Climate hazards and disaster risk: a contribution for urban planning and risk assessment in mainland Portugal

Álvaro Pimpão SILVA[1], Fátima ESPÍRITO SANTO[2], José Eduardo VENTURA[3], Armando PINTO[4]

[1] Instituto Português do Mar e da Atmosfera, I.P., Lisboa, Portugal, alvaro.silva@ipma.pt
[2] Instituto Português do Mar e da Atmosfera, I.P., Lisboa, Portugal, fatima.coelho@ipma.pt
[3] CICS.NOVA - Centro Interdisciplinar de Ciências Sociais/ Faculdade de Ciências Sociais e Humanas / Universidade Nova de Lisboa, Lisboa, Portugal, je.ventura@fcsh.unl.pt
[4] LNEC - Laboratório Nacional de Engenharia Civil, Lisboa, Portugal, apinto@lnec.pt

Abstract: Portugal is affected by recurrent meteorological, hydrological and climate extreme events, that can contribute to disasters causing losses of life and severe economic and social damages. Floods, droughts, extreme temperatures, wind-storms are natural hazards occurring in our country, can lead to disaster in communities exposed to these weather and climate-related events and incremented in some urban areas presenting a high level of vulnerability. Knowing, anticipating and managing such risks are critical tasks in urban planning.

It is crucial to take into account not only the extreme events in a statistical sense, but also the level of exposure and vulnerability of urban settlements that can transform even small scale events into disasters, contributing for increasing socio-economic and ecological impacts. Understanding and modelling disaster and climate risk is more and more essential. Appropriate spatial climate information is important to be considered at the several scales of territory management and planning. In this work not only the key concepts are described but also two hazard mapping examples concerning heat waves and snow are presented for mainland Portugal. These aspects are finally related with urban and regional planning strategies to reduce vulnerability and strengthen adaptation.

Keywords: Climate risk, natural disasters, vulnerability, exposure, urban planning.

1. Introduction

The natural risks are growing due to climate change, but the increase in vulnerability and exposure of societies also play a key role. In what concerns urban areas the European Environment Agency - EEA refers that "cities are the places where most people in Europe will experience climate change impacts first; they accommodate around three quarters of the population, a share which is expected to increase further. Urban areas are distinct from the surrounding rural regions. Their specific composition of people and activities as well as their urban design alters climate change impacts, for example exacerbates heat waves due to the UHI effect, generating urban floods due to a high share of impervious surfaces and water scarcity due to the concentration of people and socioeconomic activities" (EEA, 2012b, p. 222).

Public territory management policies must include effective exposure and vulnerability reduction measures to climate disaster risk. The social, infrastructural and institutional adaptation approaches are important adjustments to be addressed in planning at several scales, transnational, national, regional and local. Resilience of societies and ecosystems is a concept that can be understood as the capacity of a system to withstand pressures and to rebuild and renew itself if degraded (Moberg, F., Galaz, V., 2005). It is another important issue that needs to be analysed and integrated in urban and regional plans.

One objective of this work is related with the explanation of climate disaster risk, the identification of vulnerability and exposure reduction measures, and the interpretation of adaptation and resilience concepts. The main emphasis is that these theoretical concepts should all be included in territory management plans.

Another important topic is the hazard risk mapping. Some examples related with extreme temperatures are presented. This type of climate hazards is responsible for the highest number of deaths due to natural phenomena in Europe and, particularly, in Portugal.

2. Theoretical approach to climate hazards and disaster risk

There are two big types of hazards, natural (Table 1) and technological; following the classification provided by the EM-DAT the International Disaster Database. The climate and the weather (extreme) events are important subtypes of natural hazards focused in this text, and together with exposure and vulnerability generate the disaster risk (Figure 1).

Table 1 – Natural Disasters General Classification (Adapted from the EM-DAT).

Natural Disaster Subgroup	Definition	Disaster Main Type	Disaster Sub-type	Disaster Sub-Sub-Type
Geophysical	A hazard originating from solid earth. This term is used interchangeably with the term geological hazard.	Earthquake	Ground shaking, tsunami	
		Mass Movement		
		Volcanic activity	Ash fall, lahar, pyroclastic flow, lawa flow	
Meteorological	A hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days.	Extreme Temperature	Cold wave, heat wave, severe conditions	Snow, ice, frost, freeze, hot days
		Fog	-	-
		Storm	Extra-tropical storm, tropical storm, convective storm	Tornado, rain, sand storm, hail, blizzard, lighting, thunderstorm wind…
Hydrological	A hazard caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater.	Flood	Coastal, riverine and flash flood	-
		Landslide	Avalanche, debris, mudflow, rockfall	-
		Wave action	Rogue wave, seiche	-
Climatological	A hazard caused by long-lived, meso- to macro-scale atmospheric processes ranging from intra-seasonal to multi-decadal climate variability.	Drought	-	
		Glacial lake outburst	-	-
		Wildfire	Forest fire, bush fire…	-
Biological	A hazard caused by the exposure to living organisms and their toxic substances (e.g. venom, mold) or vector-borne diseases that they may carry. Examples are venomous wildlife and insects, poisonous plants, and mosquitoes carrying disease-causing agents such as parasites, bacteria, or viruses (e.g. malaria).	Epidemic	Viral, bacterial, parasitic, fungal and prion disease	-
		Insect infestation	Grasshopper, locust	
		Animal accident	-	-
Extraterrestrial	A hazard caused by asteroids, meteoroids, and comets as they pass near-earth, enter the Earth's atmosphere, and/or strike the Earth, and by changes in interplanetary conditions that effect the Earth's magnetosphere, ionosphere, and thermosphere.	Impact	Airburst	-
		Space weather	Energetic particles, geomagnetic storm, shockwave	-

The concept of climate disaster risk includes three major components:

- Hazard, namely the extreme weather or climate event;
- Exposure, related with the presence of people, houses, economical activities, environmental resources in areas that can be affected by the weather or climate event;
- Vulnerability, related to the degree of preparation or the predisposition of a society to be adversely affected.

All these factors combined lead to non-controlled modifications in a society, frequently requiring emergency rescue or support to undertake recovery. Disaster risk increases if one or more components intensify, sometimes in a nonlinear way. That's why, as referred by the Intergovernmental Panel on Climate Change - IPCC (IPCC, 2012, p.33), "extreme weather and climate events will lead to disaster if communities are exposed to those events and exposure to potentially damaging extreme events is accompanied by a high level of vulnerability (a predisposition for loss and damage)".

It is important to mention that disasters can also be triggered by events that are not extreme in a statistical sense. Small-scale events or even non rare phenomena can turn into disasters for some communities presenting high exposure and vulnerability levels.

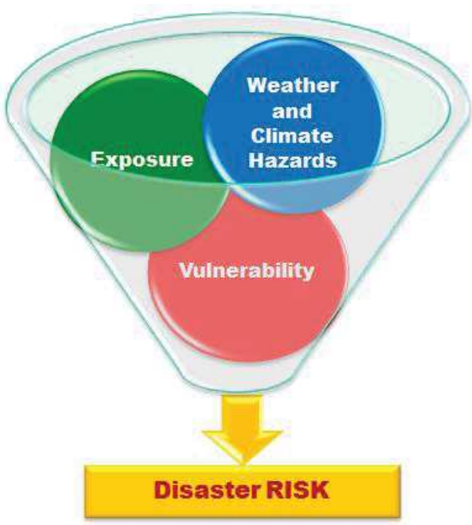

Figure 1 – Disaster risk main components (Adapted from IPCC, 2012)

"Over the past, increasing urban land take and urbanisation have in many places increased the vulnerability of European cities to different climate impacts like heat waves, flooding or water scarcity. (...) In the future, ongoing urban land take, growth and concentration of population in cities, and an ageing population contribute to further increasing the vulnerability of cities to climate change. It is, however, currently uncertain to which extent an intelligent urban design and urban management of individual cities can buffer these negative effects" (EEA, 2012b, p.222)

This idea reinforces the need that the three major components of risk should be inventoried, quantified and integrated in territorial management plans (Figure 2). Policy makers should have in mind that reducing risk cannot be achieved, without reducing vulnerability or exposure; this is true because, in general, the hazard component is increasing. "Observed changes in climate extremes reflect the influence of anthropogenic climate change in addition to natural climate variability, with changes in exposure and vulnerability influenced by both climatic and nonclimatic factors" (IPCC, 2012, p. 7).

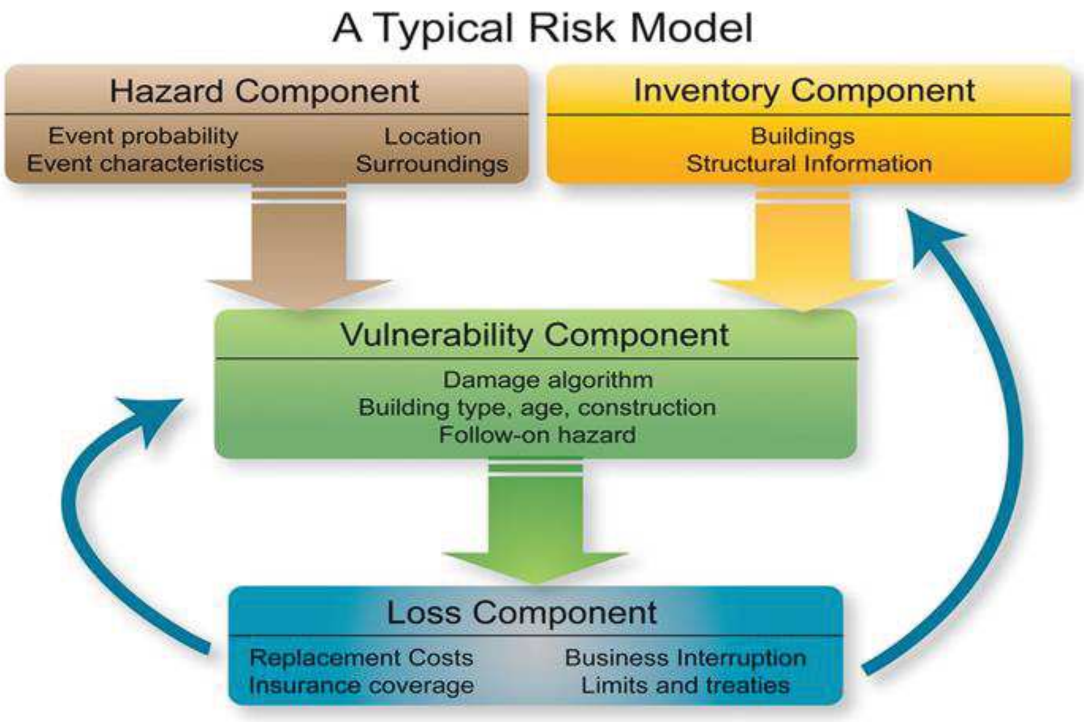

Figure 2 – Risk model (Easterling, 2009)

Vulnerability and exposure reduction can be achieved through development and planning. Some measures directly linked with management and planning are identified in the Fifth Assessment Report of IPCC (IPCC, 2014, p. 27):

- Disaster risk management.
  - Early warning systems;
  - Hazard and vulnerability mapping;
  - Diversifying water resources;
  - Improved drainage;
  - Flood and cyclone shelters;
  - Building codes and practices;
  - Storm and wastewater management;
  - Transport and road infrastructure improvements.
- Ecosystem management.
  - Maintaining wetlands and urban green spaces;
  - Coastal afforestation;
  - Watershed and reservoir management;
  - Reduction of other stressors on ecosystems and of habitat fragmentation;
  - Maintenance of genetic diversity;
  - Manipulation of disturbance regimes;
  - Community-based natural resource management.
- Spatial or land-use planning.
  - Provisioning of adequate housing, infrastructure and services;
  - Managing development in flood prone other high risk areas;
  - Urban planning and upgrading programs;
  - Land zoning laws;
  - Easements;
  - Protected areas.

Several of these measures can be implemented and improved in Portugal, towards the use of planning instruments. Furthermore, adaptation (social, structural, institutional) and scientific knowledge are factors that can contribute to strength disaster risk reduction. Scientists and technicians, public entities and private companies shall develop and make available all the decision support information, towards the improvement of the risk models, including hazard and vulnerability mapping.

3. Climate hazard mapping: examples for mainland Portugal

In risk modelling it is important to produce spatial hazard information according to the disaster types. The following examples show some climate hazards related to extreme temperatures. It is worth mentioning that the extreme temperatures events are the main cause of mortality due to climate disasters in Europe (WMO, 2014). In other parts of the world, storms or droughts are the main cause of fatalities, whilst the hydrological disasters, like flooding, are responsible for the major economic losses.

In mainland Portugal urban floods due to intense precipitation, wildfires driven by hot and dry summers, infrastructures damages caused by tornadoes or strong winds and crop or pastures losses are, in a recurrent way, responsible for a lot of damages. Nevertheless, the main causes of mortality and morbidity are related with extreme temperatures namely heat waves (Pereira *et al,* 2015; Tavares *et al*, 2011; Zêzere *et al*, 2014). In the 2003 summer heat wave, an excess of 1953 deaths were estimated due to the extreme heat (DGS and INSA, 2004).

3.1 Heat waves

The map shown in Figure 3 represents the total number of summer heat waves (number of occurrences), for the 1981-2010 period, following the definition, adopted by the World Meteorological Organization and the Intergovernmental Panel on Climate Change (e.g. Frich *et al*, 2002), and recently, in a completed review of research on indices by Zhang *et al*. (2011): period with at least five consecutive days where daily maximum temperature was greater than a fixed threshold of 5 °C above a 1961–1990 base period mean.

It was obtained for a national sectorial risk prevention and risk reduction plan - PSPRR (2014) by applying a non-linear multiregression model between the number of heat waves (calculated from 36 meteorological stations) and distance to coast, plus kriging the residuals. This output can be used in hazard mapping and adopted in regional planning, evidencing the heat wave prone regions. The risk model can be obtained by combining this heat wave hazard map with the inventory and the vulnerability components (theoretical schema in Figure 2).

3.2 – Snow

In Figure 4 it is shown the snow hazard map, also developed for the PSPRR plan (2014), and considering five levels (1-low to 5-high). This map was also obtained by applying a non-linear multiregression model between days with snow for 1961-1990 period (period with dense network of visual observations of snow), and the explanatory variables latitude, distance to coast and altitude, plus kriging the residuals.

The snow occurrence is highly related with altitude, but also latitude is an important factor because of the winter depressions trajectories that more frequently affect the northern regions. The historical impacts due to snow were also taken into account, namely the road interruptions and the affected areas.

It is important to note that snow is a rare event in some Portuguese regions; nevertheless the low hazard level in these areas (green level in map of Figure 4) doesn't mean zero risk. Thus, it is important to include all the historical information in the risk analysis.

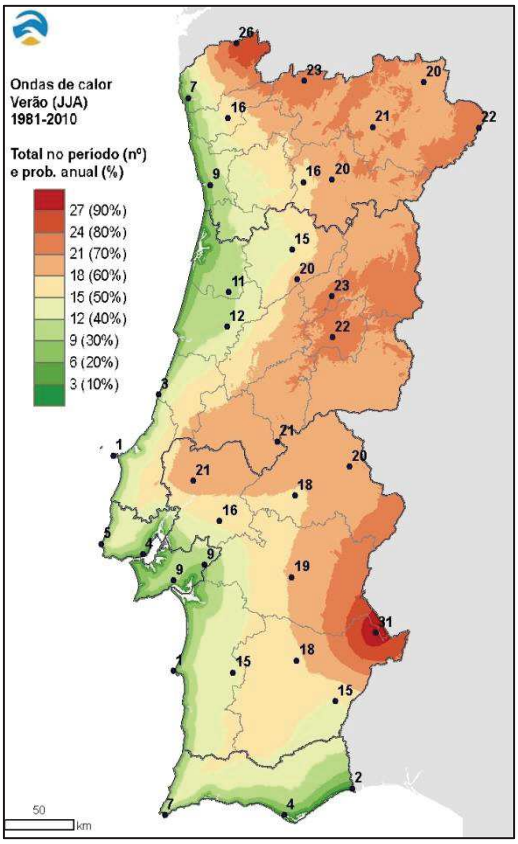

Figure 3 – Total number (nº) of Summer (June, July, August) heat waves and probability of occurrence (%), based on the 1981-2010 surface observations.

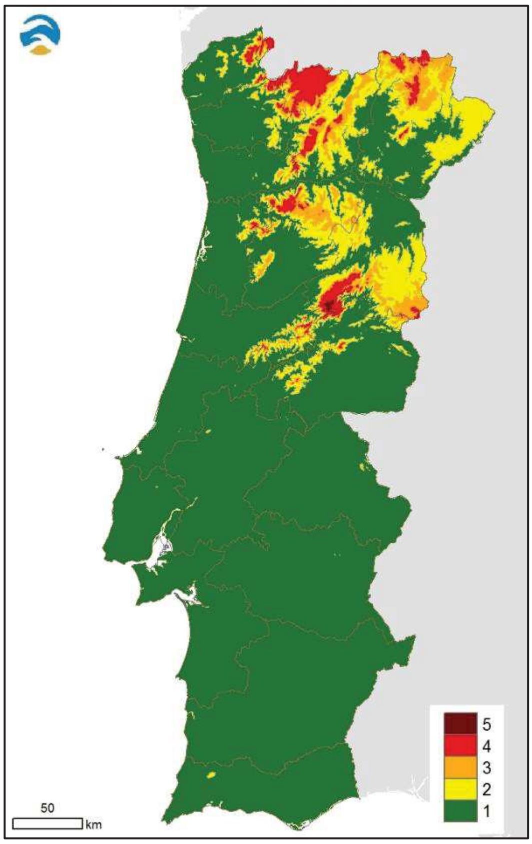

Figure 4 – Snow hazard considering 5 levels, 1-lowest to 5-highest, based on the 1961-1990 surface observations.

4. The role of adaptation and resilience on urban and regional planning

According to EEA "adaptation is a response to risks (and potential benefits) caused by climate variability and climate change in the context of continuing socio-economic development" (EEA, 2013, p. 7). In the context of adaptation policies the EEA mentions that "there is a wide range of measures that have been taken across Europe to adapt to climate change. The establishment of the European Climate Adaptation Platform (Climate-ADAPT) has begun to gather adaptation case studies of European relevance, providing an overview of this diversity of measures to all stakeholders with an interest in adaptation" (EEA, 2013, p. 23). In Portugal several Climate-ADAPT projects are on the way.

Adaptation comprises 3 groups of measures (EEA, 2013):

- Technological and infrastructural measures, like dyke building;
- "Green" interventions like the use of new crops, wetlands restoration...;
- Management, legal and policy approaches modifying human behaviour and styles of governance. Examples include early warning systems that can monitor threats from heat waves, floods and new disease types.

Frequently, the combination of these measures is an effective way to ensure and strengthen resilience. As described, the increase of weather and climate disaster risk in the context of climate change, but also as the result of more vulnerable and exposed societies requires better governance approaches at several scales of territory management. Sustainability, adaptation and resilience reinforce are major concepts to be addressed in future urban and regional plans. "Spatial or territorial planning provides an important tool for bridging existing governmental levels and sectoral agendas and provides a procedure for solving multiple problems simultaneously. The integration of climate change considerations into spatial plans at different levels can increase urban resilience in efficient and non-disruptive ways" (EEA, 2012a, p.115).

Resilience is however a complex and variable notion, related with societies economic, social and cultural development, as well with places uniqueness. The most developed communities are not always more resilient. Mulligan (2015, p.99), refers that a "self-reliance can be a significant factor in the development of individual or community resilience". Also people living in hostile sites and/or where risk management is mainly an individual feature are, in general, more resilient. Hazard exposure can capacitate people to undertake adaptation strategies. In contrast, more developed communities refuse to accept to inhabit with risks. In these societies risk prevention and management relies on planning and regulation instruments.

5. Conclusions

The use of climate information in urban and regional planning is now moving to a new paradigm. The climatological characterization is important but not enough. Zoning policies should include geographic information about hazards, keeping in mind that different phenomena require different analysis scales. This idea has to be developed in order to provide an integrated approach through the different level plans.

Examples of heat wave probability and snow hazard mapping are presented, for mainland Portugal. This spatial information can be included in planning and related with exposure and vulnerability of populations, to model extreme temperatures disaster risk.

Adaptation measures and resilience reinforcement are other key factors to be taken into account in urban and regional planning.

Acknowledgements

The authors would like to acknowledge the EEA Grants, APA and FPC for the financial support in the context of the Adapt AC:T Project (http://adapt-act.lnec.pt/).

References

DGS e INSA (2004). Onda *de calor de Agosto de 2003: os seus efeitos sobre a mortalidade da população portuguesa*, Relatório, Lisboa, Portugal.

Easterling, D. (2009). Weather and Climate Extremes: How Can We Improve Our Understanding? [Powerpoint slides], Scoping meeting for an IPCC special report on extreme events and disasters: managing the risks, 23-26 march 2009, Oslo, Norway, Retrieved online 21-02-2016: https://www.ipcc-wg2.gov/AR5-tools/extremes-sr/ScopingMeeting/PRESENTATIONS/Easterling_ppt_Mar23_09.ppt.

EEA (2012 a). Urban adaptation to climate change in Europe Challenges and opportunities for cities together with supportive national and European policies, EEA Report No 2/2012, Copenhagen, Denmark.

EEA (2012 b). Climate change, impacts and vulnerability in Europe 2012 An indicator-based report, EEA Report No 12/2012, Copenhagen, Denmark.

EEA (2013). Adaptation in Europe. Addressing risks and opportunities from climate change in the context of socio-economic developments, EEA Report No 3/2013, Copenhagen, Denmark.

EM-DAT the International Disaster Database, http://www.emdat.be/classification, accessed 21-02-2016.

Frich, P.; Alexander, L. V.; Della-Marta, P.; Gleason, B.; Haylock, M.; Klein Tank, A.; Peterson, T. (2002). Observed coherent changes in climatic extremes during the second half of the 20th century. Climate Research, 19, 193–212.

IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.). Cambridge University Press, Cambridge, UK, and New York, USA, 582 pp.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Moberg, F.; Galaz, V. (2005). Resilience: Going from Conventional to Adaptive Freshwater Management for Human and Ecosystem Compatibility. Swedish Water House Policy Brief Nr. 3. SIWI, Sweden.

Mulligan, M. (2015). An Introduction to Sustainability: Environmental, social and personal perspectives. Earthscan from Routledge, New York, USA.

Pereira, S., Zêzere, J. L., Quaresma, I., Santos, P. P. and Santos, M. (2015), Mortality Patterns of Hydro-Geomorphologic Disasters. Risk Analysis, 22.

PSPRR - Plano Setorial para a Prevenção e Redução de Riscos (2014). Fichas de Caraterização Nevões e Ondas de Calor, DGT-ANPC, Lisboa, Portugal (restricted)

Tavares, A.; Mendes, J.; Basto, E. (2011). Percepção dos riscos naturais e tecnológicos, confiança institucional e preparação para situações de emergência: O caso de Portugal continental, Revista Crítica de Ciências Sociais [Online], 93, http://rccs.revues.org/1380.

WMO (2014). Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2012), WMO-No. 1123, WMO publications, Geneva, Switzerland, 48 pp.

Zêzere, J.L.; Pereira, S.; Tavares, A.O.; Bateira, C.; Trigo, R.M.; Quaresma, I.; Santos, P.P.; Santos, M.; Verde, J. (2014) - DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal. Natural Hazards, 72, pp. 503-532.

Zhang, X.; Alexander, L.; Hegerl, G.C.; Jones, P.; Klein Tank, A.; Peterson, T.C.; Trewin, B.; Zwiers, F.W. (2011). Indices for monitoring changes in extremes based on daily temperature and precipitation data. WIREs Climate Change 2(6): 851–870, DOI: 10.1002/wcc.147.