the Environment”. This advance clearly shows the Mozambican Government's intention to respond to the Sustainable Development Goals, but at the same time, it brings more challenges to expertise. Therefore, there is a need to improve the disaster risk management system to project a safety scenario of sustainable use of natural resources. It is in this context that this study fits, to allow better targeting of national investments, taking into account the climatic adversities, and providing the best development for the country.

METHODS

This work is divided into four stages (Figure 04). First, we define the main components and indicators through the Analytical Hierarchy Process (AHP) based on predefined criteria. Second, we choose from a set of candidates the main indicator through the Indicator Method. Third, we normalize the data and determine the weight of each

component using the Iyengar and Sudarshan method. Subsequently, using the Fuzzy Logic applied to the ND-GAIN approach, we define the Climate Vulnerability Index, and the state of readiness of the system, based on its socioeconomic conditions. Fourth, we show the results and discuss them considering the proposed climate resilience scenario based on the effort made in the system.

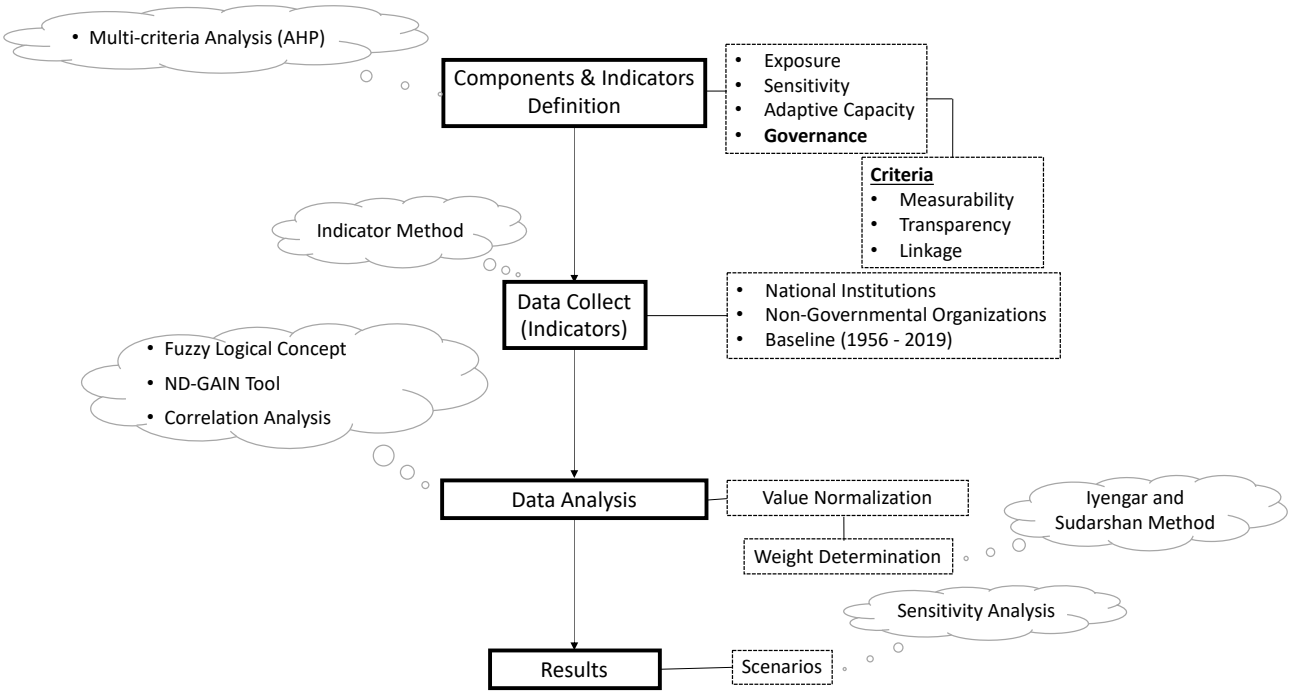


Figure 04 - The stages of the work

Data Available

To identify the indicators to be considered in the study, we followed the three-stages hierarchical process depicted in Figure 05. We collected the data from the Ministry of Land and Environment (MTA), the National Institute for Disaster Management (INGC), and the National Institute of Meteorology (INAM), in Mozambique. Alongside those national institutions, we consulted the Emergency Events Database (EM-DAT) at Catholic University of Louvain (UCL), Brussels-Belgium, through the webpage https://public.emdat.be/data. Thus, based on defined criteria (Stage II, Figure 05), and previously indicators (Stage III, Figure 05), we identified the eligible events between 1956 – 2019 in the available time-series database.

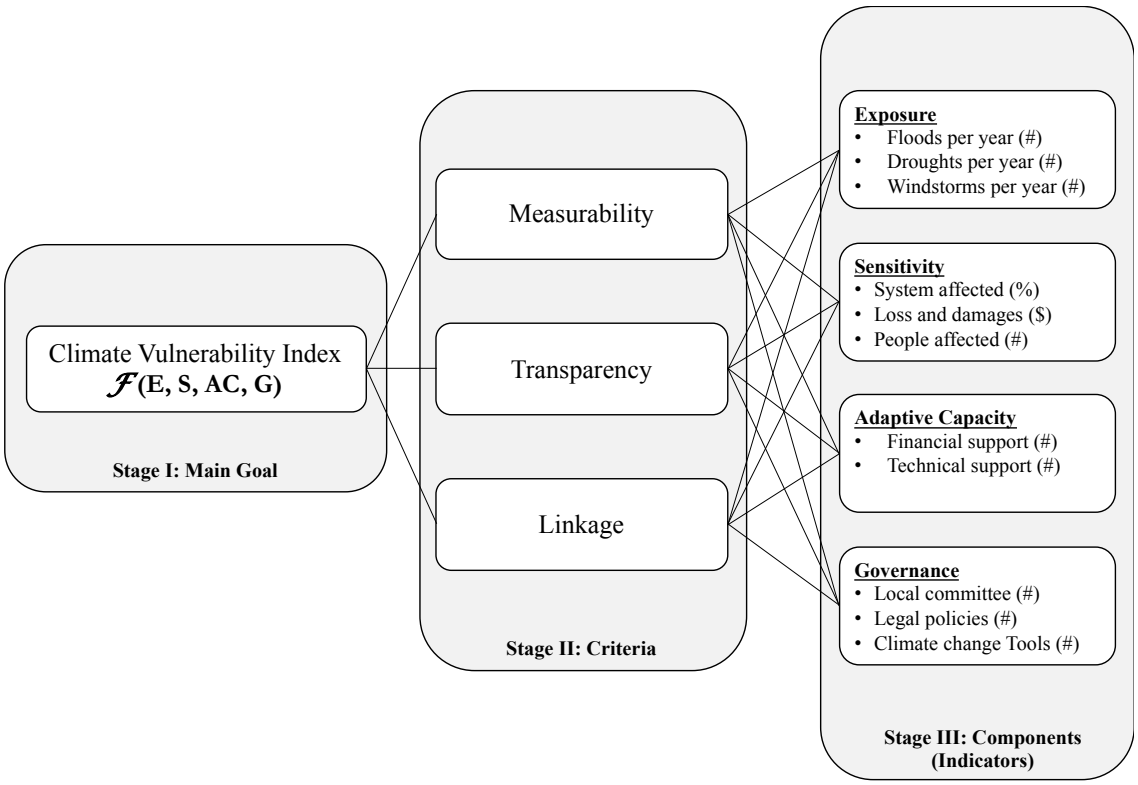


Figure 05 - Hierarchy of the problem

Indicator Determination

The indicators were identified based on defined criteria (Stage II, Figure 05), under the four main components: Exposure, Sensitivity, Adaptive Capacity, and Governance. After that, they were collected from the national institutions applying the Indicator Method, which bases on choosing the main indicators from the set of potential national indicators (Vincent, 2004; UNITED NATIONS, 2007; Hinkel, 2011; Maiti et al. 2017). Furthermore, through the Analytic Hierarchy Process (AHP) (Saaty 1989a; Saaty 1990b), we selected the best indicators (Stage III, Figure 05).

However, according to Sullivan (2002), Mazziotta and Pareto (2013), and Anandhi and Kannan (2018), it is important to mention that Climate Vulnerability is an empirical tool which is defined taking into account the main goal of the specific system (Stage I, Figure 05). Thus, to be acceptable and useful to decision-makers, we selected only 11 indicators, based on the principle of the smaller the amount of data to be collected, the greater the chance of the tool be used. Table 01 shows a detailed description of the chosen indicators.

Table 01 – Four Main Components and their Indicators

Component	N.	Indicator	Interpretation
		Measurability Transparency Linkage	
Exposure	E1	Extreme events of floods per year (#)	The exposure of the system to this event due to his geographic location (risk level).
	E2	Extreme events of droughts per year (#)	The exposure of the system to this event due to his geographic location (risk level).
	E3	Extreme events of windstorms per year (#)	The exposure of the system to this event due to his geographic location (risk level).
Sensitivity	S1	System affected by extreme events per year (%)	The impact over the system in terms of expansion/size (coverage area).
	S2	Loss and damages in the system per year ($)	The economic and physical impacts over the system. Existence of resilience (necessary budget).
	S3	People affected around the system (#)	Population Density.
Adaptive Capacity	AC1	Institutions providing financial support (#)	Organizations with willingness to invest on adaptation over the System (funding).
	AC2	Institutions providing technical support (#)	Operating institutions to cope with the negative impact on the system (knowledge and human resource)
Governance	G1	Local management committee (#)	The existence of management institutions in operation. Level of the organization to cope the climate issues
	G2	Legal policies approved (#)	Specific legislation of climate issues. Influence of the committee on management process over the System
	G3	Adaptation tools for climate change (#)	Strategies and plans elaborated and in operation in the system.

The collected data are normalized to allow comparisons between them. However, according to Ford and Smit, (2004), vulnerability is a positive function of the system's exposure and sensitivity, and a negative function of the system's adaptive capacity. Thus, it is important to know that if the available indicator increase and the vulnerability also increase, the normalization process will be by equation (01), and if the indicator increase and vulnerability decrease, will be equation (02), according to Pandey and Jha, (2012); Kumar et al. (2017); Pandey et al. (2017); and Anandhi and Kannan, (2018).

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

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

where X_v is the value to be normalized, X_{min} and X_{max} are the minimum and maximum values of the indicator on the impact area, X is the normalized value. Once normalized, the values of each component are defined by equation (03).

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

where C is each component value (E, S, AC, or G), X_i is indicator 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.

In this paper, to avoid subjectivity, we adopted the Iyengar and Sudarshan's method (equation 04), which is based on the uncertainty aggregate on variance. The method assigns smaller weights to the components with greater variance (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:

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

Table 02 shows the total and average results of the collected data for each indicator, as well as the calculated weight for the considered components.

Table 02 – Total and average results per indicator and specific weight for each component (1956 – 2019).

Component	Weight	N.	Indicator			Total	Average
			Measurability	Transparency	Linkage		
Exposure	0.259	E1	Extreme events of floods per year (#)			53	1.43
		E2	Extreme events of droughts per year (#)			13	0.35
		E3	Extreme events of windstorms per year (#)			27	0.73
Sensitivity	0.292	S1	System affected by extreme events per year			1,509.53	40.80
		S2	Loss and damages in the system per year			3,384,750,000.0	91,479,729.73
		S3	People affected around the system (#)			17,035,630,744.	460,422,452.54
Adaptive Capacity	0.213	AC1	Institutions providing financial support (#)			10	0.27
		AC2	Institutions providing technical support (#)			17	0.46
Governance	0.236	G1	Local management committee (#)			1,060	28.65
		G2	Legal policies approved (#)			1	0.03
		G3	Climate change adaptation plans and			122	3.30

The overall Climate Vulnerability Index (CVI) was determined by equation 06:

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

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.

Finally, we combined the climate vulnerability index (CVI) with the readiness value ($R_{ead}V$) to identify the relevant issues to be improved by the country (Figure 06). This analysis based on the Notre Dame-Global Adaptation Index (ND-GAIN) tool approach from the University of Notre Dame University (Chen et al., 2015).

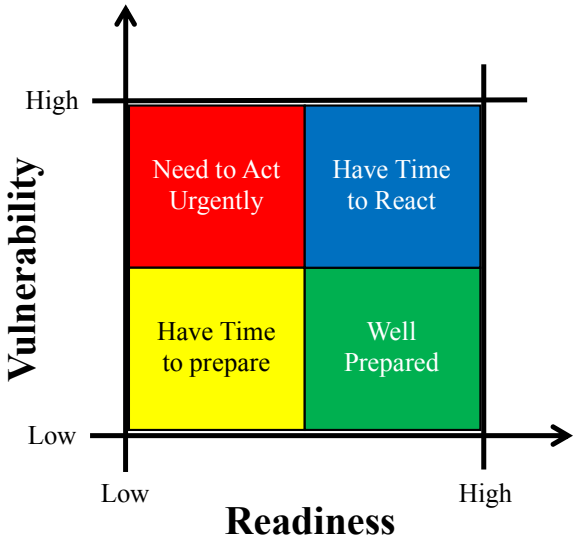


Figure 06 - Combination of vulnerability and readiness to obtain the current status of the system in terms of reacting to the negative impact of climate change (adapted from Chen et al., 2015**).**

In the $R_{ead}V$ approach, the data is taken from the adaptive capacity and governance components (Table 01) and applied in equation 07:

$$R_{ead}V = \frac{W_{AC}.AC + W_G.G}{W_{AC} + W_G} \quad (07)$$

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

To express the final results (CVI), we considered the Fuzzy Logic concept (Figure 07) and grouped them in classes to give the state or condition of the system as (0.0 – 0.3) Very Low, (0.0 – 0.4) Low, (0.2 – 0.5) Little Low, (0.3 – 0.7) Medium, (0.5 – 0.8) Little High, (0.6 – 1.0) High, and (0.7 – 1.0) Very High (Dasgupta et al. 2006; Eakin and Bojórquez-Tapia, 2008; Krishnamurthy et al. 2014).

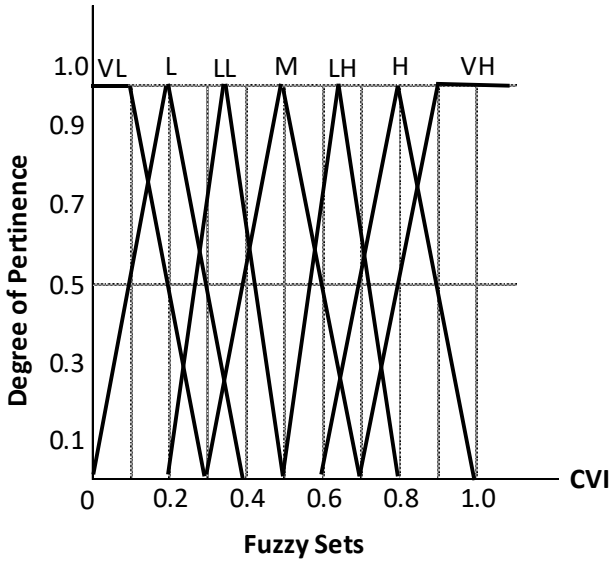


Figure 07 – Fuzzy logic concept applied to the CVI

RESULTS AND DISCUSSION

Figure 08 shows the results obtained for CVI and $R_{ead}V$ in Mozambique. Analyzing the CVI, the country is considered Little High Vulnerable ($CVI_{Mozambique}$ = 0.51). This indication is acceptable if we consider the frequency of extreme events and the socio-economic condition of the country to recover from the negative impact of extreme weather events.

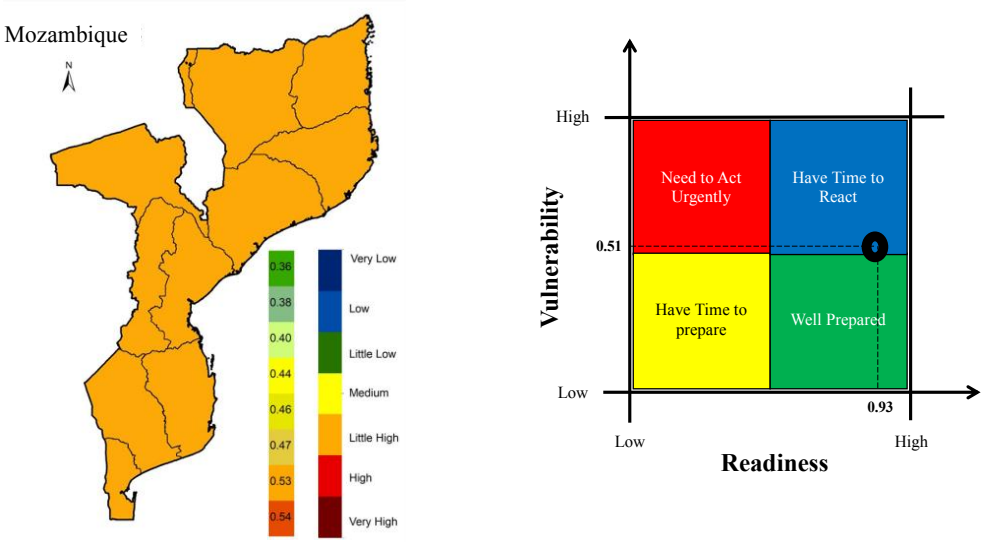


Figure 08 – Results for CVI (left) and $R_{ead}V$ (right) in Mozambique.

On the other hand, the readiness value ($R_{eadV.Mozambique}$ = 0.93) show that Mozambique is in the Blue State. It means that in case of an extreme event occurrence, the in-charge institution can be activated on time to react. These results may be controversial compared to other tools (https://gain.nd.edu/our-work/country-index/), nevertheless, it is important to mention that the indicators used on this work were adjusted to the country's reality and do not enter into political issues, just on the institutional arrangement (see Table 01). Therefore, readiness in terms of institutional capacity, policy, and strategies.

However, the country's situation is improving significantly, especially after the 2000 floods, when the country started a deep structuration of its strategies and setting up policies to deal with climate change. To fully understand this improvement, two periods were analyzed before and after ENAMMC (Figure 09).

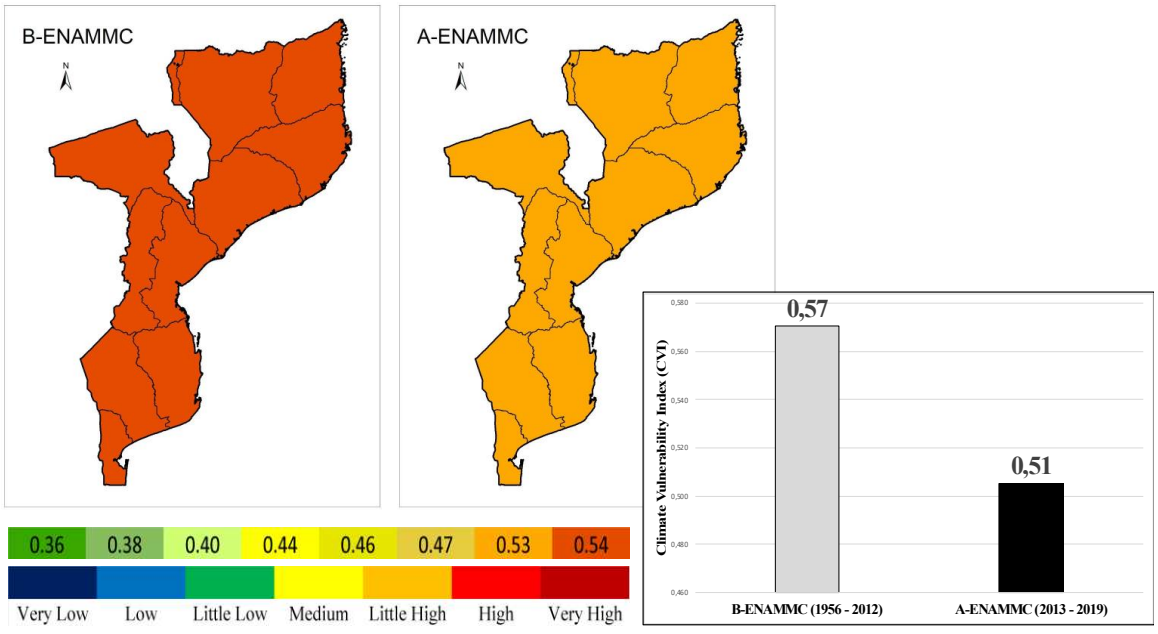


Figure 09 – Climate vulnerability index in Mozambique before and after the ENAMMC approval (B-ENAMMC and A-ENAMMC, respectively).

Therefore, Figure 9 shows that before the ENAMMC approval (B-ENAMMC), Mozambique was considered High Vulnerable ($CVI_{B\text{-}ENAMMC}$ = 0.57) to the negative impact of climate change. The same analysis after that (A-ENAMMC) showed that the climatic

vulnerability index decreases by 10.5% and were considered to be Little High vulnerable ($CVI_{A\text{-}ENAMMC}$ = 0.51). To further explore this issue, we consider the proposed alternative climate vulnerability function *CV = f(E, S, AC, G)*, which explicitly considers the governance component in the original function (Figure 10).

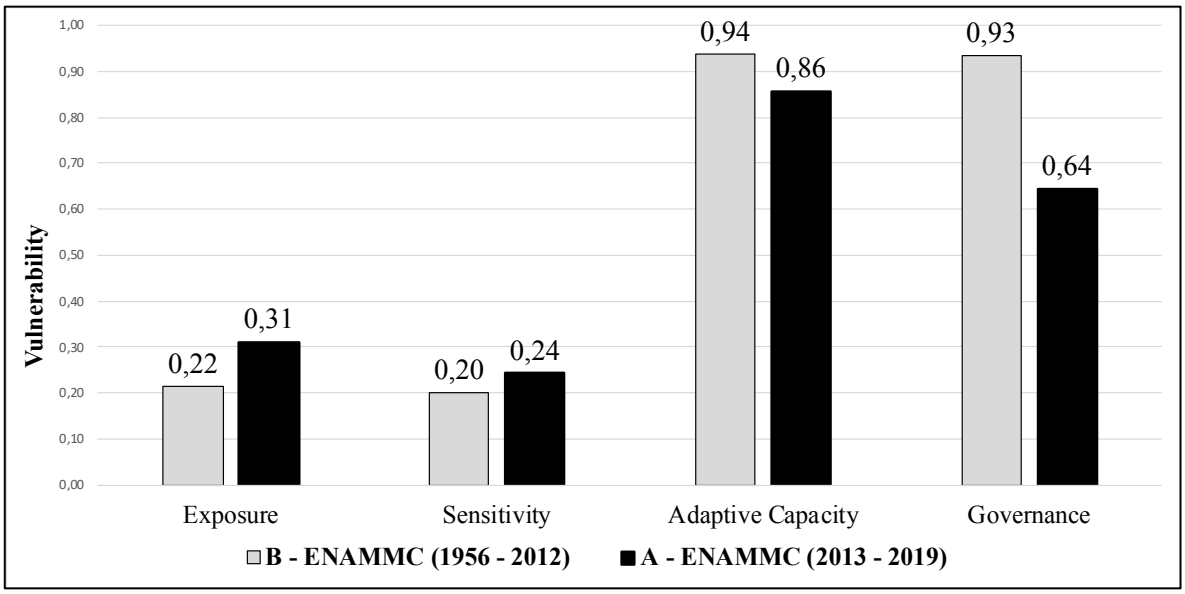


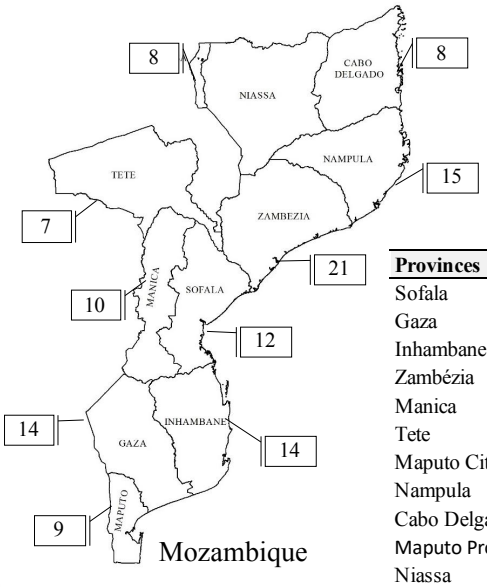
Figure 10 – Vulnerable components in Mozambique before and after the ENAMMC approval.

With this alternative approach, explicitly considering the Governance component, we observe that, although the country is more exposed in terms of the frequency and magnitude of extreme weather events, the improvement in the adaptation capacity, mainly in the governance component, resulted in the reduction of climate vulnerability. These observations make sense if we examine the number of local committees (G1) and local adaptation plans (G3), constituted and prepared after the approval of ENAMMC in 2012 (Table 03).

Table 03 – Average results per indicator before and after the ENAMMC approval.

Component	N.	Indicator			Mozambique (B - ENAMMC)	Mozambique (A - ENAMMC)
		Measurability	Transparency	Linkage		
Exposure	E1	Extreme events of floods per year (#)			1.43	1.43
	E2	Extreme events of droughts per year (#)			0.40	0.14
	E3	Extreme events of windstorms per year (#)			0.77	0.57
Sensitivity	S1	System affected by extreme events per year (%)			39.93	44.52
	S2	Loss and damages in the system per year ($)			36,705,000.00	326,228,571.43
	S3	People affected around the system (#)			993,843.37	2,429,402,206.14
Adaptive Capacity	AC1	Institutions providing financial support (#)			0.07	2.29
	AC2	Institutions providing technical support (#)			0.30	1.14
Governance	G1	Local management committee (#)			22.23	56.14
	G2	Legal policies approved (#)			0.00	0.14
	G3	Climate change adaptation plans and strategies (#)			0.10	17.00

These improvements are related to government initiatives, such as the decentralization process that has increased the representation of local communities in several aspects. On the other hand, through the introduction of climate change issues in the mandatory land-use plans, came the opportunity to strengthen development strategies at the local level (Figure 11). This process resulted in more than 390 local committees and 118 Local Adaptation Plans (LAP), created after the ENAMMC approval, covering most of the country's 154 districts.



Provinces	Extreme Events	%
Sofala	28	13,86
Gaza	27	13,37
Inhambane	27	13,37
Zambézia	24	11,88
Manica	20	9,90
Tete	20	9,90
Maputo City	19	9,41
Nampula	16	7,92
Cabo Delgado	10	4,95
Maputo Province	8	3,96
Niassa	3	1,49

Figure 11 – Plans elaborate in the context of integrating climate change in development strategies at the local level.

Sensitivity analysis

When proposing an analysis based on climate vulnerability reduction scenarios, we noted that the system can have different resilience scenarios according to the effort made. To explore this issue, we performed a sensitivity analysis combining several possible adaptation efforts. Figure 12 exhibits four representative scenarios obtained with this analysis.

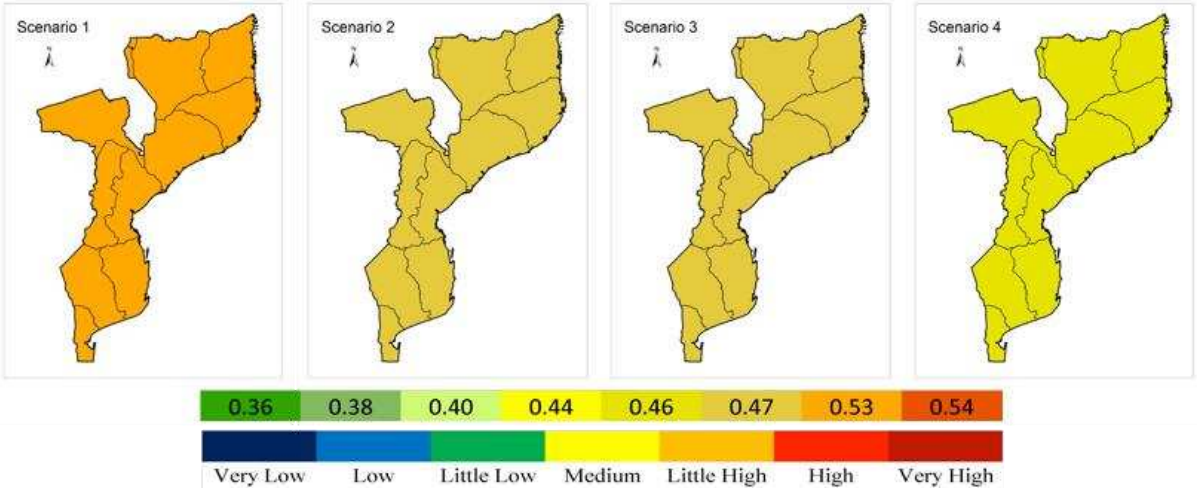


Figure 12 – CVI obtained with different scenarios of adaptation efforts.

In Figure 12, the scenario 1 is the current scenario ($CVI_{scenario\ 01}$ = 0.51, Little High Vulnerable), and scenario 4 is seen as the best scenario ($CVI_{scenario\ 04}$ = 0.45, Medium Vulnerable). This last one is the result of improvement in all components. However, an improvement in adaptive capacity only (scenario 2), or in the governance component (scenario 3), will result also in climate vulnerability reduction ($CVI_{scenario\ 02}$ = 0.48; $CVI_{scenario}$ 03 = 0.48). Nevertheless, it will not take to the best scenario. This means that to obtain the best scenario, an improvement effort in all components is necessary.

Therefore, taking scenario 1 as the baseline, we adjusted with the support of a Monte Carlo-scheme simulation, increasing one by one the efforts of each indicator (Figure 13a). As an example, we increased the number of financial institutions until we get the lowest value of the CVI (Figure 13b). Once that the number increment result also an increment of climate vulnerability index (AC1 = 21, CVI = 0,51), it is assumed that the number before that is the best scenario for that indicator (AC1 = 20, CVI = 0,50). This exercise was made for all Adaptive Capacity and Governance indicators to get the best scenario (Figure 13b-f), always keeping fixed the Exposure and Sensitivity indicators (Table 04).

Thus, scenario 04 ($CVI_{scenario}$ 04 = 0.45) is the result of the combination of the each best result of each indicators scenario (AC1 = 20, CVI = 0,50; AC2 = 26, CVI = 0,50; G1 = 1260, CVI = 0,50; G2 = 2, CVI = 0,49; G3 = 122, CVI = 0,51). However, even knowing the best scenario, Mozambique needs more effort on adaptive capacity, according to the increased effort to get the best scenario (Table 04).

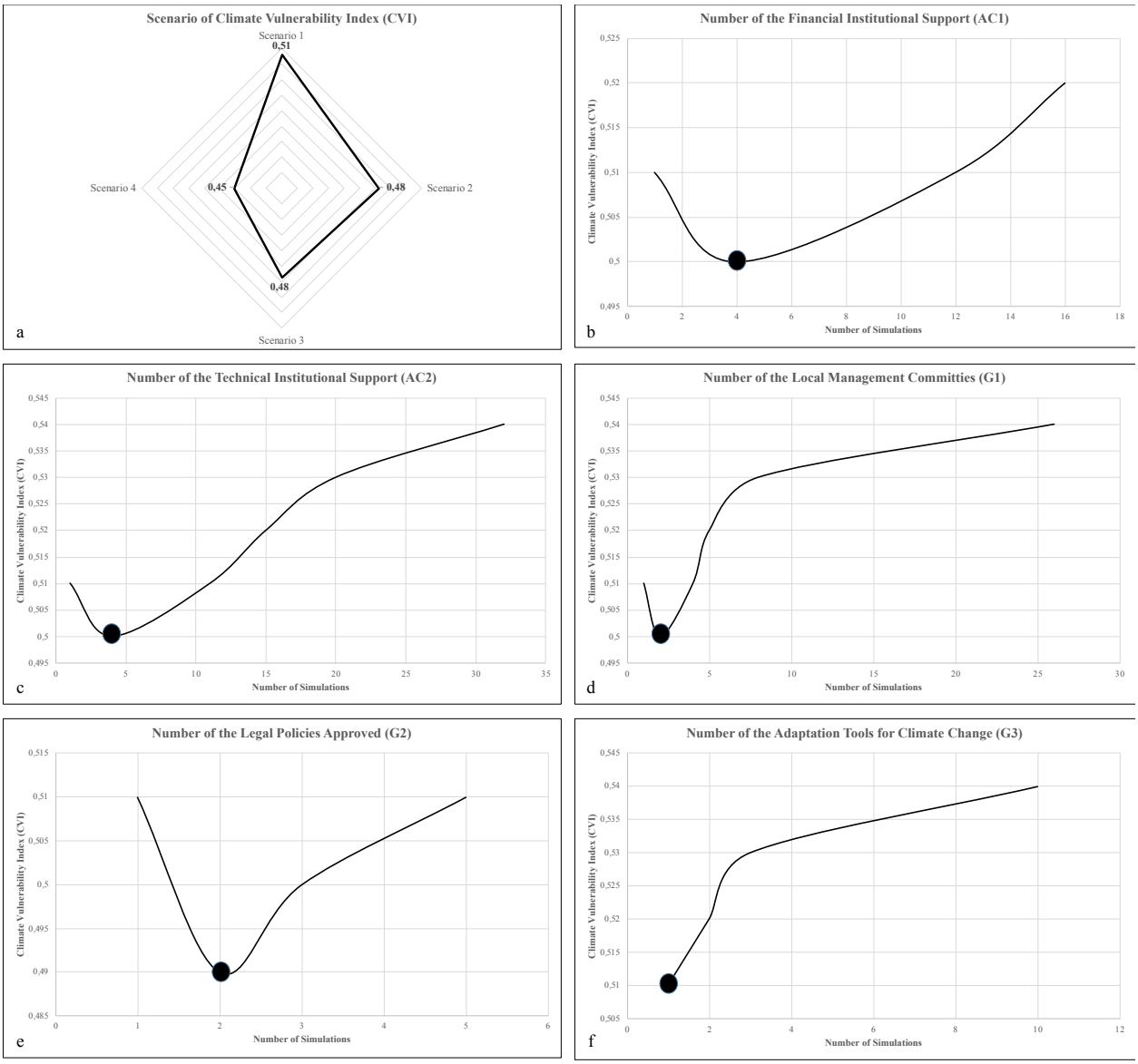


Figure 13 – The best scenario for each indicator

Table 04 - The average occurrence of extreme events on different scenarios (Mozambique)

Component	N.	Indicator			Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Measurability	Transparency	Linkage				
Exposure	E1	Extreme events of floods per year (#)			53,00	53,00	53,00	53,00
	E2	Extreme events of droughts per year (#)			13,00	13,01	13,01	13,01
	E3	Extreme events of windstorms per year (#)			27,00	27,00	27,00	27,00
Sensitivity	S1	System affected by extreme events per year (%)			1.509,53	1.509,53	1.509,53	1.509,53
	S2	Loss and damages in the system per year ($)			3.384.750.000,00	3.384.750.000,00	3.384.750.000,00	3.384.750.000,00
	S3	People affected around the system (#)			17.035.630.744,00	17.035.630.744,00	17.035.630.744,00	17.035.630.744,00
Adaptive Capacity	AC1	Institutions providing financial support (#)			10,00	20,00	10,00	20,00
	AC2	Institutions providing technical support (#)			17,00	26,00	17,00	26,00
Governance	G1	Local management committee (#)			1.060,00	1.060,00	1.260,00	1.260,00
	G2	Legal policies approved (#)			1,00	1,00	2,00	2,00
	G3	Climate change adaptation plans and strategies (#)			122,00	122,00	122,00	122,00

CONCLUSION

This work aimed to emphasize the role of decision-makers on the climate vulnerability assessment, through explicit consideration of the Governance component in the climate vulnerability function. Here, it has shown that the Governance component has an important role in identifying the needs of adaptation and the management institutions with a commitment to improving policies and develop strategies that include climate change. However, according to Luers et al. (2003), it is necessary a set of metrics to fully capture the multiple dimensions of vulnerability and, the lack of one of these metrics may lead to an improbable outcome on climate vulnerability assessment, as reinforced by Marques et al. (2018).

Thus, remembering that in climate change, governance could be the process of empowering people and strengthening public institutions to build climate resilience (Meadowcroft, 2009), Mozambique was an example with the ENAMMC approval and inter-institutional group on climate change (GIIMC), which resulted in more 118 local adaptation plans. On the other hand, the creation of the National Directorate for Climate Change in the Ministry of the Environment, as climate change focal point in Mozambique, provided comfort in terms of readiness at strategies level, and institutional arrangement. In conclusion, Mozambique is in a good position to react strategically if a climactic event occurs.

However, according to the ND-GAIN tool from Notre Dame University, Mozambique should invest more in government policies (Chen et al., 2015). On the other hand, this study shows that this investment should be in research directly linked to climate change and fully aligned with the government strategies plans. This position will provide more technical and financial investment for the development of research related to climate issues. Therefore, it is not a question of increasing funding or change government behavior, but more engagement from the academic institutions and private sector on these issues, as well as regular reports to parliament on climate change performance.

Nevertheless, this approach of identifying specific indicators to be improved, with the decision-makers as leaders of the process, became successful in Mozambique improving their local development strategies for effective long-term vision, on the way to achieve climate resilience. Therefore, although the Governance component has shown as a strong tool to assist decision-makers in assessing the impact of climate change, no single measure can be fully inclusive, mainly due to some subjectivity related to human judgment.

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CHAPTER 7

CLIMATE CHANGE MAINSTREAMING INTO LOCAL PLANNING

HIGHLIGHTS

This chapter aims to present the details of the process of integrating climate change into strategic development plans.

CLIMATE CHANGE MAINSTREAMING INTO LOCAL PLANNING

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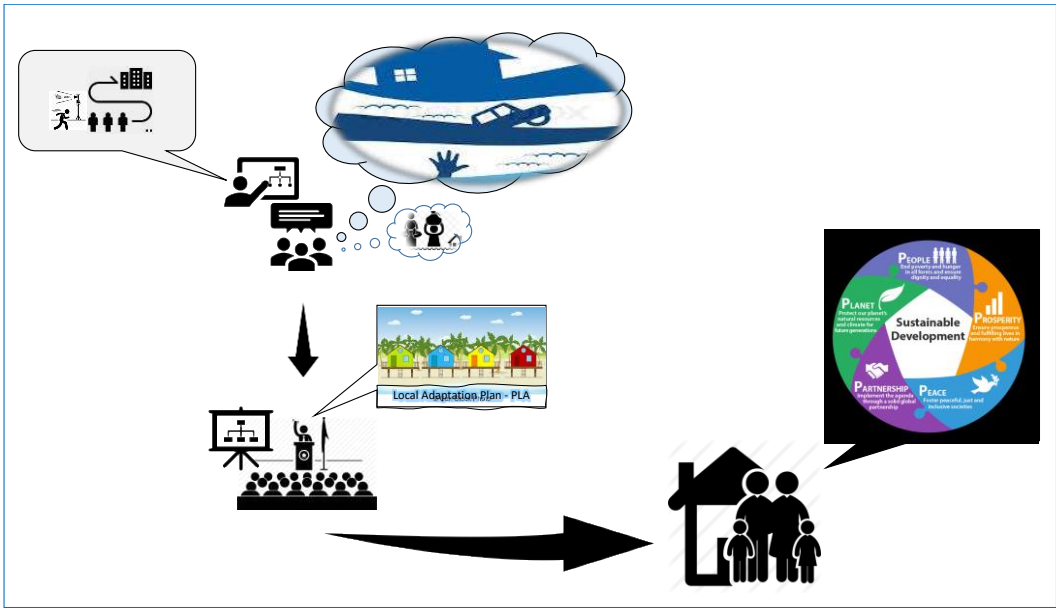
GRAPHICAL ABSTRACT



Highlights

- The integration of climate change at the local level.
- The role of decision-makers as the leads of the process of disaster risk reduction.
- The impact of governance process on climate adaptation.

Keywords: Climate Vulnerability; Adaptation Plans; Governance; Decision-makers.

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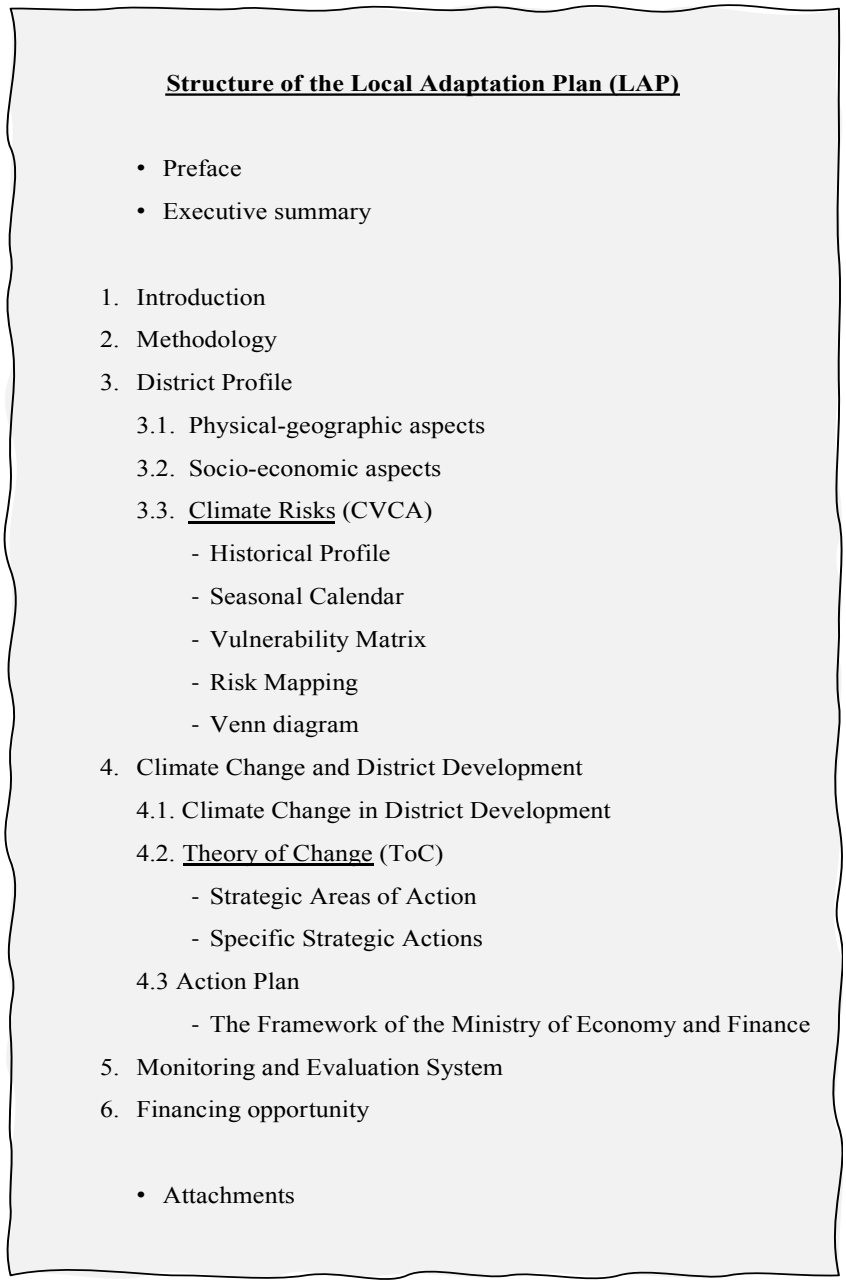
INTRODUCTION

Climate resilience is an essential stage to deal with the impact of climate change. But what is that mean? How can countries be climate resilient? The are several approaches around these issues, and all of them are lead to a consensus that climate resilience is the ability of the system to recover from the impact of future extreme weather events (Brooks et al., 2005; Dasgupta et al., 2006; Jubeh and Mimi, 2012; Pandey et al., 2017; Oculi and Stephenson, 2018; Weiler et al., 2018). However, these abilities have to come from medium-long term planning. Therefore, to get climate resilience, countries were invited to develop their National Adaptation Plans (NAP). For most of the Least Developed Countries (LDC), the challenge is not just on disaster risk reduction but on the way to come up with the new strategic development plans. There is a lot of effort to integrate climate change in regional and sectoral development plans. Countries like Mozambique are a good example of this effort with visible results in the climate change introduction process at local planning. So, how they got these results?

The role of Local Adaptation Plans

Mainstreaming climate change at different levels still a big challenge for all. Therefore, having a tool that can provide information about climate vulnerability level and system ability to adapt to the impact of extreme events is a tremendous step forward in this process of the identification and prioritizing adaptation measures to be integrated into the local planning. However, the success of all of this is on the lead. It means the integration process must be ownership by decision-makers. Therefore, the governance issue is extremely important in this process. Overall, the Local Adaptation Plans (LAP - Figure 01) were introduced to guarantee the integration of the climate change issue into the District Development Plan (PDD in portuguese) process, and thus implement the National Strategies of Climate Change and will contribute on NAP development process. Or will guide the NAP development process.



Structure of the Local Adaptation Plan (LAP)

- Preface
- Executive summary

1. Introduction
2. Methodology
3. District Profile
   - 3.1. Physical-geographic aspects
   - 3.2. Socio-economic aspects
   - 3.3. Climate Risks (CVCA)
     - Historical Profile
     - Seasonal Calendar
     - Vulnerability Matrix
     - Risk Mapping
     - Venn diagram
4. Climate Change and District Development
   - 4.1. Climate Change in District Development
   - 4.2. Theory of Change (ToC)
     - Strategic Areas of Action
     - Specific Strategic Actions
   - 4.3 Action Plan
     - The Framework of the Ministry of Economy and Finance
5. Monitoring and Evaluation System
6. Financing opportunity

- Attachments

Figure 01 – Structure of the Local Adaptation Plan

There are many studies that mention the role of decision-makers and the governance process as the way forward to reduce climate vulnerability. However, few of them have clearly demonstrated that having both pathways together is the right way to guarantee the integration of climate change in development strategies. According to IPCC (2001), climate adaptation is a positive effort in the system to reduce climate vulnerability, and these can achieve through institutional arrangements and policies (Huitema et al., 2016). It means, in the context of climate adaptation, governance represents the effort of national and international actors, involving the decision-makers, in search of joint solutions to deal with the negative impacts of climate change, which includes the civil society and the private sector (Keskitalo, 2009).

Therefore, to address this issue, this paper aims to share some thoughts and good practices on climate vulnerability reduction through the Governance process. This process is a mechanism of mainstreaming climate change based on the elaboration of the Local Adaptation Plans. The following sections will demonstrate how this process happened in Mozambique, the tools and methodologies used to collect and analyse data. Furthermore, according to the Fuzzy Logic concept, here will present the results through the illustration maps of climate vulnerability. However, the most important issue is valorising the impacts of the efforts given on the governance component.

Study Area

Mozambique is a country from the extreme south of the African continent, located between 10-27º S and 30-41º E (Figure 02). His population is about 28,000,000 inhabitants into 799,380 km² coverage area. Mozambique has 2700 Km of coastline, besides the 09 international river basins, which give him the privilege to be called the pearl of the Indian Ocean.

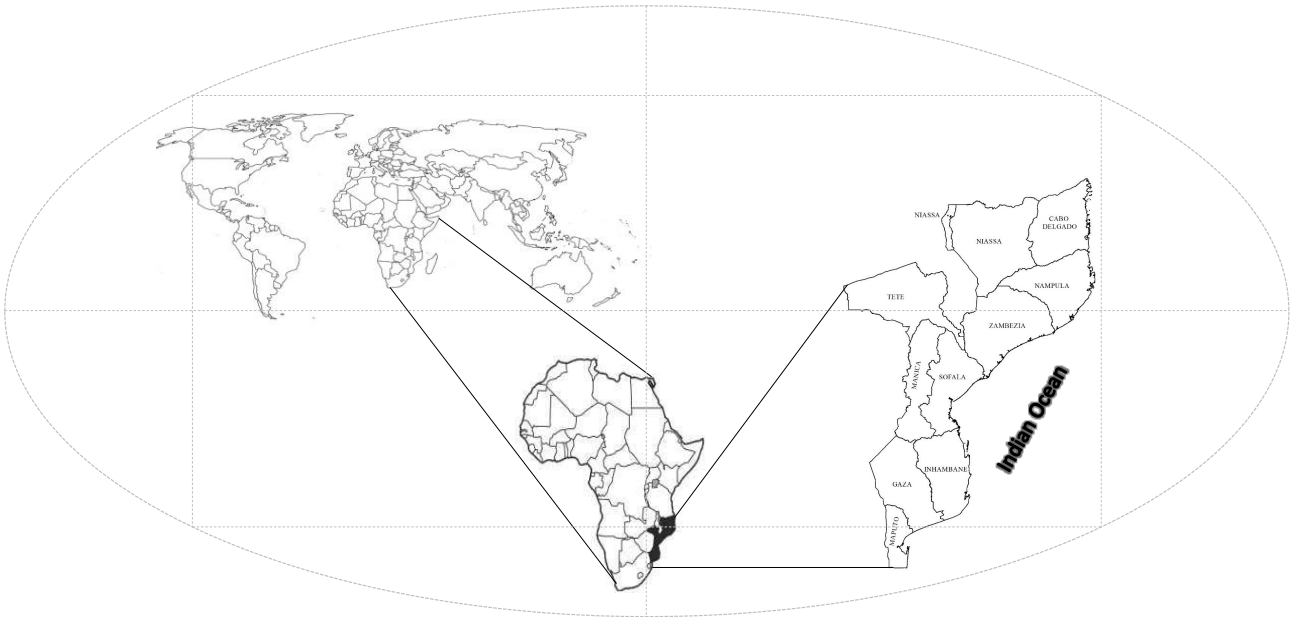


Figure 02 - Republic of Mozambique in southern Africa (Adapted from Buchir et al., 2020)

In terms of morphology, Mozambique has about 50% of the national territory cover by lands characterized by coastal plains, extend to the inland. In the climatology scenario, Mozambique is considered semi-arid and subtropical in the south part and tropical in the north. The temperature range is around 22 ºC to 27 ºC in the summer and 14 ºC to 18 ºC in the winter. In terms of annual precipitation, the country is between 500 to 2000 mm. The

rainy season (October - April) is around 1000 - 1500 mm, and 600 - 800 mm in the dry season (May - September) (Uele et al., 2017).

Besides that, due to its socio-economic situation, coupled with its geographical location, Mozambique ($CVI_{Mozambique}$ = 0.51, Little High Vulnerable), is considered one of the most vulnerable countries to the adverse impact of climate change (Artur, 2012; Buchir et al., 2020). These statements make sense if we take into account the extreme weather events scenario in the last 20 years (Figure 03), where 53% of these events resulted in visible disasters, affected 14% of the population. As an example of this scenario 500,000 Mozambicans was affected by the 2000 flood, and more recently, in 2019, the IDAI and Kennedy cyclone that affected about 600,000 people. That experience shows us that the Mozambique channel is very active on cyclone.

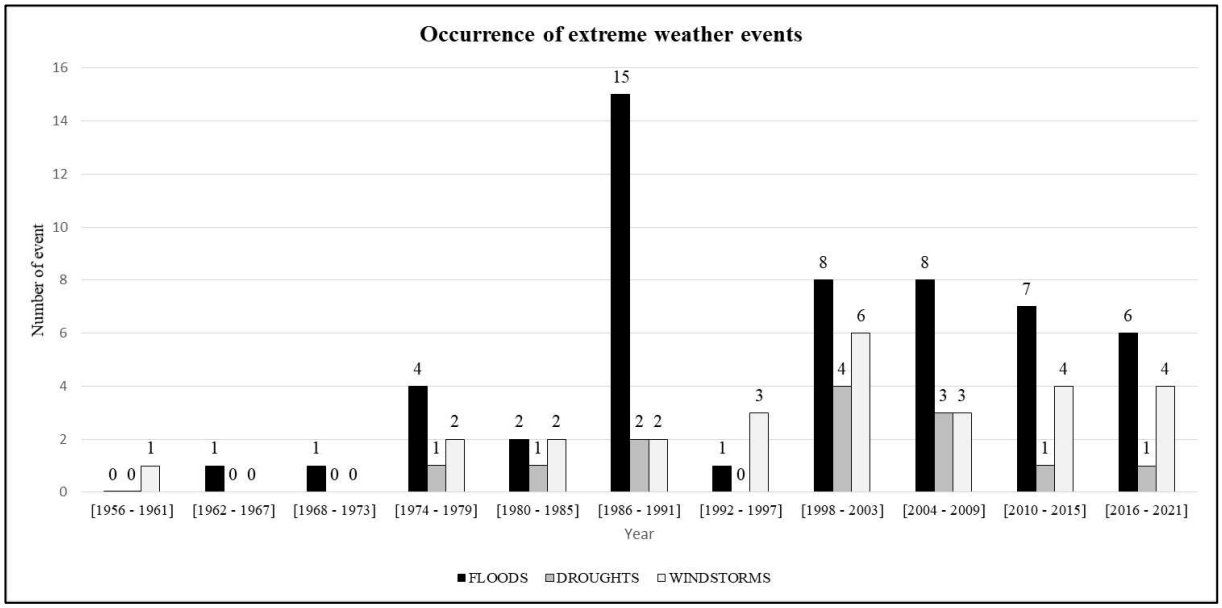


Figure 03 – Frequency of extreme weather events between 1956 – 2020 (Adapted from Buchir et al., 2020)

This scenario put Mozambique in a vigilant position, mainly due to most of the development sectors such as agriculture and fishing are vulnerable to extreme events. However, it is important to mention that some specific tools, already in place to be used, such as the National Strategy for Adaptation and Mitigation to Climate Change 2013-2025 (ENAMMC) and the Master Plan for Disaster Risk Reduction. The downscale implementation of these tools to reduce climate vulnerability has resulted in successful Local Adaptation Plans (LAP).

METHODS

The first goal of this work was the LAP elaboration process. However, based on the method of Climate Vulnerability and Capacity Analysis (CVCA) and the Theory of Change analysis (ToC), this process is divided into ten (10) main steps (Figure 04).

The data were collected, based on household surveys and community/public consultation in more than 118 districts. However, some data came from national institutions such as the Ministry of Land and Environment (MTA), the National Institute for Disaster Management (INGC), and the National Institute of Meteorology (INAM), besides those that were facilitated by the Emergency Events Database (EM-DAT) through the webpage https://public.emdat.be/data.

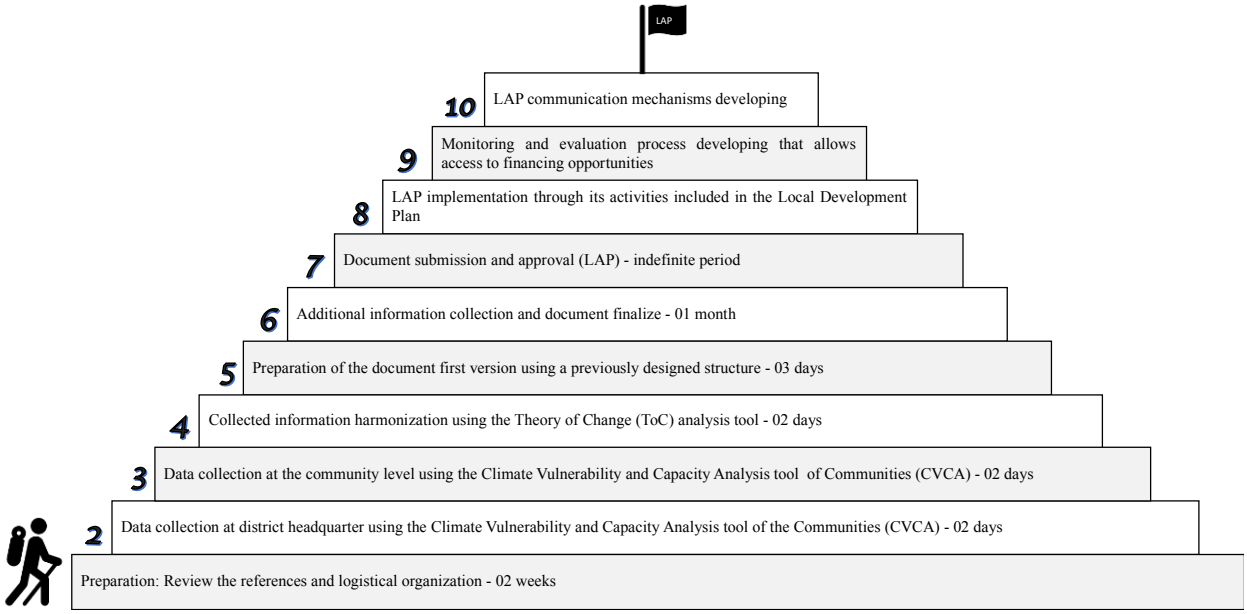


Figure 04 - The 10 steps for LAP elaboration to integrate climate change in the local development plans

Therefore, to analyze climate vulnerability and adaptation capacities at the community level, the CARE Organization developed the Climate Vulnerability and Capacity Analysis Handbook (CARE, 2019). The CVCA provides necessary information about local climate adaptation actions to reduce the risk of disaster, based on the information of the historical events in that region, the map scenario of the events, institutional arrangement, and others kinds of information. On the other hand, Theory of Change (ToC) is a participatory methodology for planning and evaluation to promote social change and define long-term goals. It is a mapping that helps to identify necessary preconditions to achieve

the community's main vision, pass through four main levels (Figure 05). Also help to define indicators for monitoring and evaluation system at different stages of implementation.

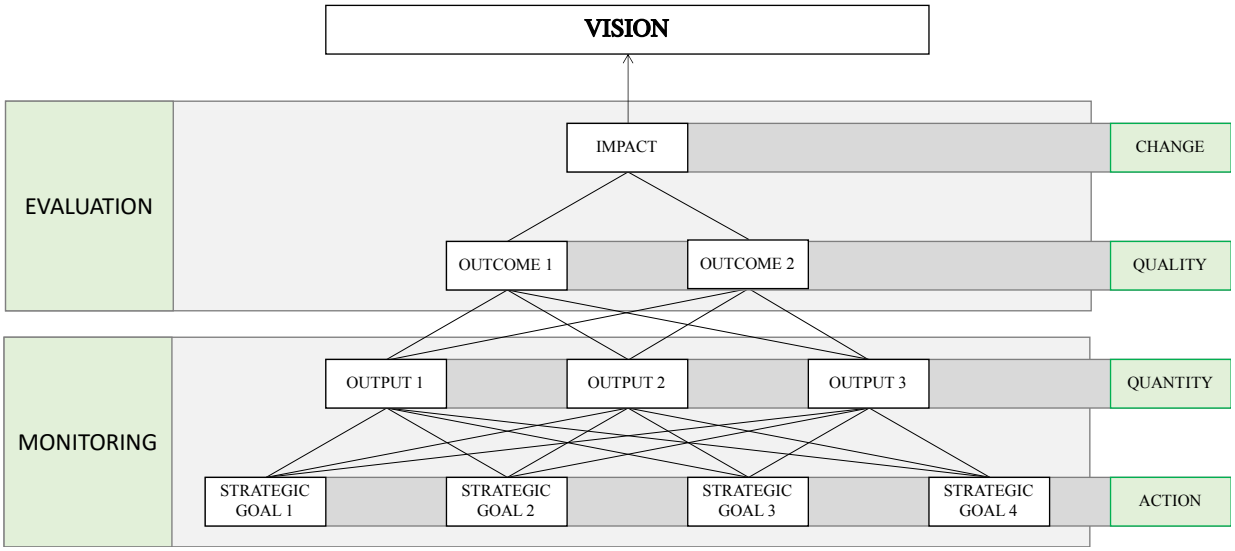


Figure 05 - The ToC elaboration structure to define the main vision and identify strategical goals

RESULTS AND DISCUSSION

These government-specific initiatives resulted in more than 118 Local Adaptation Plans (LAP), including district and sectoral plans (Figure 06). Therefore, the LAP's are also responsible for part of the country change in terms of Climate Vulnerability Index status (CVI), moving from High Vulnerable (CVI = 0.57) to Little High Vulnerable (CVI = 0.51). These conclusions result from two periods of analysing take as a baseline the country status before and after the approval of the National Strategy for Adaptation and Mitigation to Climate Change (Buchir et al., 2020).

On the other hand, this change also can be related to many other initiatives, such as the decentralized finance planning program, in 2005, which focused on the empowerment of the local government agencies and the specific budget code for climate change provided by the ministry of planning and finance. Years later, they resulted in the mandatory land-use plans elaboration, and updated, local development plans. Those were the main entry point to introduce climate change issues into development strategies.

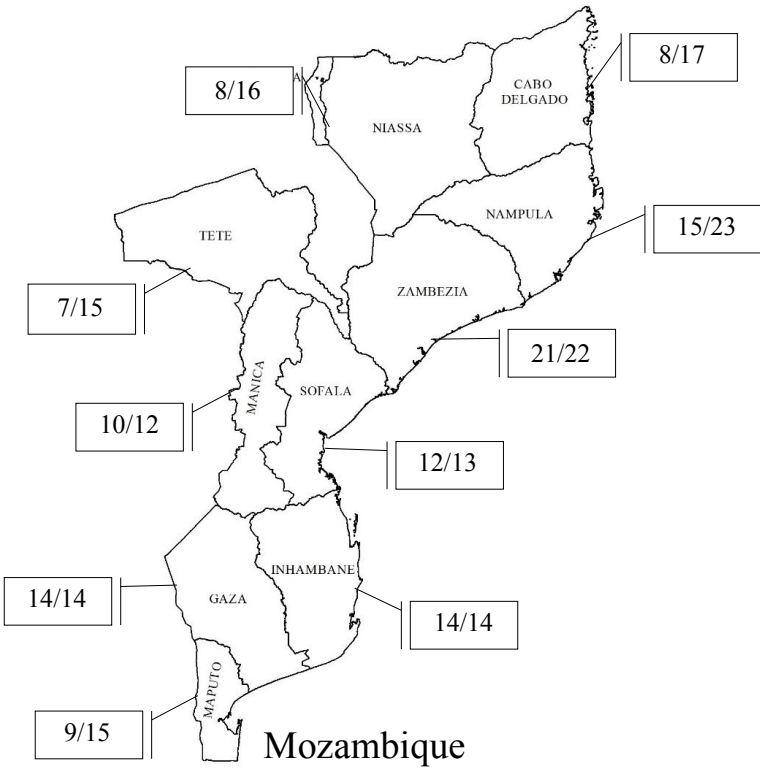


Figure 06 – Represents the number of plans elaborate from the total in each district in the context of integrating climate change in development strategies at the local level

FINAL CONSIDERATION

As a readiness proposal to deal with the negative impact of climate change, countries, mainly those called the Least Developing Countries (LDC), are invited to present their National Adaptation Plans (NAP). This acceptance makes sense if we take into account their scenario of climate vulnerability and social-economic impact. Therefore, this work is a result of a series of initiatives that countries have been carrying out to reduce climate vulnerability. This paper, in particular, share experiences and good practices on governance initiatives on climate change issues mainstreaming. However, the main issues/challenge for most LDC are related to technical capacity and finance. Therefore, in Mozambique, the Local Adaptation Plans (LAP) came as small efforts putting in action the National Strategy for Adaptation and Mitigation to Climate Change. This bottom-up approach moving from the LAP to NAP, identifying the needs of adaptation and adaptive capacity of the system, suddenly became the empowerment vehicle for the local governments, which results in climate change issues integrated at the local level planning. This initiative led the government to create the National Directorate for Climate Change. This group is composed of government institutions, academia, civil society, and the private sector and also

responsible for coordinating the interinstitutional group on climate change (GIIMC). This step forward provided more technical and financial support, which allowed more engagement of academic institutions and the private sector. However, for more effectiveness and long-term vision ahead to climate resilience, this process must be a leader by the decision-makers.

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CHAPTER 8

GENERAL CONSIDERATIONS, AND RECOMMENDATIONS

HIGHLIGHTS

This chapter presents the final remarks of the work and the next steps for future research.

GENERAL CONSIDERATIONS AND RECOMMENDATIONS

The purpose of this work is the definition of an alternative tool to assess climatic vulnerability level of a system, explicitly considering the Governance as a fourth component, with the inclusion of specific indicators in the climate vulnerability function now defined by *CVI = f(E, S, AC, G)*. The evidence shows that with 04 components, the tool becomes more sensitive, as observed in the Curitiba municipality (CVI = 5.3, little high vulnerable), rather than 03 components (CVI = 4.2, medium vulnerable). This last was also found by the Osvaldo Cruz Foundation (FioCruz), in their study using a tool called Climate Vulnerability System (SisVuClima), developed to support Brazil in identifying the municipalities most vulnerable to climate change. On the other hand, to identify the main components to be reinforced, it was concluded that there are still several issues, such as improving existing infrastructure and synergies between sectors that must be taken into account to be resilient. In this case, taking Mozambique as an example, it was observed that improving technical capacity, and creating legal instruments, could lead to a rapid reduction in the vulnerability of a system. This evidence comes from two periods of action analyzed (before and after the ENAMMC approval). The outcomes clearly showed that after the approval of this legal instrument to define strategic actions on climate change, the country reduced its level of vulnerability from CVI = 0.57 (high vulnerability) to CVI = 0.51 (medium vulnerability). However, to make these systems resilient to climate change it is extremely important to find a balance between the Governance and Adaptive Capacity components to get the best resilient scenario. Therefore, in-depth studies on these matters are always welcome. Nevertheless, the solutions or proposals must be easily accessible, especially for the main users or decision-makers, so that the tools become operational. That is, the more comprehensive and less data it requires, the better its acceptance by all.

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APPENDIX: A - C

HIGHLIGHTS

Here, will present additional information on climate vulnerability issues, the common sense of the indices and indicators, and details on how to use the Analytic Hierarchy Method (AHP), beyond the tables with the collected data.

APPENDIX A: Methods and Models (Support information to paper 2)

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), converts human judgment on numerical value based on human perception, and combining psychology and maths (SAATY, 1987, SAATY, 1990, SAATY; VARGAS, 2013). AHP is a pair comparison of all criteria combination Russo and Camanho (2015), and most used to eliminate similar or duplicate criteria. Therefore, compares qualitative and quantitative criteria to determine the preferred alternative, based on available criteria. (Saaty, 1987; Saaty TL, 1990; Saaty and Vargas, 2013)

How to apply the Analytic Hierarchy Process (AHP)

Step 1: Structure the hierarchy of the problem and define the criteria

Based on the main goal (stage I), are define the criteria (stage II) which provides alternatives (stage III) to address the main goal (Figure 01).

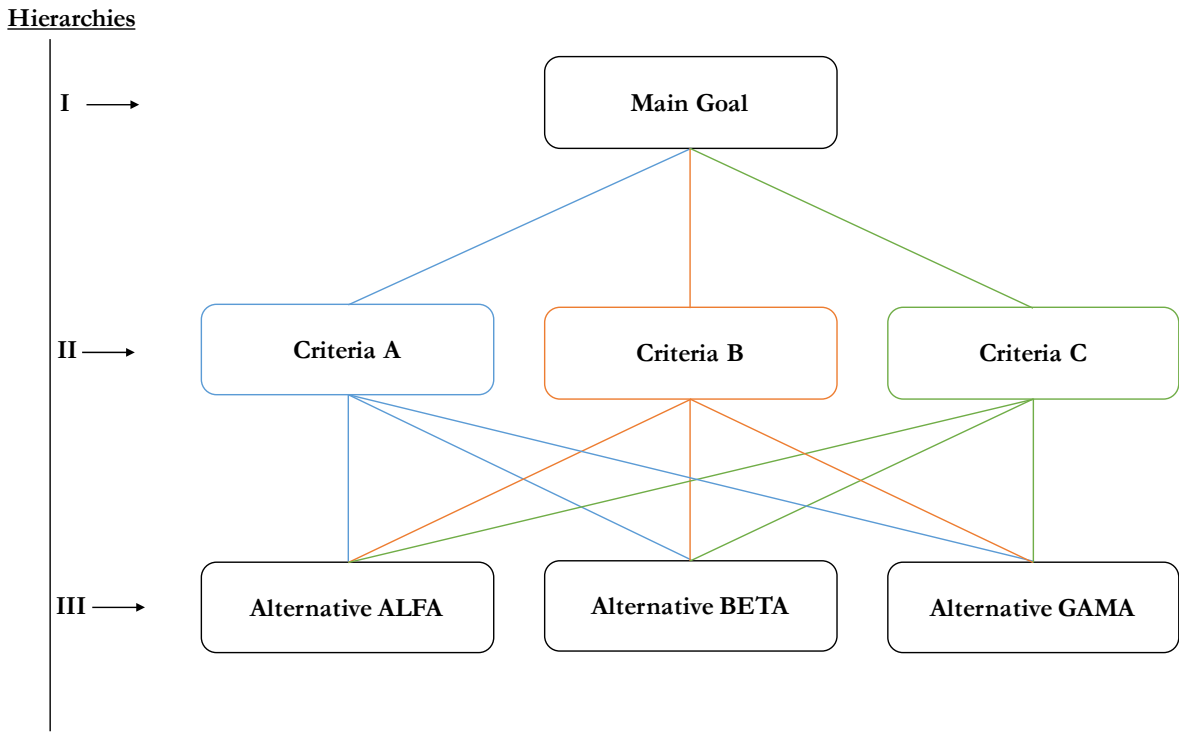

Figure 01 - Hierarchy of the problem.
Source: Author (2018)

Step 2: Compare the pairs

The criterion defined in stage II must be compared each other to know the most influent in the main goal (Table 01), and the same must be done in stage III to have the best alternative. Each element (n), have n(n–1)/2 comparison to be made.

Table 01 - Comparison of the criteria

	Extreme importance	Very strong importance	Essential or strong importance	Moderate importance of one over another	Equal importance	Moderate importance of one over another	Essential or strong importance	Very strong importance	Extreme importance	
A						X				**B**
A							X	X		**C**
B						X				**C**

Source: Author (2018)

Therefore, based on table (02) Saaty (1987), the most influential element defined in table (01), as a result of the human judgment can be converted in numerical value (Table 02).

Table 02 - Numerical value proposed by Saaty (1987)

Numerical Value	Judgment	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 3, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity ***j***, then *j* has the reciprocal value when com pared with ***i***	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Source: Adapted by Saaty (1987)

To compare the criterion in the column with the criterion in the row, a matrix [n x n] composed of judgment value is needed (Table 02). In the matrix [n x n], the diagonal elements are always 1. The right side of diagonal is filled with the judgment value, and on the left side, the reciprocal value is inserted (Table 03).

Table 03 - Comparison Matrix with the numerical value

CRITERIA	A	B	C
A	1	3	6
B	1/6	1	3
C	1/5	1/2	1

Source: Author (2018)

Step 3: Determine the Relative Weight

As known, the criteria could have different importance according to the decision-maker. Therefore, by having the sum of each column (Table 04), the normalization process is applied to one of the elements of the comparison matrix (Table 03).

Table 04 - Value of the sum of each column

		A	B	C
	A	1	7	1
=	**B**	1/6	1	1
	C	1/5	1/2	1
	SUM	1 3/8	8 1/2	3

Source: Author (2018)

Next, divide each element of the matrix with the sum of its column. The sum of each column must be 1. The result it a normalized matrix (Table 05).

Table 05 - Normalized matrix

	A	B	C
A	0,7317	0,8235	0,3333
B	0,1220	0,1176	0,3333
C	0,1463	0,0588	0,3333
SUM	1	1	1

Source: Author (2018)

With normalized matrix one determines the average across the rows to obtain the eigenvector, also called the priority vector. This vector gives the relative weight of each criterion and the rank position (Table 06).

Table 06 - Relative weight of each criteria

		A		B		C	W	
	A	0,7317	+	0,8235	+	0,3333	0,6295	62,95%
W = 1/3 *	**B**	0,1220	+	0,1176	+	0,3333	0,1910	19,10%
	C	0,1463	+	0,0588	+	0,3333	0,1795	17,95%
	SUM	1		1		1	1	

Source: Author (2018)

The Criteria A has 71.89% of the influence in the main goal, 4.27 (71.89/16.84) times more important than Criteria B, and 6.38 (71.89/11.27) times more important than Criteria C.

Step 4: Determine the Consistency of the judgment

The consistency analysis helps to verify the confidence of the judgment. First, the eigenvalue (equation 01) is computed, which obtained by the sum of the products between each element of the eigenvector and the sum of the column of the comparison matrix (Table 04 and Table 06).

$$\lambda_{max} = \frac{13}{8}(0.6661) + \frac{41}{2}(0.2147) + 10(0.1192) = 3.0681 \qquad (01)$$

Second, the Consistency Index (CI) is calculated by equation 02:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} = \frac{(3.0681 - 3)}{3 - 1} = 0.0341 \qquad (02)$$

where n is the number of the criteria.

Finally, using equation 03, compare the calculated Consistency Index (CI) with tabled Consistency Index (RI) propose by Saaty and Sodenkamp (2010), Saaty and Vargas (2013), which based on the number of elements compared (n), (Table 07).

Table 07 - Consistency Index for randomly

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49	1,51	1,54	1,56	1,57	1,58

Source: Adapted by Saaty and Vargas (2013)

Having n = 3, it means that RI = 0,52. Thus, equation (03) will give:

$$CR = \frac{CI}{RI} = \frac{0.0341}{0.52} = 0.0655 \qquad (03)$$

According to Saaty (1990), if the consistency value (CR) is less or equal to 0.1, the inconsistency is rejected. But, if the CR is greater than 0.1, an inconsistency is detected, suggesting a judgment revision. In this case, CR = 0.0655 is acceptable.

Step 5: Repeat step 2, 3 and 4 for alternative options, using different criteria

The steps 2, 3 and 4 are repeated for alternative options ALFA (Table 08), BETA (Table 09), and GAMA (Table 10), as follow:

Table 08 - Relative weight of each alternative – Consider criteria A

ALTERNATIVE	ALFA	BETA	GAMA	WEIGHT
ALFA	1	5	9	**0,7730**
BETA	1/6	1	1	**0,1222**
GAMA	1/5	1/2	1	**0,1047**
SUM	1 3/8	6 1/2	11	100%

λ_{max}	3,0030
CI	0,0015
RI	0,52
CR	0,0029
Consistency	ACCEPTEB

Source: Author (2018)

Table 09 - Relative weight of each alternative – Consider criteria B

ALTERNATIVE	ALFA	BETA	GAMA	WEIGHT
ALFA	1	9	5	**0,7677**
BETA	1/6	1	1	**0,1200**
GAMA	1/5	1/2	1	**0,1123**
SUM	1 3/8	10 1/2	7	100%

λ_{max}	3,0953
CI	0,0476
RI	0,52
CR	0,0916
Consistency	ACCEPTEBLE

Source: Author (2018)

Table 10 - Relative weight of each alternative – Consider criteria C

ALTERNATIVE	ALFA	BETA	GAMA	WEIGHT
ALFA	1	3	1	**0,5217**
BETA	1/6	1	4	**0,3369**
GAMA	1/5	1/2	1	**0,1414**
SUM	1 3/8	4 1/2	6	100%

λ_{max}	3,0775
CI	0,0387
RI	0,52
CR	0,0745
Consistency	ACCEPTEBLE

Source: Author (2018)

Step 6: Final decision

The alternatives based on criterion given are compared to select the best option which attends the main goal. For each criteria weight in the row, will be a respective alternative weight in column (ALFA, BETA, and GAMA). Basically, the result column will be the sum of the multiplications between, each criteria weight and respective alternative weight (Table 11). In this exercise, the alternative ALFA is the best option.

Table 11 - Matrix of Decision

ALTERNATIVE | CRITERIA	A	B	C	Result
WEIGHT	**0,6661**	**0,2147**	**0,1192**	
ALFA	0,7730	0,7677	0,5217	0,6996
BETA	0,1222	0,1200	0,3369	0,1310
GAMA	0,1047	0,1123	0,1414	0,0939
SUM	1	1	1	1

Source: Author (2018)

Sensitivity Analyse

To understand the robust of the decisions the weight of the criteria are changed to know if the importance change giving them equal weight or other alteration (Table 12).

Table 12 - Variation of the judgment value for sensitivity analyse

COMPARISON	ORIGINAL VALUE	VARIATION
A - B	3	7
A - C	6	1
B - C	3	1
CR	0,0213	ACCEPTEBLE

ALTERNATIVE | CRITERIA	A	B	C	Result
WEIGHT	0,6295	0,1910	0,1795	
ALFA	0,7730	0,7677	0,5217	0,6632
BETA	0,1222	0,1200	0,3369	0,1358
GAMA	0,1047	0,1123	0,1414	0,0874
SUM	1	1	1	1

Source: Author (2018)

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APPENDIX B: Structure of the Local Adaptation Plan (Support information to paper 6)

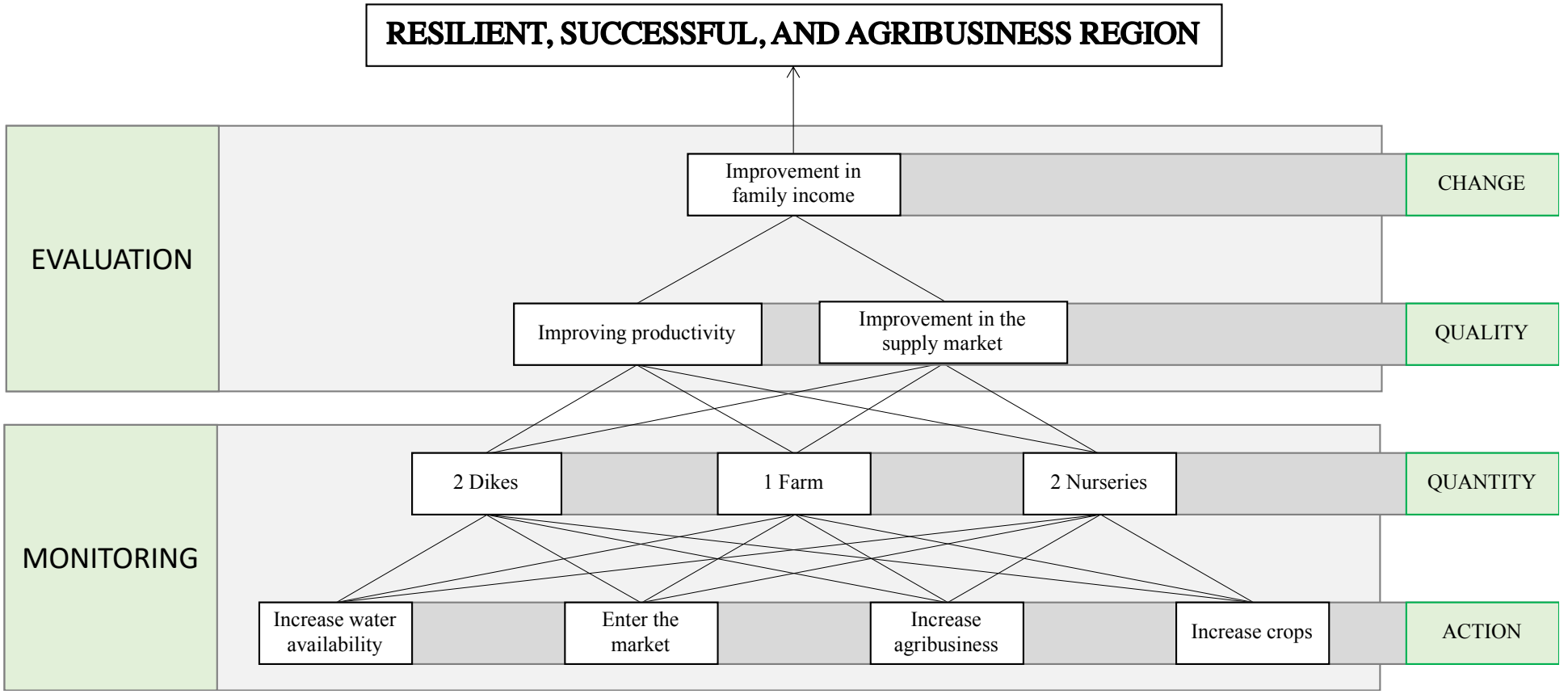
Highlight: Support document for local development.

- Preface
- Executive summary

1. Introduction
2. Methodology
3. District Profile
   3.1. Physical-geographic aspects
   3.2. Socio-economic aspects
   3.3. Climate Risks (CVCA)
      - Historical Profile
      - Seasonal Calendar
      - Vulnerability Matrix
      - Risk Mapping
      - Venn diagram
4. Climate Change and District Development
   4.1. Climate Change in District Development
   4.2. Theory of Change (ToC)
      - Strategic Areas of Action
      - Specific Strategic Actions
   4.3 Action Plan
      - The Framework of the Ministry of Economy and Finance
5. Monitoring and Evaluation System
6. Financing opportunity

- Attachments

APPENDIX C: Map structure of the theory of change (ToC) (Support information to paper 6)



APPENDIX: D - J

DATA COLLECTED

HIGHLIGHTS

This part presents the necessary data to conduct this study on climate vulnerability assessment.

APPENDIX D: Par Comparison - Indicator Definition (Support information to Paper 2)

Table F1 – Exposure: LINKAGE CRITERIA

INDICATOR	Extreme events of floods per year	Extreme events of droughts per year	Extreme events of windstorms per year	Frequency of haevy winds	Frequency of haevy rain	Frequency of rainfall below average	Frequency of high-temperature	Frequency Low-temperature
Extreme events of floods per year	1	1	1	3	1	2	2	3
Extreme events of droughts per year	1	1	1	3	2	1	2	3
Extreme events of windstorms per year	1	1	1	3	1	1	2	3
Frequency of haevy winds	1/3	1/3	1/3	1	1/2	2	1/2	2
Frequency of haevy rain	1	1/2	1	2	1	1/2	1/2	3
Frequency of rainfall below average	1/2	1	1	1/2	2	1	1/2	3
Frequency of high-temperature	1/2	1/2	1/2	2	2	2	1	3
Frequency Low-temperature	1/3	1/3	1/3	1/2	1/3	1/3	1/3	1

Table D2 – Exposure: MEASURABILITY CRITERIA

INDICATOR	Extreme events of floods per year	Extreme events of droughts per year	Extreme events of windstorms per year	Frequency of haevy winds	Frequency of haevy rain	Frequency of rainfall below average	Frequency of high-temperature	Frequency Low-temperature
Extreme events of floods per year	1	1	1	2	2	2	2	3
Extreme events of droughts per year	1	1	1	2	2	2	2	3
Extreme events of windstorms per year	1	1	1	2	2	2	2	3
Frequency of haevy winds	1/2	1/2	1/2	1	1/2	1/2	1/2	2
Frequency of haevy rain	1/2	1/2	1/2	2	1	1	1/3	2
Frequency of rainfall below average	1/2	1/2	1/2	2	1	1	1/3	2
Frequency of high-temperature	1/2	1/2	1/2	2	3	3	1	3
Frequency Low-temperature	1/3	1/3	1/3	1/2	1/2	1/2	1/3	1

Table D3 – Exposure: TRANSPARENCY CRITERIA

INDICATOR	Extreme events of floods per year	Extreme events of droughts per year	Extreme events of windstorms per year	Frequency of haevy winds	Frequency of haevy rain	Frequency of rainfall below average	Frequency of high-temperature	Frequency Low-temperature
Extreme events of floods per year	1	1	1	3	2	2	1/2	2
Extreme events of droughts per year	1	1	1	3	2	2	1/2	2
Extreme events of windstorms per year	1	1	1	3	2	2	1/2	2
Frequency of haevy winds	1/3	1/3	1/3	1	1/2	1/2	1/3	1/2
Frequency of haevy rain	1/2	1/2	1/2	2	1	1	1/2	2
Frequency of rainfall below average	1/2	1/2	1/2	2	1	1	1/2	2
Frequency of high-temperature	2	2	2	3	2	2	1	2
Frequency Low-temperature	1/2	1/2	1/2	2	1/2	1/2	1/2	1

Table D4 – Sensitivity: LINKAGE CRITERIA

INDICATOR	System afected by extreme events per year	Loss and damages in the system per year	Population Density	System cover by ecosystems	Economic incomes	Ecosystem diversity	Investment in the system	Infrastructures in the system
System affected by extreme events per year	1	1	3	3	3	3	5	3
Loss and damages in the system per year	1	1	2	3	3	3	5	2
Population Density	1/3	1/2	1	2	2	2	3	2
System cover by ecosystems	1/3	1/3	1/2	1	1/2	1	3	1/2
Economic incomes	1/3	1/3	1/2	2	1	1/2	1	1/2
Ecosystem diversity	1/3	1/3	1/2	1	2	1	3	1/2
Investment in the system	1/5	1/5	1/3	1/3	1	1/3	1	1/3
Infrastructures in the system	1/3	1/2	1/2	2	2	2	3	1

Table D5 – Sensitivity: MEASURABILITY CRITERIA

INDICATOR	System afected by extreme events per year	Loss and damages in the system per year	Population Density	System cover by ecosystems	Economic incomes	Ecosystem diversity	Investment in the system	Infrastructures in the system
System affected by extreme events per year	1	2	3	3	3	3	3	2
Loss and damages in the system per year	1/2	1	2	3	3	3	3	2
Population Density	1/3	1/2	1	3	3	3	3	2
System cover by ecosystems	1/3	1/3	1/3	1	2	1/2	3	1/2
Economic incomes	1/3	1/3	1/3	1/2	1	1/2	2	1/2
Ecosystem diversity	1/3	1/3	1/3	2	2	1	3	1/2
Investment in the system	1/3	1/3	1/3	1/3	1/2	1/3	1	1/3
Infrastructures in the system	1/2	1/2	1/2	2	2	2	3	1

Table D6 – Sensitivity: TRANSPARENCY CRITERIA

INDICATOR	System afected by extreme events per year	Loss and damages in the system per year	Population Density	System cover by ecosystems	Economic incomes	Ecosystem diversity	Investment in the system	Infrastructures in the system
System affected by extreme events per year	1	2	2	3	3	2	5	2
Loss and damages in the system per year	1/2	1	2	3	3	2	5	2
Population Density	1/2	1/2	1	3	3	2	5	2
System cover by ecosystems	1/3	1/3	1/3	1	2	1	3	1/2
Economic incomes	1/3	1/3	1/3	1/2	1	1/2	1	1/2
Ecosystem diversity	1/2	1/2	1/2	1	2	1	3	1/2
Investment in the system	1/5	1/5	1/5	1/3	1	1/3	1	1/3
Infrastructures in the system	1/2	1/2	1/2	2	2	2	3	1

Table D7 – Adaptive Capacity: LINKAGE CRITERIA

INDICATOR	Institutions providing financial support	Institutions providing technical support	Human capital (literature rate)	Physical capital (quality of insfrastructure)	Community training per year (Community-based preparedness)	Early warning sytems instaled	Research institutions involved on climate vulnerability	Published on the system (priority)
Institutions providing financial support	1	1/2	3	1/3	1	1/3	1/3	3
Institutions providing technical support	2	1	3	3	2	1	2	3
Human capital (literature rate)	1/3	1/3	1	2	1/2	1/3	1/3	2
Physical capital (quality of insfrastructure)	3	1/3	1/2	1	2	1/2	1/2	3
Community training per year (Community-based preparedness)	1	1/2	2	1/2	1	2	1/3	3
Early warning sytems instaled	3	1	3	2	1/2	1	1/3	3
Research institutions involved on climate vulnerability	3	1/2	3	2	3	3	1	2
Published on the system (priority)	1/3	1/3	1/2	1/3	1/3	1/3	1/2	1

Table D8 – Adaptive Capacity: MEASURABILITY CRITERIA

INDICATOR	Institutions providing financial support	Institutions providing technical support	Human capital (literature rate)	Physical capital (quality of insfrastructure)	Community training per year (Community-based preparedness)	Early warning sytems instaled	Research institutions involved on climate vulnerability	Published on the system (priority)
Institutions providing financial support	1	1	3	2	3	2	3	3
Institutions providing technical support	1	1	3	2	3	1	2	3
Human capital (literature rate)	1/3	1/3	1	1/2	1/2	1/3	1/3	1/2
Physical capital (quality of insfrastructure)	1/2	1/2	2	1	1/2	1/2	1/2	1/3
Community training per year (Community-based preparedness)	1/3	1/3	2	2	1	2	1/3	2
Early warning sytems instaled	1/2	1	3	2	1/2	1	1/3	2
Research institutions involved on climate vulnerability	1/3	1/2	3	2	3	3	1	2
Published on the system (priority)	1/3	1/3	2	3	1/2	1/2	1/2	1

Table D9 – Adaptive Capacity: TRANSPARENCY CRITERIA

INDICATOR	Institutions providing financial support	Institutions providing technical support	Human capital (literature rate)	Physical capital (quality of insfrastructure)	Community training per year (Community-based preparedness)	Early warning sytems instaled	Research institutions involved on climate vulnerability	Published on the system (priority)
Institutions providing financial support	1	1/2	3	2	2	2	2	2
Institutions providing technical support	2	1	3	2	2	2	2	2
Human capital (literature rate)	1/3	1/3	1	1	1/2	1/2	1/3	1/2
Physical capital (quality of insfrastructure)	1/2	1/2	1	1	1/2	1/2	1/3	1/3
Community training per year (Community-based preparedness)	1/2	1/2	2	2	1	1	1/2	1/2
Early warning sytems instaled	1/2	1/2	2	2	1	1	2	2
Research institutions involved on climate vulnerability	1/2	1/2	3	3	2	1/2	1	2
Published on the system (priority)	1/2	1/2	2	3	2	1/2	1/2	1

Table D10 – Governance: LINKAGE CRITERIA

INDICATOR	Local management committee	Legal policies aproved	Specialized members on the committee	Climate change adaptation plans and strategies	Community participation (local priority)	Climate change issues integrated into different sectors	Border agreements on areas of shared extreme events	Periodic reports
Local management committee	1	3	3	2	2	3	2	3
Legal policies aproved	1/3	1	3	1	3	1	1	3
Specialized members on the committee	1/3	1/3	1	2	2	2	2	3
Climate change adaptation plans and strategies	1/2	1	1/2	1	1/2	1	1	2
Community participation (local priority)	1/2	1/3	1/2	2	1	2	3	2
Climate change issues integrated into different sectors	1/3	1	1/2	1	1/2	1	2	2
Border agreements on areas of shared extreme events	1/2	1	1/2	1	1/3	1/2	1	3
Periodic reports	1/3	1/3	1/3	1/2	1/2	1/2	1/3	1

Table D11 – Governance: MEASURABILITY CRITERIA

INDICATOR	Local management committee	Legal policies aproved	Specialized members on the committee	Climate change adaptation plans and strategies	Community participation (local priority)	Climate change issues integrated into different sectors	Border agreements on areas of shared extreme events	Periodic reports
Local management committee	1	1	3	2	3	3	2	2
Legal policies aproved	1	1	3	1	3	3	1	2
Specialized members on the committee	1/3	1/3	1	1/3	2	2	1/2	1/2
Climate change adaptation plans and strategies	1/2	1	3	1	3	3	1	2
Community participation (local priority)	1/3	1/3	1/2	1/3	1	2	1/3	1/3
Climate change issues integrated into different sectors	1/3	1/3	1/2	1/3	1/2	1	1/3	1/3
Border agreements on areas of shared extreme events	1/2	1	2	1	3	3	1	2
Periodic reports	1/2	1/2	2	1/2	3	3	1/2	1

Table D12 – Governance: TRANSPARENCY CRITERIA

INDICATOR	Local management committee	Legal policies aproved	Specialized members on the committee	Climate change adaptation plans and strategies	Community participation (local priority)	Climate change issues integrated into different sectors	Border agreements on areas of shared extreme events	Periodic reports
Local management committee	1	3	3	2	2	3	3	2
Legal policies aproved	1/3	1	2	1	2	2	2	2
Specialized members on the committee	1/3	1/2	1	1/2	2	2	2	1/2
Climate change adaptation plans and strategies	1/2	1	2	1	3	2	2	2
Community participation (local priority)	1/2	1/2	1/2	1/3	1	1	2	2
Climate change issues integrated into different sectors	1/3	1/2	1/2	1/2	1	1	2	1/2
Border agreements on areas of shared extreme events	1/3	1/2	1/2	1/2	1/2	1/2	1	1/2
Periodic reports	1/2	1/2	2	1/2	1/2	2	2	1

APPENDIX E: Vulnerable Indicators (Support information to paper 2, 3, 4 and 5)

Table E1 – Relationship between Indicator and Vulnerability Index

Component	N.	Indicator			Interpretation	Vulnerability Relationship
		Measurability	Transparency	Linkage		
Exposure	E1	The number of extreme events of floods per year (#)			This indicator gives us the level of the exposure of the system to this event.	↑ Increase
	E2	The number of extreme events of droughts per year (#)			This indicator gives us the level of the exposure of the system to this event.	↑ Increase
	E3	The number of extreme events of windstorms per year (#)			This indicator gives us the level of the exposure of the system to this event.	↑ Increase
Sensitivity	S1	The percentage of the system affected by extreme events per year (%)			This indicator gives us the dimension of the affected area in the system.	↑ Increase
	S2	The cost of the loss and damages in the system per year ($)			This indicator gives us the dimension of the negative impact of extreme events in the system through the budget expenditures for the recovery process.	↑ Increase
	S3	The number of the affected people in the system (#)			This indicator gives us the dimension of the affected people in the system.	↑ Increase
Adaptive Capacity	AC1	The number of institutions providing financial support (#)			This indicator gives us global information about existing organizations that invest financially in adaptive actions in the System. The level of the organization to cope with the climate issues.	↓ Decrease
	AC2	The number of institutions providing technical support (#)			This indicator gives us global information about the institutional capacity, in the system, in terms of technical and scientific knowledge to cope with the negative impact of extreme events. The level of the organization to cope with the climate issues.	↓ Decrease
Governance	G1	The number of local management committee (#)			This indicator gives us information about the existence of the local management institutions to cope with the climate issues. The level of the local organization to cope with the climate issues.	↓ Decrease
	G2	The number of legal policies approved (#)			This indicator gives us information about the available specific legislation of climate issues for the system.	↓ Decrease
	G3	The number of climate change adaptation plans and strategies (#)			This indicator gives us the dimension of the institutional commitment on management process over the System. The local influence of the organizations to cope with climate issues.	↓ Decrease

APPENDIX F: Number of events per year (Support information to paper 4)

Table I1 – Curitiba Municipality

Component	N.	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Average
		1981	1982	1983	1985	1986	1989	1996	1998	2001	2010	2011	2013	2014	2015	2016	2017	2018	
Exposure	E1	1	0	1	0	0	0	0	0	0	1	2	9	6	4	4	3	3	2.00
	E2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06
	E3	0	1	0	0	1	1	1	2	1	1	3	16	4	7	3	5	3	2.88
Sensitivity	S1	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	21.89	40.00	100.00	79.00	100.00	100.00	100.00	100.00	90.64
	S2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,079,404.00	200.00	42,000.00	1,000.00	10,000.00	0.00	243,094.35
	S3	600	547	5,000	0	0	1,002	51	208	0	3,765	1,726	398,854	42,487	56,177	178	4,958	2,137	30,452.35
Adaptive Capacity	AC1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0.06
	AC2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0.06
Governance	G1	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0.59
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00

Table F2 – Araucária Municipality

Component	N.	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Average
		1983	2004	2006	2007	2008	2009	2010	2011	2012	2013	2015	2016	2017	2018	
Exposure	E1	1	1	1	3	0	4	4	2	2	1	1	1	4	1	1.86
	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	E3	0	0	1	0	2	1	4	2	9	2	3	0	1	1	1.86
Sensitivity	S1	100.00	100.00	100.00	2.51	9.89	7.90	19.95	8.58	26.03	4.29	5.44	0.48	4.76	9.60	28.53
	S2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26,150.00	0.00	0.00	0.00	1,867.86
	S3	500	0	2,060	229	500	910	1,859	312	6,084	376	110	70	244	274	966.29
Adaptive Capacity	AC1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0.07
	AC2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0.07
Governance	G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00

Table F3 – Almirante Tamandaré Municipality

Component	N.	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Average
		1992	1998	2007	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Exposure	E1	0	0	0	0	1	1	1	1	1	3	1	0	1	0.77
	E2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	E3	1	1	1	1	0	0	2	0	3	2	0	1	2	1.08
Sensitivity	S1	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
	S2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	130,500.00	251,000.00	61,000.00	0.00	25,000.00	2,000.00	36,115.38
	S3	1,764	400	9	12	80	200	450	20	91	1,476	4	1	184	360.85
Adaptive Capacity	AC1	0	0	0	0	0	0	0	1	0	0	0	0	0	0.08
	AC2	0	0	0	0	0	0	0	1	0	0	0	0	0	0.08
Governance	G1	0	0	0	0	0	0	0	2	0	0	0	0	0	0.15
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00

Table F4 – Value Normalization

Component	Indicator	Original			Normalized		
		Area 1	**Area 2**	**Area 3**	**Area 1**	**Area 2**	**Area 3**
Exposure	E1	2.00	1.86	0.77	1.000	0.884	0.000
	E2	0.06	0.00	0.00	1.000	0.000	0.001
	E3	2.88	1.86	1.08	1.000	0.432	0.000
Sensitivity	S1	90.64	28.53	50.00	1.000	0.000	0.346
	S2	243094.35	1867.86	36115.38	1.000	0.000	0.142
	S3	30452.35	966.29	360.85	1.000	0.020	0.000
Adaptive Capacity	AC1	0	0	0	1.000	0.304	0.000
	AC2	0	0	0	1.000	0.304	0.000
Governance	G1	1	0	0	0.000	1.000	0.738
	G2	0	0	0	1.000	0.491	0.000
	G3	0	0	0	0.932	1.000	0.000

Table F5 – Most Vulnerable Component (03)

Component	Curitiba	Araucária	Almirante Tamandaré	Average
E	0.1502	0.3598	0.3562	0.2887
S	0.3026	0.1573	0.1380	0.1993
AC	0.9412	0.9286	0.9231	0.9309

Table F6 – Most Vulnerable System (03)

	Curitiba	Araucária	Almirante Tamandaré
CVI	0.42	0.42	0.43

Table F7 – Most Vulnerable Component (04)

Component	Curitiba	Araucária	Almirante Tamandaré	Average
E	0.1502	0.3598	0.3562	0.2887
S	0.3026	0.1573	0.1380	0.1993
AC	0.9412	0.9286	0.9231	0.9309
G	0.9412	0.9286	0.9231	0.9309

Table F8 – Most Vulnerable System (04)

	Curitiba	Araucária	Almirante Tamandaré
CVI	0.53	0.53	0.54

APPENDIX G: Number of events per year (Support information to paper 5)

Table I1: Number of events per year in Mozambique (1956 – 2019)

Component	N.	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17	Ano 18	Ano 19	Ano 20
		1956	1967	1971	1975	1977	1978	1979	1981	1984	1985	1987	1988	1989	1991	1994	1996	1997	1998	1999	2000
Exposure	E1	0	1	1	2	1	1	0	1	0	1	9	6	0	0	0	0	1	0	1	1
	E2	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0
	E3	1	0	0	0	1	1	0	0	1	1	0	1	1	0	1	1	1	0	0	4
Sensitivity	S1	0,00	9,51	9,47	12,73	9,51	52,17	40,86	39,74	9,51	3,26	8,58	13,14	8,51	41,96	39,57	31,23	41,96	18,09	53,04	100,00
	S2	0,00	180.000.000,00	0,00	0,00	55.500.000,00	63.000.000,00	0,00	0,00	75.000.000,00	500.000,00	0,00	0,00	0,00	50.000.000,00	0,00	14.500.000,00	50.000,00	0,00	12.400.000,00	420.200.000,00
	S3	0	50.000	500.000	0	440.051	305.000	6.000.000	5.250.000	350.000	500.000	8.000	4.000	0	3.300.000	2.502.000	200.000	400.000	2.500	70.000	4.501.404
Adaptive Capacity	AC1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	AC2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Governance	G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table G2: Continuation - Number of events per year in Mozambique (1956 – 2019)

Component	N.	Ano 21	Ano 22	Ano 23	Ano 24	Ano 25	Ano 26	Ano 27	Ano 28	Ano 29	Ano 30	Ano 31	Ano 32	Ano 33	Ano 34	Ano 35	Ano 36	Ano 37	Total	Average
		2001	2002	2003	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019		
Exposure	E1	2	1	3	2	4	1	1	1	2	0	2	1	1	2	0	1	3	53	1,43
	E2	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	13	0,35
	E3	0	1	1	0	1	1	1	0	1	3	0	0	0	1	1	0	2	27	0,73
Sensitivity	S1	60,01	62,55	80,56	80,60	80,60	70,26	23,38	70,26	63,31	63,54	50,71	12,77	43,19	63,01	18,05	36,69	87,23	1.509,53	40,80
	S2	36.000.000,00	0,00	0,00	0,00	171.000.000,00	20.000.000,00	3.000.000,00	0,00	0,00	0,00	30.000.000,00	0,00	0,00	1.500.000,00	17.000.000,00	5.100.000,00	2.230.000.000,00	3.384.750.000,00	91.479.729,73
	S3	849.356	4.517	657.513	1.447.837	1.081.655	726.536	14.028	477.000	63.946	109.958	315.986	300	177.645	17.002.471.600	750.102	77.150	2.022.660	17.035.630.744,00	460.422.452,54
Adaptive Capacity	AC1	0	0	0	0	2	0	0	0	0	0	0	0	8	0	0	0	0	10	0,27
	AC2	0	0	2	2	3	0	0	0	0	0	0	0	8	0	0	0	0	17	0,46
Governance	G1	0	0	10	13	89	140	145	118	52	100	120	165	63	20	22	3	0	1.060	28,65
	G2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0,03
	G3	0	0	0	0	2	0	0	0	0	1	0	7	22	19	30	15	26	122	3,30

Table G3: Number of events per year in Mozambique (B-ENAMMC)

Component	N.	Ano 1	Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Ano 7	Ano 8	Ano 9	Ano 10	Ano 11	Ano 12	Ano 13	Ano 14	Ano 15	Ano 16	Ano 17
		1956	1967	1971	1975	1977	1978	1979	1981	1984	1985	1987	1988	1989	1991	1994	1996	1997
Exposure	E1	0	1	1	2	1	1	0	1	0	1	9	6	0	0	0	0	1
	E2	0	0	0	0	0	0	1	1	0	0	1	0	0	1	0	0	0
	E3	1	0	0	0	1	1	0	0	1	1	0	1	1	0	1	1	1
Sensitivity	S1	0,00	9,51	9,47	12,73	9,51	52,17	40,86	39,74	9,51	3,26	8,58	13,14	8,51	41,96	39,57	31,23	41,96
	S2	0,00	180.000.000,00	0,00	0,00	55.500.000,00	63.000.000,00	0,00	0,00	75.000.000,00	500.000,00	0,00	0,00	0,00	50.000.000,00	0,00	14.500.000,00	50.000,00
	S3	0	50.000	500.000	0	440.051	305.000	6.000.000	5.250.000	350.000	500.000	8.000	4.000	0	3.300.000	2.502.000	200.000	400.000
Adaptive Capacity	AC1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	AC2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Governance	G1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table G4: Continuation - Number of events per year in Mozambique (B-ENAMMC)

Component	N.	Ano 18	Ano 19	Ano 20	Ano 21	Ano 22	Ano 23	Ano 24	Ano 25	Ano 26	Ano 27	Ano 28	Ano 29	Ano 30	Average	Total
		1998	1999	2000	2001	2002	2003	2005	2007	2008	2009	2010	2011	2012		
Exposure	E1	0	1	1	2	1	3	2	4	1	1	1	2	0	1,43	43,00
	E2	1	0	0	1	1	1	1	1	1	0	1	0	0	0,40	12,01
	E3	0	0	4	0	1	1	0	1	1	1	0	1	3	0,77	23,00
Sensitivity	S1	18,09	53,04	100,00	60,01	62,55	80,56	80,60	80,60	70,26	23,38	70,26	63,31	63,54	39,93	1.197,88
	S2	0,00	12.400.000,00	420.200.000,00	36.000.000,00	0,00	0,00	0,00	171.000.000,00	20.000.000,00	3.000.000,00	0,00	0,00	0,00	36.705.000,00	1.101.150.000,00
	S3	2.500	70.000	4.501.404	849.356	4.517	657.513	1.447.837	1.081.655	726.536	14.028	477.000	63.946	109.958	993.843,37	29.815.301,00
Adaptive Capacity	AC1	0	0	0	0	0	0	0	2	0	0	0	0	0	0,07	2,00
	AC2	0	1	1	0	0	2	2	3	0	0	0	0	0	0,30	9,00
Governance	G1	0	0	0	0	0	10	13	89	140	145	118	52	100	22,23	667,00
	G2	0	0	0	0	0	0	0	0	0	0	0	0	0	0,00	0,00
	G3	0	0	0	0	0	0	0	2	0	0	0	0	1	0,10	3,00

Table G5: Number of events per year in Mozambique (A-ENAMMC)

Component	N.	Ano 1		Ano 2	Ano 3	Ano 4	Ano 5	Ano 6	Average	Total
		2013	2014	2015	2016	2017	2018	2019		
Exposure	E1	2	1	1	2	0	1	3	1,43	10,00
	E2	0	0	0	1	0	0	0	0,14	1,00
	E3	0	0	0	1	1	0	2	0,57	4,00
Sensitivity	S1	50,71	12,77	43,19	63,01	18,05	36,69	87,23	44,52	311,65
	S2	30.000.000,00	0,00	0,00	1.500.000,00	17.000.000,00	5.100.000,00	2.230.000.000,00	326.228.571,43	2.283.600.000,00
	S3	315.986	300	177.645	17.002.471.600	750.102	77.150	2.022.660	2.429.402.206,14	17.005.815.443,00
Adaptive Capacity	AC1	0	0	16	0	0	0	0	2,29	16,00
	AC2	0	0	8	0	0	0	0	1,14	8,00
Governance	G1	120	165	63	20	22	3	0	56,14	393,00
	G2	0	1	0	0	0	0	0	0,14	1,00
	G3	0	7	22	19	30	15	26	17,00	119,00

Table G6 – Most Vulnerable Component in Mozambique (Before and After the ENAMMC)

Component	B-ENAMMC	A-ENAMMC	Average
E	0,2158	0,3108	0,2633
S	0,2018	0,2441	0,2230
AC	0,9385	0,8571	0,8978
G	0,9326	0,6449	0,7887

APPENDIX H: Sensitivity analyse (Support information to paper 5)

Table H1 – Optimal point indication based on different simulations (Mozambique)

N	AC1	CVI	AC2	CVI	G1	CVI	G2	CVI	G3	CVI
1	10	0,51	17	0,51	1060	0,51	1	0,51	**122**	**0,51**
2	11	0,51	18	0,51	**1160**	**0,5**	**2**	**0,49**	152	0,52
3	12	0,51	19	0,51	**1260**	**0,5**	3	0,5	182	0,53
4	**13**	**0,50**	**20**	**0,5**	1360	0,51	4	0,5	212	0,53
5	14	0,50	21	0,5	1460	0,52	5	0,51	242	0,53
6	15	0,50	22	0,5	1560	0,52	6	0,51	272	0,53
7	16	0,50	23	0,5	1660	0,52	7	0,51	302	0,53
8	17	0,50	24	0,5	1760	0,53	8	0,51	332	0,53
9	18	0,50	25	0,5	1860	0,53	9	0,51	362	0,53
10	19	0,50	**26**	**0,5**	1960	0,53	10	0,51	392	0,54
11	**20**	**0,50**	27	0,51	2060	0,53	11	0,51	422	0,54
12	21	0,51	28	0,51	2160	0,53	12	0,51	452	0,54
13	22	0,51	29	0,51	2260	0,53	13	0,51	482	0,54
14	23	0,51	30	0,51	2360	0,53	14	0,51	512	0,54
15	24	0,51	31	0,52	2460	0,53	15	0,51	542	0,54
16	25	0,52	32	0,52	2560	0,53	16	0,51	572	0,54
17	26	0,52	33	0,52	2660	0,53	17	0,51	602	0,54
18	27	0,52	34	0,52	2760	0,53	18	0,51	632	0,54
19	28	0,52	35	0,52	2860	0,53	19	0,51	662	0,54
20	29	0,52	36	0,53	2960	0,53	20	0,51	692	0,54
21	30	0,52	37	0,53	3060	0,53	21	0,51	722	0,54
22	31	0,52	38	0,53	3160	0,53	22	0,51	752	0,54
23	32	0,52	39	0,53	3260	0,53	23	0,51	782	0,54
24	33	0,53	40	0,53	3360	0,53	24	0,51	812	0,54
25	34	0,53	41	0,53	3460	0,53	25	0,51	842	0,54
26	35	0,53	42	0,53	3560	0,54	26	0,51	872	0,54
27	36	0,53	43	0,53	3660	0,54	27	0,51	902	0,54
28	37	0,53	44	0,53	3760	0,54	28	0,51	932	0,54
29	38	0,53	45	0,53	3860	0,54	29	0,51	962	0,54
30	39	0,53	46	0,53	3960	0,54	30	0,51	992	0,54
31	40	0,53	47	0,53	4060	0,54	31	0,51	1022	0,54
32	41	0,53	48	0,54	4160	0,54	32	0,51	1052	0,54
33	42	0,53	49	0,54	4260	0,54	33	0,51	1082	0,54
34	43	0,53	50	0,54	4360	0,54	34	0,51	1112	0,54
35	44	0,53	51	0,54	4460	0,54	35	0,51	1142	0,54
36	45	0,53	52	0,54	4560	0,54	36	0,51	1172	0,54
37	46	0,53	53	0,54	4660	0,54	37	0,51	1202	0,54
38	47	0,53	54	0,54	4760	0,54	38	0,51	1232	0,54
39	48	0,53	55	0,54	4860	0,54	39	0,51	1262	0,54
40	49	0,53	56	0,54	4960	0,54	40	0,51	1292	0,54
n	1000000	0,55	1000000	0,55	1001060	0,54	1000000	0,51	1000000	0,54

Table H2 – The average occurrence of extreme events on different scenarios (Mozambique)

Component	N.	Indicator			Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Measurability	Transparency	Linkage				
Exposure	E1	Extreme events of floods per year (#)			1,43	1,43	1,43	1,43
	E2	Extreme events of droughts per year (#)			0,35	0,35	0,35	0,35
	E3	Extreme events of windstorms per year (#)			0,73	0,73	0,73	0,73
Sensitivity	S1	System affected by extreme events per year (%)			40,80	40,80	40,80	40,80
	S2	Loss and damages in the system per year ($)			91.479.729,73	91.479.729,73	91.479.729,73	91.479.729,73
	S3	People affected around the system (#)			460.422.452,54	460.422.452,54	460.422.452,54	460.422.452,54
Adaptive Capacity	AC1	Institutions providing financial support (#)			0,27	0,54	0,27	0,54
	AC2	Institutions providing technical support (#)			0,46	0,70	0,46	0,70
Governance	G1	Local management committee (#)			28,65	28,65	34,05	34,05
	G2	Legal policies approved (#)			0,03	0,03	0,05	0,05
	G3	Climate change adaptation plans and strategies (#)			3,30	3,30	3,30	26,00

Table H3 – The most vulnerable component on different scenario (Mozambique)

Component	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Average
E	0,2023	0,2023	0,2023	0,2023	0,2023
S	0,1197	0,1197	0,1197	0,1197	0,1197
AC	0,9548	0,9343	0,9548	0,9343	0,9446
G	0,9126	0,9126	0,8930	0,8930	0,9028

Table H4 – Different climate vulnerability scenarios according to the effort (Mozambique)

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Moçambique	0,51	0,48	0,48	0,45

APPENDIX I: Main Readiness indicators (Support information to paper 5)

Component	N.	Indicator			Total	Average
		Measurability	Transparency	Linkage		
Readiness	AC1	Institutions providing financial support (#)			10	0,27
	AC2	Institutions providing technical support (#)			17	0,46
	G1	Local management committee (#)			1.060	28,65
	G2	Legal policies approved (#)			1	0,03
	G3	Adaptation tools for climate change (#)			122	3,30

ANNEX

HIGHLIGHTS

Here, will are a present, some data and results from similar studies on climate change vulnerability.

ANNEX A: Disaster records from Mozambique (1900 - 2020) – Support information to paper 5

Year	Disaster Type	Location	Total Affected	Total Damages ('000 US$)
1956	Storm			
1967	Flood	Lourenco Marq. & Gaza	50.000	180.000,00
1971	Flood		500.000	
1975	Flood	Limpolo R. Valley	75.000	
1975	Flood	Incomati river		
1977	Storm	Maputo	51	
1977	Flood	Limpopo River Valley (Gaza province)	440.000	55.500,00
1978	Flood	Zambesi valley	200.000	63.000,00
1978	Storm	Nampula province	105.000	
1979	Drought	Nampula (North province), Cabo Delgado, Nampula, Tete, Manica provinces	6.000.000	
1981	Drought	South, Central, Maputo, Gaza, Inhambane, Manica, Sofala, Zambezi	4.750.000	
1981	Flood		500.000	
1984	Storm	Maputo, Gaza	350.000	75.000,00
1985	Flood	Maputo province	500.000	500,00
1985	Storm	Maputo province		
1987	Drought	Inhambane province	8.000	
1988	Storm	Quelimane	4.000	
1989	Flood	Sofala		
1990	Drought	Center	3.300.000	50.000,00
1994	Storm	Nampula, Zambesia, Manica, Sofala	2.502.000	
1996	Storm	Zambezia, Gaza, Maputo, Inhambane provinces	200.000	14.500,00
1997	Flood	Manica, Sofala, Tete, Zambezia provinces	400.000	
1997	Storm			50,00
1998	Landslide	Milange district (Zambezia province)	2.500	
1998	Drought	Maputo, Gaza, Inhame (south)		
1999	Flood	Nampula, Inhambane, Sofala, Tete and Zambezi Provinces	70.000	12.400,00
2000	Flood	Matutuine, Manhica, Magude, Marracuene districts (Maputo province), Chibuto, Chokwe, Mabalane districts (Gaza Province), Inhambane, Sofala, Manica, Tete provinces	4.500.000	419.200,00
2000	Storm	Cabo Delgado, Gaza, Inhambane, Manica, Nampula, Niassa, Sofala, Tete, Zambezia, Maputo, Lago niassa provinces		1.000,00
2000	Storm	Angoche, Moma, Mogincual districts (Nampula province)	304	
2000	Storm	Zambezia, Nampula provinces	750	
2000	Storm	Pebane, Milange districts (Zambezia Province)	350	
2001	Flood	Nhacolo town (Tambara district, Manica province), Nova Mambone area (Govuro district, Inhambane province), Nicoadala, Namacurra, Pebane, Chinde, Maganja da Costa, Morrumbala, Mopeia, Cidade de Quelimane districts (Zambezia province), Cidade da Beira, Buzi, Chibabava, Dondo, Marromeu, Nhamatanda, Caia, Chemba districts (Sofala province),Mutarara, Zumbo, Magoe, Macanga, Cidad de Tete districts (Tete province), Massangena district (Gaza province)	549.326	36.000,00
2001	Drought	Inhambane province	100.000	
2001	Drought	Maputo, Gaza, Inhambane, Sofala, Tete, Zambezia provinces	600.000	
2001	Flood	Cabo Delgado, Gaza, Inhambane, Manica, Maputo, Nampula, Niassa, Sofala, Tete, Zambezia provinces	200.000	
2002	Flood	Cidade de Nampula district (Nampula province), Cidade da Beira (Sofala province)	500	
2002	Storm	Cidade da Beira district (Sofala province)	4.017	
2003	Storm	Inhambane, Sofala, Manica, Gaza provinces	23.010	
2003	Flood	Moma, Angoche, Mogovolas, Mongicual, Lalaua, Nampula, Cidade de Nampula, Murrupula, Ribaue, Malema, Mecuburi districts (Nampula province), Cidade de Quelimane, Nicoadala, Maganja da Costa, Namacurra, Mocuba, Pebane, Gurue districts (Zambezia province), Pemba, Cidade de Pemba districts (Cabo Delgado province), Tete province	100.003	
2003	Flood	Metuge area (Pemba district, Cabo Delgado province), Nampula, Manica, Inhambane provinces	400.000	
2003	Flood	Cidade da Beira district (Sofala province)	15.000	
2003	Drought	Magoe, Zumbu, Cahora Bassa, Changara, Moatize, Chiuta, Mutarara districts (Tete province)	119.500	
2005	Flood	Mutarara districts (Tete province), Caia, Marromeu districts (Sofala province), Mopeia, Chinde districts (Zambezia province)	18.825	
2005	Drought	Maputo, Gaza, Inhambane, Manica, Sofala, Zambezia, Tete provinces	1.400.000	
2005	Flood	Nampula district (Nampula province), Dondo, Nhamatanda, Buzi, Cidade da Beira, Caia, Marromeu districts (Sofala province), Xai-Xai district (Gaza province), Gurue district (Zambezia province), Cabo Delgado, Inhambane, Maputo provinces	29.012	
2006	Earthquake	Machaze, Mossurize, Cidade de Chimoio districts (Manica province), Cidade da Beira district (Sofala province)	1.476	
2007	Flood	Buzi, Grudja areas (Buzi district, Sofala province), Caia, Sena areas (Caia district, Sofala province), Gurue, Quelimane, Namacurra, Mocuba, Maganja da Costa, Mopeia, Chinde, Nicoadala, Morrumbala districts (Zambezia province), Tambara, Guro, Sussundenga districts (Manica province), Marromeu, Chemba, Chibabava, Cidade da Beira districts (Sofala province), Mutarara, Zumbo, Chuita, Moatize, Magoe, Cahora Bassa, Changara districts (Tete province), Moma, Mogovolas districts (Nampula province)	285.000	71.000,00
2007	Flood	Cidade de Quelimane, Namacurra districts (Zambezia province)	3.500	
2007	Storm	Vilankulo district (Inhambane province)	162.770	
2007	Drought	Gaza, Inhambane, Manica, Sofala, Maputo provinces (Centre and south of the country)	520.000	
2007	Flood	Nova Mambone area (Govuro district, Inhambane province), Machanga district (Sofala province)		
2007	Flood	Mutarara, Nhamayabue, Inhangoma areas (Mutarara district, Tete province), Nova Mabone area (Govuro district, Inhambane province), Mossurize, Sussundenga, Tambara (Manica province), Mopeia, Chinde, Morrumbala, Maganja da Costa, Namacurra, Nicoadala districts (Zambezia province), Nampula, Cabo Delgado, Sofala provinces	113.535	100.000,00
2008	Drought	Maputo, Gaza, Inhambane, Manica, Sofala, Tete provinces	500.000	
2008	Flood	Manica, Mossurize, Tambara districts (Manica province), Maputo, Inhambane, Gaza, Tete provinces	3.500	
2008	Storm	Mossuril, Angoche, Nacala, Moma, Ilha de Mocambique, Mogovolas districts (Nampula province), Zambezia, Sofala provinces	220.013	20.000,00
2008	Wildfire	Manica, Sofala, Zambezia provinces	3.023	
2009	Storm	Zambezia province	7.103	3.000,00
2009	Flood	Cuamba district (Southern province), Zambezia, Nampula, Maputo provinces	6.925	
2010	Drought	Maputo, Inhambane, Gaza provinces (South)	460.000	
2010	Flood	Buzi, Chemba, Nhamatanda, Caia, Dondo, Marromeu districts (Sofala province), Mopeia, Chinde, Morrumbala districts (Zambezia province), Mutarara, Cahora Bassa, Cidade de Tete districts (Tete province), Tambara, Sussundenga districts (Manica province), Nampula, Inhambane provinces	17.000	
2011	Flood	Maputo, Gaza, Inhambane, Manica, Sofala, Tete, Zambezia provinces	30.000	
2011	Flood	Dombe village (Sussundenga district, Manica province), Magude town (Magude district, Maputo province), Caia village (Manhica (41376) district, Maputo province), Cidade de Maputo district (Maputo province), Bilene, Chibuto, Chokwe, Cidade de Xai-Xai, Guija, Xai-Xai districts (Gaza province), Tete, Zambezia provinces	33.946	
2011	Storm	Cidade de Chimoio district (Manica province)		
2012	Storm	Cabo Delgado, Sofala provinces	4.958	
2012	Storm	Nicoadala, Cidade de Quelimane, Chinde, Pebane, Maganja da Costa, Namacurra, Gurue, Mocuba districts (Zambezia province), Mossuril, Nacal-A-Velha districts (Nampula province)	65.000	
2012	Storm	Chokwe, Xai-Xai districts (Gaza province), Cidade de Maputo district (Maputo province), Zavala district (Inhambane province), Nampula, Zambezia, Sofala provinces	40.000	
2013	Flood	KaMavota, KaMubukwana, KaMaxakeni boroughs (Cidade de Maputo district, Maputo province), Chigubo, Chibuto, Mandlakaze, Massangena, Chicualacuala, Guija, Chokwe, Bilene, Xai-Xai districts (Gaza province), Panda, Homoine, Govuro districts (Inhambane province), Milange, Gile, Nicoadala, Chinde, Namarroi, Maganja da Costa, Namacurra, Cidade de Quelimane, Morrumbala districts (Zambezia province), Cidade de Chimoio, Gondola, Sussundenga, Barue, Mossurize, Macossa districts (Manica province), Nhamatanda, Machanga, Muanza, Cidade de Beira, Chemba, Caia districts (Sofala province)	240.000	30.000,00
2014	Flood	Nhamatanda, Buzi, Chibabava, Cidade da Beira districts (Sofala province), Sussundenga district (Manica province), Cabo Delgado, Nampula provinces	75.986	
2014	Flood	Cidade de Maputo, Cidade de Matola districts (Maputo province) Cidade de Xai-Xai district (Gaza province)	300	
2015	Flood	Zambezia, Nampula, Maputo, Gaza, Cabo Delgado provinces	177.645	
2016	Drought	Magude, Manhiça districts (Maputo province), Massingir, Chibuto, Mabalane districts (Gaza province), Funhaloro, Panda, Govuro districts (Inhambane province), Sofala, Tete	2.300.000	
2016	Flood	Cabo Delgado province	6.600	
2016	Flood	South of the country and capital, Maputo, Gaza, Inhambane, Nampula,Tete, Sofala	165.000	
2016	Storm	Maputo	1.700	1.500,00
2017	Storm	Vilankulo, Massinga, Maxixe, Jangamo, Morrumbene Inhambane City, Funhalouro, Homoine, Jangamo, Inharrime, Panda, Zavala (Inhambane province); Chibuto, Guja, Chokwe distrcits (Gaza province)	750.102	17.000,00
2018	Landslide	Hulene (Maputo)	300	
2018	Flood	Nampula, Niassa, Cabo Delgado, Mozambique Isl.	77.150	5.100,00
2019	Storm	Beira (Sofala province); Zambezia, Manica and Inhambane provinces	1.501.500	2.000.000,00
2019	Storm	Cabo Delgado	400.094	230.000,00
2019	Flood	Zambezia and Niassa provinces		
2019	Flood	Tete, Zambeze provinces	63.000	
2019	Flood	Cabo Delgado, Nampula, Zambezia, Tete, Sofala provinces	58.066	
2020	Flood	Grudja, Estaquinha, Bandua, Guara-Guara, Vila de Buzi, Muchanesse, Munimucua (Buzi distrcit, Sofala province); Sussundenga District (Manica)	8.700	

Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium - www.emdat.be (D. Guha-Sapir)

ANNEX B: Water Poverty Index

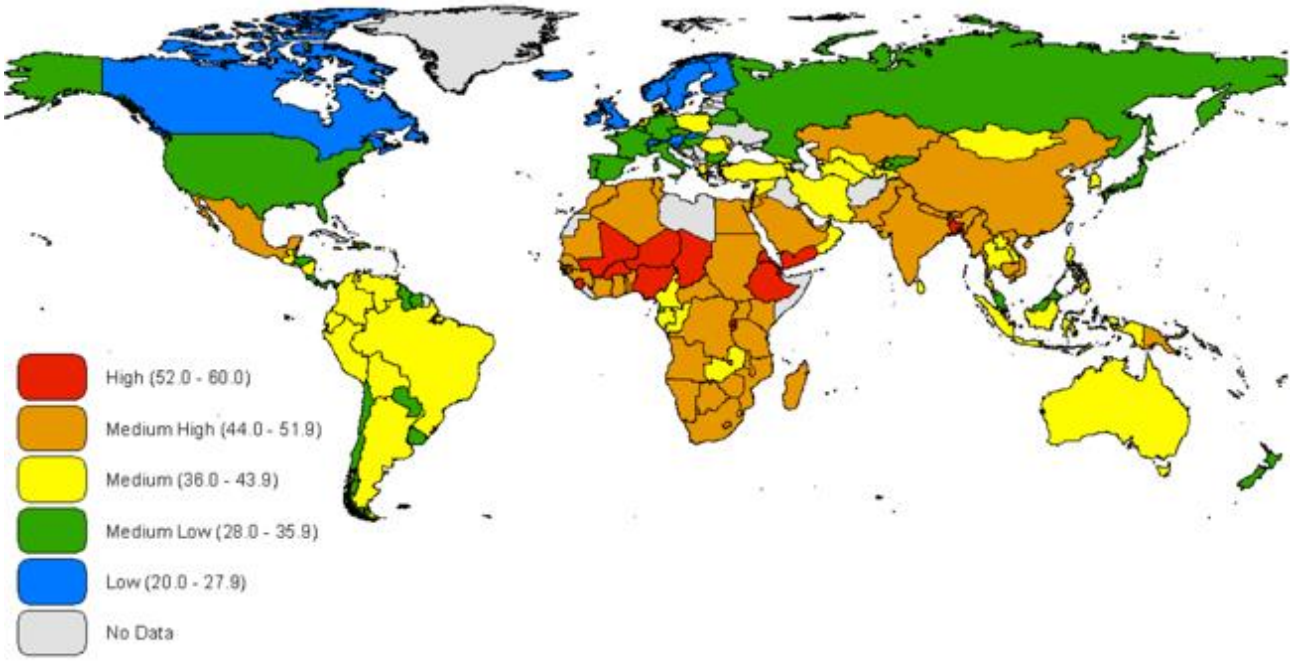


Figure 02 – This picture above reflects the local climate vulnerability assessment to water-related risks (Adapted from SULLIVAN, 2002).

ANNEX C: Notre Dame-Global Adaptation Index (ND-GAIN) – Support to paper 5

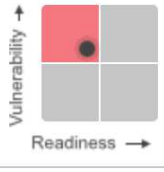
Mozambique

GDP (PPP) per capita (2017): 1,247.60 Int. Dollar Population (2017): 29,668,834 HDI (2017): 0.44

ND-GAIN Country Index rank

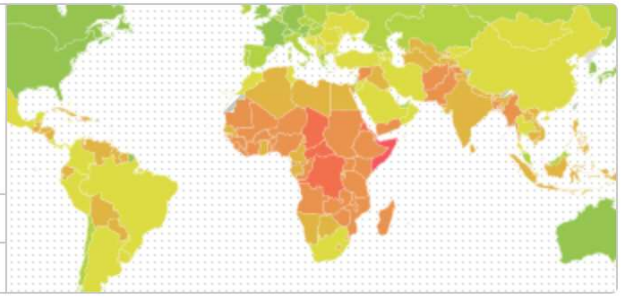
159

Score: 35.4



Vulnerability 0.541

Readiness 0.249



The high vulnerability score and low readiness score of Mozambique places it in the upper-left quadrant of the ND-GAIN Matrix. It has both a great need for investment and innovations to improve readiness and a great urgency for action. Mozambique is the 39th most vulnerable country and the 24th least ready country.

ND-GAIN Ranking since 1995

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Ranking	156	155	155	154	153	150	150	150	151	149	149	146	146	143	144	145	145	148	149	151	152	160	159

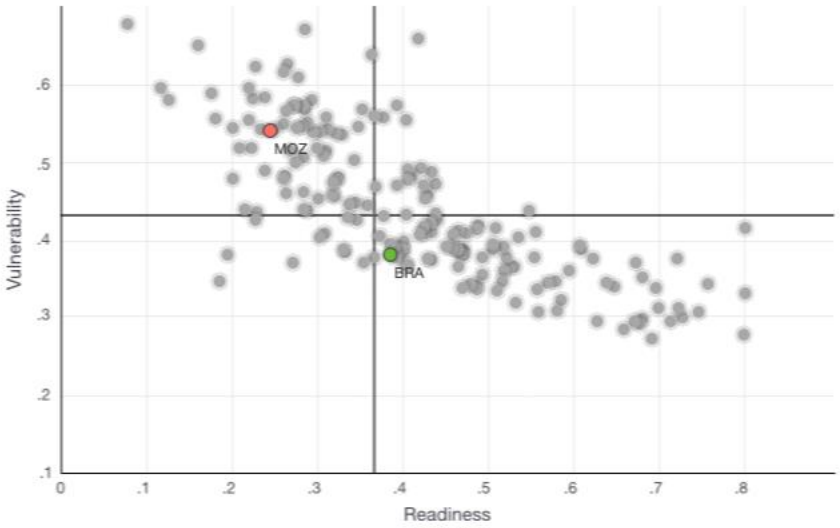
Indicator	*1998 to 2017*	*Score*
Vulnerability		**0.541**
Exposure		**0.433**
Projected change of biome distribution		0.576
Projected change of marine biodiversity		0.323
Projected change of cereal yields		0.940
Projected population change		0.582
Projected change of warm periods		0.144
Projected change of flood hazard		0.625
Projected change of deaths from climate change induced diseases		0.364
Projected change in vector-borne diseases		0
Projected change of hydropower generation capacity		0.693
Projected change of sea level rise impacts		0.099
Projected change of annual runoff		0.629
Projected change of annual groundwater recharge		0.225

Sensitivity		**0.513**
Natural capital dependency		0.422
Ecological footprint		0.127
Food import dependency		0.787
Rural population		0.696
Urban concentration		0.074
Age dependency ratio		0.865
Dependency on external resource for health services		1.000
Slum population		0.828
Dependency on imported energy		0.506
Population living under 5m above sea level		0.301
Fresh water withdrawal rate		0.009
Water dependency ratio		0.538

Adaptive Capacity		**0.676**
Protected biome		0.783
Engagement in international environmental conventions		0.858
Agriculture capacity		0.979 ●
Child malnutrition		0.235
Quality of trade and transport infrastructure		0.708
Paved roads		0.798
Medical staff		0.989 ●
Access to improved sanitation facilities		0.820
Electricity access		0.758
Disaster preparedness		0.201
Dam capacity		0.378
Access to reliable drinking water		0.607

● *Denotes worst scores*

Indicator	*1998 to 2017*	*Score*
Readiness		**0.249**
Economic		**0.237**
Doing business		0.237
Governance		**0.330**
Political stability and non-violence		0.402
Control of corruption		0.232
Regulatory quality		0.372
Rule of law		0.313
Social readiness		**0.179** ●
Social inequality		0.388
ICT infrastructure		0.271
Education		0.053 ●
Innovation		0.002 ●


Vulnerability
.6
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.1
.2
.3
.4
.5
.6
.7
.8
Readiness
MOZ
BRA