

A new method to build a vulnerability index¹

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Resumo:

Um novo método para construir um Índice de Vulnerabilidade

A Universidade das Nações Unidas criou em 1973 o Instituto de Meio Ambiente e Segurança Humana (UNU-EHS) para enfrentar os riscos e as vulnerabilidades, as consequências de complexos, agudos e latentes riscos ambientais. Assim, o UNU-EHS tem desenvolvido metodologias de avaliação de vulnerabilidade e pesquisa de vulnerabilidades tendo em conta vários impactos de fenómenos perigosos, que afetam principalmente as áreas costeiras, e sobretudo as cidades costeiras. Ao longo das duas últimas décadas, o desenvolvimento sustentável tornou-se a questão política mais relevante, estimulando diversos tipos de abordagens e respostas. Há, também, um reconhecimento crescente da importância da gestão de vulnerabilidade e resiliência na abordagem de problemas de desenvolvimento sustentável. Apresentamos aqui uma proposta de um novo método para a construção de um Índice de Vulnerabilidade.

Palavras-chave: Vulnerabilidade. Resiliência. Modelo de Índice de Vulnerabilidade.

Abstract:

The United Nations University established in 1973 the Institute for Environment and Human Security (UNU-EHS) to address risks and vulnerabilities, consequences of complex, acute and latent, environmental hazards. Accordingly, UNU-EHS has developed vulnerability assessment methodologies and vulnerability research looking at various hazards impacts, mostly affecting coastal areas, namely coastal cities. Over the last two decades, sustainable development became the most relevant political issue, stimulating diverse types of approaches and responses. There is, also, a growing recognition of the importance of managing vulnerability and resilience in addressing sustainable development problems. We present here a proposal of a new method to build a Vulnerability Index.

Key Words: Vulnerability. Resilience. Vulnerability Index.

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I. Socio-ecological systems

Most of the activities implemented by Institute for Environment and Human Security (UNU-EHS) were centered on vulnerability assessment - the most crucial and least known part of the risk equation. Multiple complex assessment tools are necessary to conceive models systems and to define the quantification thresholds, in the characterization of the states of these systems. Nature cannot be dissociated from social systems; both interact in complex, non-linear, and unsteady stochastic ways. Community vulnerability of single or multiple hazards is thus best analyzed by considering environmental, social and economic dimensions, or by analyzing coupled human-environment or socio-ecological systems.

Disasters are non-routine events in societies that involve social disruption and human harm (KREPS, 2001). Capturing antecedents and consequences of disasters is part and parcel of constructing descriptive and explanatory models of hazards and disasters. In addition, Tierney and colleagues (TIERNEY *et al.*, 2001), refer that before, during, and after they occur, disasters are physical and social catalysts of collective action.

Complexity increases in the case of interactions between elements at various temporal and spatial scales, and it is difficult to quantify the amount of disturbance that a system can absorb, before it changes to a new and usually unfavorable state. The vulnerability of coupled human-environment systems requires improved dialogue between several scientific disciplines and between them and decision making.

I.1. Cities, hazards and “natural” disasters

To a politician or a planner, a city is a place of connections: network of roads, electrical cables, piped water and drains. To the urban workforce, and the tourists attracted to the city, it offers shelter, safety and a livelihood source. To property owners, developers and planners, a city is its housing, its stock of physical assets. To someone who lives in a city and that includes all of the above and many more - a city is a physical and cultural arena, a place of political freedom, and a source of cultural and intellectual vitality.

But, all of this can be at risk from a seismic source, a catastrophic volcanic eruption, or a set of powerful earthquake waves which can set up a disaster, or even a catastrophe.

Natural phenomena (or hazard) by themselves are not disasters. They become disasters when they impact communities and regions that are vulnerable to their effects, (AGUIRRE, 2006). Vulnerability, in turn, may be defined by the degree to which a system, subsystem, or system component experiment harm, due to hazard exposure, either a perturbation or stress/stressor.

In this sense, disasters are not natural; they are also consequences of decisions, often seemingly unconnected to their ultimate consequences, of collectivities of people, and are caused by their inability or unwillingness to adopt sustainable patterns of living. Unfortunately, so called natural disasters are often misunderstood as natural phenomena, when in reality they represent an interaction between the natural world and socio-cultural systems, particularly with regard to social vulnerability.

Conceptual frameworks that account for this kind of vulnerability must be developed. Susan Cutter (CUTTER *et al.*, 2003), using the model of disaster places (DROP model - Disaster Resilience of Place), suggests that social vulnerability is a multidimensional concept that helps

to identify those characteristics and experiences of communities (and individuals) that allow them to respond and recover from natural disasters, and in this sense it is not disconnected from the concept of resilience.

Understanding resilience as the capacity of socio-ecological systems to support disturbances and reorganize, the relationship between resilience and planning is very relevant (TEIGÃO DOS SANTOS e PARTIDÁRIO, 2011). To preserve advance human safety, principal priorities of a dedicate program, accordingly UNU-EHS, should consider: (i) Vulnerability assessment, resilience analysis, risk management and adaptations strategies within linked human-environment systems; (ii) Internal displacement and trans-boundary migration due to environmental push-factors; (iii) Preparedness, adaptation, response and recovery. Within this framework, resilience emerges as an advantageous concept with potential for promoting more sustainable trajectories for policy and planning processes, reflecting the capacity of a system (a region, an economic activity, a city, a household) to absorb disturbance and reorganize without collapsing or considerably changing their identity, thus losing its fundamental features, and appears to have the potential to play a critical role, namely when crisis, instability, uncertainty and complexity are interconnected factors that characterize a context.

1.2. Vulnerability, risk index

The concept of vulnerability has different connotations in the literature on disasters, depending on the orientation and perspective of research, (DOW, 1992), (CUTTER, 1996, 2001). There are three main research directions on vulnerability: (a) an exposure model, referring to the identification of conditions that make people and places vulnerable to extreme natural hazards, (BURTON *et al.*, 1993), (ANDERSON, 2000); (b) a measure of social resistance or resilience to hazards associated with the assumption that vulnerability is a social condition, (BLAIKIE *et al.*, 1994), (HEWITT, 1997); (c) the integration of potential exposures and social resilience with a specific focus in particular places or regions, (KASPERSON and KASPERSON, 1995), (CUTTER *et al.*, 2000, 2010). This recognition requires revisions and enlargements in the basic design of vulnerability assessments, including the capacity to treat coupled human-environment systems and those linkages within or without the systems that affect their vulnerability.

In fact, considerable research attention has been paid to different components of biophysical and environmental vulnerability (MILETI, 1999) and to the vulnerability of the civil infrastructure. However, our current knowledge about the social and individual aspects of vulnerability is minimal.

Several vulnerability frameworks have been developed in academic circles to try to capture the above complexities in cities. Research demonstrates that vulnerability is evaluated not only by exposure to hazards (perturbations and stresses) alone, but also resides in the sensibility and resilience of the system experiencing such hazards.

Experts and Researchers from around the world have to develop new approaches and also they have to assure training programs for experts dealing with risk and vulnerability assessments in large cities. Studies have investigated methods to develop vulnerability indicators. These include the Earthquake Disaster Risk Index (EDRI) developed and applied to several cities (DAVIDSON, 1997). In the calculation of the EDRI for each city, five main factors – hazard, exposure, vulnerability, context, and emergency response and recovery planning – are measured and combined into

the EDRI. The Cities Project methodology for assessing relative community vulnerability was developed by (GRANGER *et al.*, 1999). This involves indicators that contribute to an overall “relative risk rank”. The indicators are grouped into five categories: setting, society, security, sustenance and shelter. Within these five themes, the indicators are a collection of physical, structural, economic and lifestyle factors chosen to measure a community’s vulnerability (Dwyer *et al.*, 2004). Nevertheless, socially generated vulnerabilities are largely ignored, and are often described solely by individual characteristics (age, gender, health, income, type of housing, employment). This may be due to the complex nature of people, social structures and culture, as well as to the multi-disciplinary approach that is required to do such research.

All these activities will help, in the long run, to define assessment tools and methodologies, to identify policies and concrete actions designed to reduce the vulnerability of communities facing natural hazards, avoiding disasters and catastrophes. It is fundamental to set up and foster multi-stakeholder platforms for disaster risk reduction, giving consideration to local and sustainable urbanization issues (according vulnerability and resilience indices). Planning and policy making are the obligations of institutions that take risk reduction into consideration, where local priorities clearly identify responsibilities at all levels.

1.3. Risks, hazard models

Risk hazards models sought to understand the impact of a hazard as a function of exposure, and the typology of the entity exposed.

Various lines of investigation reveal large inadequacies of this Research Hazards model framework, it those not treat: (i) the ways in which the systems in question amplify or attenuate the impacts of the hazard; (ii) the distinctions among exposed subsystems and components that lead to significant variations in the consequences of the hazards; (iii) the role of the political economy especially social structures and institutions, in shaping differential exposure and consequences. The conditions that make exposure unsafe, leading to vulnerability have to be clarified. So, this model seems insufficiently comprehensive for the broader concerns of sustainability science.

By your turn, vulnerability analysis draws on three major concepts: (a) entitlement (license), (b) coping through diversity, (c) resilience. Different systems maintain different sensitivities to perturbations and stressors and this characteristic, for individuals and groups (human), is strongly to entitlements: legal and customary rights to exercise command over food and other necessities of life. These entitlements are determined by the units and endowments (grants). Social units also have different coping capacities, which enable them to respond to the registered harm, as well as, to alert the potential harm of a hazard. In one sense, entitlement and endowment link to these capacities, and either concept can be expanded to include a large array of social institutions, such as societal “safety nets”, that empower coping capacity.

Accordingly, the definition of risk elements will condition risk assessment and have implications for the variables that quantify it. Risk analysis requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties or economic losses (direct impact), but also the conditions related to social fragility and to the lack of resilience, which enable second order effects (indirect impact) when a hazardous event strikes, for example, a urban center (CARREÑO *et al.*, 2005).

1.4. Disasters models and resilience

Managing complex, coevolving social-ecological systems for sustainability therefore requires resilience as the ability to cope with, adapt to and shape change without losing options for future development (FOLKE, 2006).

Resilience - as the ability of the system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and deficient manner, including through the preservation and restoration of its essential basic structures and functions - enters vulnerability analysis from ecology, where it has evolved in meaning through extended debate and application. As a result, the resilience of the system is often evaluate in terms of the amount of change a given system can undergo and still remain within the set of natural or desirable states, and influence a variety of interdisciplinary research focused on coupled human-environment systems, especially through the key component of “adaptive capacity”, the flexibility of ecosystems, and the ability of social system to learn in response to disturbances.

Comprehensive vulnerability analysis ideally considers the totality of the system. This ideal, however, is unrealistic. Real-world data and other constraints invariably necessitate a “reduced” vulnerability assessment. Nevertheless, analysts must be aware that vulnerability rests in a multifaceted coupled system, with connections operating at different spatiotemporal scales and commonly involving stochastic and nonlinear processes. The basic architecture consists of: (i) linkages to the broader human - environmental conditions and processes operating on the coupled system in question; (ii) perturbations and stressors/stress that emerge from these conditions and processes; (iii) the coupled human-environment system of concern in which vulnerability resides, including exposure and responses (i.e., coping, impacts, adjustments, and adaptations). Those elements are interactive and scale dependent; that analysis is affected by the way the coupled system is conceptualized and bounded for study.

The coupled human-environment system, whatever its spatial dimensions, constitutes the key of analysis. The hazards acting on the system arise from influences outside and inside the system and place, but given their complexity and nonlinearity, their precise character is commonly specific to the place-based system

Building adaptive capacity is a prerequisite for sustainability in a world of rapid transformations (GUNDERSON e HOLLING, 2002). And resilience can be seen as an issue of environmental, social and economic security (GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE, 2000).

Social capital is another emerging concept as a key dimension on disaster preparedness and mitigation. Within the scope of disaster models, social capital refers to social networks, the reciprocities that arise from them, and their value in achieving mutually beneficial goals. Social capital is about trust, associations, and norms of reciprocity among groups and individuals, including beliefs and customs. And it can act in reducing social vulnerabilities and increasing resilience, namely in aging, frail and physically limited individuals (TIERNEY *et al.*, 2001; PUTNAM, 2000; BLAIKIE *et al.*, 1994).

The incorporation of differential resilience has become a critical element of analysis in human-environmental systems.

1.5. Systemic adaptation

The human-environment conditions of the system determine its sensitivity to any set of exposures. The framework illustrates the complexity and interactions involved in vulnerability analysis, drawing attention to the array of factors and linkages that potentially affect the vulnerability of the coupled human-environment system in a place. Its systemic qualities are open to hazards-consequences or consequences-hazards applications, depending on the interest and aims of the user.

The following check-list of Essentials for Making Cities Resilient derives from five priorities of the “Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters”, a key instrument for implementing disaster risk reduction. The City Council and local governments have to assure the following list of activities for making more resilient cities: (i) to put in place organization and coordination to understand and reduce disaster risk, based on participation of citizen groups and civil society. Build local alliances. Ensure that all departments understand their role in disaster risk reduction and preparedness; (ii) assign a budget for disaster risk reduction and provide incentives for homeowners, low-income families, communities, businesses and the public sector to invest in reducing the risks they face; (iii) maintain up-to-date data on hazards and vulnerabilities, prepare risk assessments and use these as the basis for urban development plans and decisions. Ensure that this information and the plans for your city’s resilience are readily available to the public and fully discussed with them; (iv) invest and maintain critical infrastructure that reduces risk, such as flood drainage, adjusted where needed to cope with climate change; (v) assess the safety of all schools and health facilities and upgrade them as necessary; (vi) apply and enforce realistic, risk-compliant building regulations and land-use planning principles. Identify safe land for low-income citizens and develop upgrading of informal settlements, wherever feasible; (vii) ensure that education programs and training on disaster risk reduction are in place in schools and local communities; (viii) protect ecosystems and natural buffers to mitigate floods, storm surges and other hazards to which your city may be vulnerable. Adapt to climate change by building on good risk reduction practices; (ix) install early warning systems and emergency management capacities in your city and hold regular public preparedness drills; (x) after any disaster, ensure that the needs of the survivors are placed at the centre of reconstruction with support for them and their community organizations to design and help implement responses, including rebuilding homes and livelihoods.

In order to characterize the Societal Impact, some actions and oriented recommendations from the geo-scientific community can be used to evaluate, formulate and create a plan of both national and international policies for sustainable development of our society: (a) *Geophysical Risks: Prevention of Natural Hazards* (Interactions Between Community and Geo-science; Efficient Use of Hazard Maps; Employing Early Warning System); (b) *Effective Use Of Technology And Scientific Results* (Comprehensive Observation for Hazard Mitigation, Information Technology; Improve Predictability; Simulation Geo-hazards); (c) *Some Counter-Measures Against Gigantic Natural Hazards* (Extreme Weather Events; Volcanic Activity; Earthquakes; Tsunami); (d) *Human Life and Environment* (Global Change and Human Activity; Anthropogenic Effects; Observation System; Modeling Climate; Role of Geosciences in Environmental Issues; Increased Public Awareness of Issues Affecting Our Climate; Political Aspects); (e) *Geo-science Education And*

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Out-Reach (Efficient Use of Modern Technology for Scientific Education; Promoting Training International Schools; Communication with Society).

II. A new method to build a vulnerability index

II.1. The idea

The 2011 census for Portugal lists values for several demographic and infrastructural attributes for the 4050 parishes of Portugal (exclusive of Madeira and Azores).

To illustrate a new method to build a vulnerability index, we have selected three attributes: age distribution of the population; educational level of the population and structural type of residential buildings -- further details on these attributes are given below.

The idea is to rank the parishes according to their perceived vulnerability, separately from the viewpoint of each of these three attributes (the method would be the same if we had used more attributes, and in general it is preferable to use as many attributes as may be available).

Once this has been completed, we have three independent rankings of all the parishes, from least vulnerable to most vulnerable. Then we combine the three rankings in a way that is consistent and that produces an overall ranking of the parishes, and that assigns a vulnerability score to each of them.

These scores are numbers between 0 and 1, and the larger the score the greater the vulnerability.

This way of building a vulnerability index is entirely data driven, and its strength lies in its ability to combine multiple facets of vulnerability.

Another strength is the fact that it relies on rankings, rather than on any social arithmetic whose adequacy naturally would be arbitrary to some extent, hence would be questionable.

II.1.1. Step 1

The 2011 census lists numbers of residents of each parish in eight age classes:

0-4, 5-9, 10-13, 14-19, 15-19, 20-24, 25-64, and 65+.

We computed the corresponding proportions for each parish, and then partitioned the parishes into 10 clusters, using the procedure Partition Around Medoids (PAM) described by L. (KAUFMAN e ROUSSEEUW, 1990).

We selected 10 clusters based on an inspection of a series of silhouette plots, for different numbers of clusters, as described by those authors. We used the procedure as implemented in function `pam` of package `cluster` for the R environment for data analysis and graphics (MAECHLER, *et al.*, 2013).

We then assigned the same rank to the parishes in the same cluster. For example, all 91 parishes in cluster 5 are deemed most vulnerable (vulnerability rank 1) because the medoid of their cluster has the largest proportion of residents who are 65 years old or older. These are the definitions of the medoids determined by function `pam` and the ranks assigned to them based

on the proportion of 65+ years old people in the medoid. More complex ranking criteria may be used, and one of them will be illustrated below.

Table I
Proportion of 65+ years old people in the medoid.

Cluster	0-4	5-9	10-13	14-19	15-19	20-24	25-64	65+	Rank
1	3	4	4	5	5	5	49	26	6
2	4	4	4	6	5	5	50	23	7
3	5	5	4	6	5	5	54	15	9
4	4	4	4	6	5	5	52	19	8
5	1	1	1	2	2	2	31	59	1
6	3	3	3	5	4	5	47	30	5
7	2	3	3	5	4	4	44	35	4
8	5	5	5	7	6	6	53	11	10
9	2	2	2	4	3	4	42	41	3
10	2	3	2	3	2	3	38		

Fonte: A. POSSOLO (NIST-USA), 2013.

II.1.2. Step 2

The 2011 census lists numbers of residents of each parish that can read and write, or that have completed several different levels of schooling (7 levels: LERESCRV, 1BAS, 2BAS, 3BAS, SEC, POSEC, SUP).

We computed their proportions in each parish, and clustered the parishes based on the logarithms of these proportions (because the distributions of schooling are rather skewed), using the same pam procedure described above, with 12 classes in this case.

And we ranked as **most vulnerable** the parishes with the highest proportions of residents **who can only read and write but have no further education**, breaking ties according to the proportion of residents that have completed secondary education.

II.1.3. Step 3

The 2011 census lists numbers of buildings in each parish in the following structural categories: BETAO, COMPLACA, SEMPLACA, ADOBEPEDRA.

We computed their proportions in each parish, and clustered the parishes based on the square roots of these proportions (because the distributions of schooling are fairly skewed), using the same pam procedure described above, with 12 classes in this case.

And we ranked as most vulnerable the parishes with the largest proportions of ADOBEPEDRA buildings, breaking ties according to the proportion of SEMPLACA buildings.

II.1.4. Step 4

Now we have three independent rankings of the 4050 parishes, which we combine using a robust rank aggregation procedure (KOLDE *et al.*, 2012).

We did the computations using function `aggregate Ranks` of the R package `RobustRankAggreg` (KOLDE e LAUR, 2011).

The result of this computation is a numerical score that is assigned to each parish, between 0 and 1, with the vulnerability increasing with increasing score.

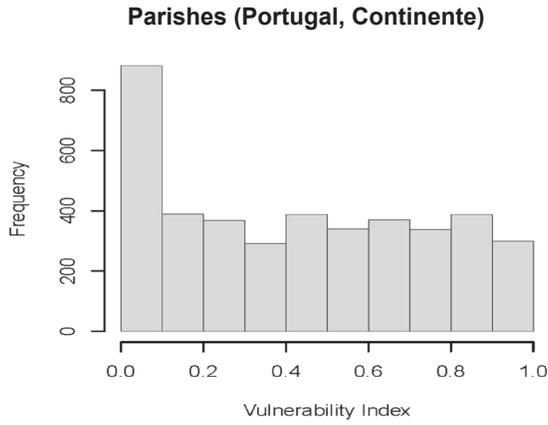


Figure 1
Histogram of the vulnerability scores assigned to the 4050 parishes.
Fonte: A. POSSOLO (NIST-USA), 2013.

These scores are depicted in the accompanying map, where each circle represents a parish, and the colors increase from pale yellow to red according to increasing vulnerability (see Figure 2).



Figure 2
Map of increasing vulnerability assigned to the 4050 parishes.
Fonte: A. POSSOLO (NIST-USA), 2013.

Discussion

The index can be improved by considering additional vulnerability attributes. The clustering steps may be replaced by other means of ranking the parishes according to increasing vulnerability gauged from the viewpoint reflected in the corresponding attribute.

The particular assignment of vulnerability scores to these parishes is preliminary because it relies on just these three attributes that do not fully capture the spectrum of vulnerability factors that should be taken into account. But our objective is methodological, and for this purpose this simple illustration suffices.

III. Cascais and Lagos

Additional information is available for the parishes of Cascais and Lagos.

III.1. Cascais

Cascais, has the following parishes: Alcabideche, Carcavelos, Cascais, Estoril, Parede, São Domingos de Rana.

- (a) These have been ranked from most vulnerable to least vulnerable from three complementary viewpoints: age distribution; (b) educational level distribution; (c) local geology

The first two evaluations were done as already described for all the parishes of continental Portugal.

The evaluation of local geology was done by an expert who is familiar with the area.

These are the rankings of the parishes, in order of decreasing vulnerability, according to each of the three criteria above:

- (a) Parede, Estoril, Cascais, Carcavelos, Alcabideche, São Domingos de Rana
 (b) Alcabideche, São Domingos de Rana, Cascais, Estoril, Carcavelos, Parede
 (c) Estoril, Cascais, Carcavelos, Alcabideche, Parede, São Domingos de Rana

The results of robustly aggregating these three rankings are the following (the larger the vulnerability score, the greater the composite vulnerability):

Table II
Robustly aggregation of the three rankings used for Cascais.

Parish	Vulnerability Score
Cascais	0.7
Estoril	0.4
Parede	0.2
Alcabideche	0.2
Carcavelos	0.07
São Domingos de Rana	0.03

Fonte: A. POSSOLO (NIST-USA), 2013.

III.2. Lagos

Lagos has the following parishes: Barão de São João, Bensafrim, Lagos (Santa Maria), Lagos (São Sebastião), Luz, Odiáxere.

These have been ranked from most vulnerable to least vulnerable from three complementary viewpoints: (a) age distribution; (b) educational level distribution; (c) local geology; (d) fire hazard; (e) fire risk.

The first two evaluations were done as already described for all the parishes of continental Portugal.

The evaluation of seismic risk, fire danger, and fire risk, were done by experts who are familiar with the area.

These are the rankings of the parishes, in order of decreasing vulnerability, according to each of the five criteria above: (a) Luz, Bensafrim, Odiáxere, Barão de São João, Lagos (Santa Maria), Lagos (São Sebastião); (b) Luz, Odiáxere, Bensafrim, Barão de São João, Lagos (São Sebastião), Lagos (Santa Maria); (c) Lagos (São Sebastião), Luz, Odiáxere, Bensafrim, Barão de São João, Lagos (Santa Maria); (d) Odiáxere, Bensafrim, Barão de São João, Lagos (Santa Maria), Lagos (São Sebastião), Luz; (e) Lagos (Santa Maria), Lagos (São Sebastião), Luz, Odiáxere, Barão de São João, Bensafrim.

The results of robustly aggregating these three rankings are the following (the larger the vulnerability score, the greater the composite vulnerability):

Table III
Robustly aggregating of the three rankings used for Lagos.

<i>Parish</i>	<i>Vulnerability Score</i>
Odiáxere	0.5
Luz	0.4
Barão de São João	0.08
Bensafrim	0.05
Lagos (São Sebastião)	0.02
Lagos (Santa Maria)	0.01

Fonte: A. POSSOLO (NIST-USA), 2013.

III.3. Cascais and Lagos

NOTE: The vulnerability Scores for Cascais and Lagos are not comparable because the rankings for the two sets of parishes were done separately.

Furthermore, they are based on different criteria (more criteria for Lagos than for Cascais).

Therefore, and in particular, one cannot infer that Cascais is more vulnerable than Odiáxere.

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