Integration of Remote Sensing Data to Facilitate Multi-Hazards Risk Assessments in Coastal Regions

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1 RESEARCH PROBLEM

Risk management is amongst the priorities of Portugal's national strategic policies, including regional and national spatial planning programmes (PROT and PNPOT). According to Europe 2020 Strategy, there is a global need to strengthen economies towards climate risks, disaster prevention and response.

Following the EU Internal Security Strategy target of establish a risk management policy linking threat and risk assessments to decision making in each member state, the Sectorial Plan for Risk Prevention and Reduction has been developed to include risk assessment and cartography (ANPC, 2014). However, several difficulties have been recognized by the Portuguese Directorate-General for the Territory (DGT) and the National Civil Protection Authority (ANPC), regarding complexity and lack of consensus from multiple scientific domains (DGT, 2013).

Multi-Hazard Risk Assessments (MHRA) deal with the combination of multiple hazardous sources and multiple variable elements overlapping in time and space. Such approaches can go beyond the simple aggregation of single-hazard assessments, by considering several types of interactions, which may amplify their consequences (Delmonaco, Margottini and Spizzichino, 2007; Marzocchi *et al.*, 2012). MHRA are solutions capable of supporting spatial planning decisions and emergency strategies. One of the most important considerations concerns the availability of ready and reliable data, which if often expensive or unavailable to risk assessment experts. Earth Observation (EO) using satellite Remote Sensing (RS) have been widely used to provide data for single hazard risk assessments, as complement to ground-based data. However, the main research question arises: 'Can multi-hazard risk assessments be based on freely available RS data?'

2 OUTLINE OF OBJECTIVES

This thesis aims at providing practical methodologies and tools to improve and facilitate multi-hazard assessments in populated and natural territories. The main objective is to develop an innovative methodology for multi-hazard risk assessments, using satellite multi-spectral RS images and digital elevation data as the main data source. The methodology will be applied to the Aveiro region (in the Norwest of Central Portugal), using alternative data sources for validation purposes.
To achieve this objective, the following specific goals should be accomplished:
- to systematize detailed geospatial information about coastal and riverine floods, wave overtopping, wildfires and soil erosion hazards in the Aveiro region, based on the available literature and databases;
- to study the effects and interactions between land cover types, elevation, temperatures, humidity and water levels with hazard events;
- to develop a methodological approach for multi-harzard risk assessments, based on satellite RS data;
- to test, apply and validate the methodology in the Aveiro Region;
- to discuss the potential uses of this new methodology, including applications with different hazard types, semi-automatic routines for primary risk assessments, and application on large/remote areas.

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3 STATE OF THE ART

The coexistence of modern industrial societies together with fragile natural territories increases the vulnerabilities and exposure to both technological and natural risks, placing new challenges for risk-management at local and regional scales (de Souza Porto and de Freitas, 2003). The effects of global climate change are contributing to increase the frequency and intensity of weather related hazards (Adger *et al*, 2007; Deleu, Tambuyzer and Stephenne, 2011), requiring decision support information tools in order to establish effective disaster mitigation strategies (Grünthal *et al.*, 2006).

Traditional Single-Hazard Risk Assessment (SHRA) approaches include vulnerability and exposure analysis of the affected elements by one hazard (e.g. buildings, people, cars, land uses, infrastructures). Nonetheless, most natural and anthropogenic risks are likely to occur at one same location and, not rarely, at the same time (Carpignano *et al*, 2009). Experiences with decision makers show that a territorial perspective is desirable for spatial planning decisions and emergency strategies (Grünthal *et al.*, 2006), in a way that Multi-Hazard Risk Assessment (MHRA) combines multiple hazardous sources and multiple vulnerable elements overlapping in time and space, which may be as close as possible to the reality of spatial management for decision-makers (Carpignano *et al.*, 2009). Beyond the territorial perspective, MHRA can be element oriented, concentrating on the potential impacts from various events in the same element at risk (Delmonaco, Margottini and Spizzichino, 2007). Another highlighted aspect is the interaction among different risks (Marzocchi *et al.*, 2009; Selva, 2013), and the so-called "cascade effects", which are often neglected in SHRAs (Marzocchi *et al.*, 2012).

Mapping is usually amongst the first steps to take preventive measures, allowing decision makers to identify the spatial distribution of hazard intensities, exposed population and values, as well as expected losses. Complete MHRAs enable significance comparison of different hazard types, contributing to raise awareness and develop tailor-made mitigation strategies (Carpignano *et al.*, 2009; EC, 2010).

Spatial and statistical data have different relevancies for each hazard type. Nevertheless, data requirements for natural hazard assessments include land use, vegetation, slope, oceanographic and meteorological factors (Van Westen, 2013). Remote Sensing (RS) has provided a synoptic perspective for many of these measurements, for variable spatial scales and temporal resolutions, contributing for a wide range of disciplines (Tralli *et al.*, 2005). Satellite earth observations have been used in many SHRAs, enabling the possibility to reconstruct recent-history catastrophic events and providing data for prediction and mitigation planning actions (e.g., Lu *et al.*, 2004; Grünthal *et al.*, 2006; Chuvieco *et al.*, 2010; Leifer *et al.*, 2012).

4 METHODOLOGY

This thesis is being developed within a research group which as participated in several projects concerning the Aveiro region and its relation to hazards and global change scenarios (e.g. ADAPTARia (FCT), LAGOONS (FP7), SPRES (EU-INTERREG IV), ClimAdaPT.Local (MFEEE/EEA-Grants)). This experience is considered relevant to the thesis development, providing insights and relevant inputs from these projects databases.

Given the complex interactions between different hazard types and the innovative character of this study, the list of selected hazards was restricted to: floods (river and coastal), wildfires and soil erosion. Not only are they amongst the most significant and studied hazards affecting this study area, but they are also in terms of RS, directly related with two of the most studied and easily-identifiable land cover elements - water and vegetation.

To minimize the costs of this thesis (which will also affect its potential applications), the methodological development and application will be based on free available data and freeware/open-source software. In RS, this represents a significant constraint in terms of available resolutions – temporal, spectral, but mostly spatial. However, they should be suitable for regional assessments, allowing the compliance with national and European strategies.

This innovative methodology will provide solutions to reduce efforts, costs and time of traditional field monitoring and campaigns and surveys for MHRA. By delivering a simplified methodology based on freely available resources and easily accessible to risk managers and the public, socioeconomic benefits should be generated, promoting risk awareness and contributing for increasing the resilience of populations and ecosystems.

4.1 Literature Review

The initial steps of this PhD consist in the elaboration of an exhaustive literature review about the main topics relevant to this thesis. Several methods regarding single and multi-hazard risk assessments were classified in terms of the possibility of integration of RS methods and applicability to the study area. This work has been summarized and submitted as a review paper in a relevant peer-review scientific journal.

4.2 Single Hazard Risk Assessments

This sub-section includes the collection of hazard or risk assessment studies comprising the study area, as well as other literature with similar approaches to this working programme.
Relevant geospatial data regarding floods, wildfires and soil erosion, have been collected to support both single and multi-hazard risk assessments.
Historical hazard-related events occurring in the study area will be reconstructed and characterized, including present conditions and global change scenarios. The available databases of previous research projects are important information sources (e.g. geomorphologic variables; meteorological data; hazard occurrences, consequences and responses; socioeconomic variables), which can be complemented with press-archives and other studies.
The characterization will continue with data acquisition from satellite imagery databases, for those periods around hazard occurrences (prior, after and if possible during), to determine possible correlations RS data and the occurrence of hazard events, which will be crossed with
Land cover changes will be analysed using freely available RS multispectral images, from medium spatial resolution satellites (e.g. Landsat, Sentinel, ASTER). MODIS (TERRA and AQUA) will be used whenever higher temporal resolutions are required, providing information about temperatures, humidity and water levels.
SRTM, ASTER DEM and ALOS data will be used to obtain elevation data.
By the end of this step, single risk assessments will be established for each of the selected hazards, using either data-driven or physically based methods.

Each historical event occurring since the late seventies (which corresponds to the oldest records of Landsar series will be carefully analysed in order to identify usable satellite images. Potential interactions between multiple hazards will be analysed, focusing on simultaneous or cumulative occurrences. These results will be published in relevant peer-review scientific journals, together with further methodological developments.

4.3 Development of an Innovative Methodology for MHRA based on Satellite RS Data

The methodology to be developed in the context of this PhD is based on the co-relation of changes detected in previous hazard-related events, privileging RS data to provide fast and reliable risk assessment solutions.

4.3.1 Exposure Assessment

The first step will be dedicated to identify methods for determining levels of multi-hazard exposures. Each event will be analysed to identify predisposing conditions for single hazards' direct effects, and in terms of triggering effects which may generate secondary hazards (e.g. floods occurring in recently burned areas, or floods following wave overtopping events) (Van Westen, 2013).

4.3.2 Vulnerability Assessment

Subsequently, a global vulnerability index will be developed for covering individual aspects for each specific hazard, including expected effects on physical, biological and socioeconomic dimensions. Source data will be directly (or indirectly) obtained through RS methods (e.g. geomorpholical features, land covers, buildings).

4.3.3 Multi-Hazard Risk Assessment

By the end of this step, an innovative risk index will be proposed to relate multi-hazard exposures and vulnerabilities, using qualitative relations (matrixes) or algebraic operations between different indexes. Another scientific publication will resume these developments.

4.4 Methodological Application to the Case Study Area and Validation

The Aveiro region will be used to test and validate single and multi-hazard risk assessments. The application of RS based methods will be compared to others obtained from alternative data sources in order to validate results. These can be found in several projects related with risk assessments in the Aveiro

Region (e.g. ADAPTARia, Lagoons, MISRaR, Plano de Ordenamento da Orla Costeira de Ovar-Marinha-Grande, Secur-Ria, PESERA).

4.5 Exploring the Relationship between Semi-Automatic Remote Sensing Data and Multi-Risk Analysis

All results and conclusions obtained in the previous stages of the doctorate will be compiled in the dissertation and a final scientific publication. The real uses of the developed methodologies will be discussed, allowing the compliance with national and European sectorial plans and strategic goals.
The topics for discussion include the application in large or remote areas, accuracy levels, and incorporation of semi-automatic routines.

5 EXPECTED OUTCOME

The main deliverable of this thesis will be an innovative methodology for multi-hazard risk assessments based on RS methods, which remain underexploited. Its highest potential concerns regional scale applications, in line with the requirements of national and European strategies and sectorial plans for risk prevention and management. The outputs of this work will provide spatial managers and decision-makers with an integrated reliable and facilitative approach to support private and public sectors in increasing territorial resilience to risk, and to generate socioeconomic benefits from sustainable use of resources.

6 STAGE OF THE RESEARCH

At the time of this writing, the thesis is at is half-way point. A paper containing the literature review has already been submitted to a scientific journal.
The PhD candidate has collaborated in a publication about a RS based method for modelling shoreline evolution to support coastal risk management, including an application to the study area (Cenci *et al.*, 2015, 2017).
Another paper is being concluded, consisting in a RS method for river flood detection (again with application to the study area).
The following step should address the remaining single hazard assessments (wildfires and soil erosion) and the application of an overall vulnerability index.
The final task will consist in the definition and application of a multi-hazard risk assessment, which will consider all the previous steps of this thesis, including every single-hazard risk assessment. The validation of results is being made together with each individual hazard assessment.

REFERENCES

Adger, W. *et al.* (2007) 'Assessment of adaptation practices, options, constrains and capacity', in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernamental Panel on Climate Change*, pp. 717–743.

ANPC (2014) 'Avaliação nacional de risco', *Anpc*, p. 221.

Carpignano, A. *et al.* (2009) 'A methodological approach for the definition of multi□risk maps at regional level: first application', *Journal of Risk Research*, 12(3–4), pp. 513–534. doi: 10.1080/13669870903050269.

Cenci, L. *et al.* (2015) 'Remote sensing for coastal risk reduction purposes: Optical and microwave data fusion for shoreline evolution monitoring and modelling', *2015 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pp. 1417–1420. doi: 10.1109/IGARSS.2015.7326043.

Cenci, L. *et al.* (2017) 'Integrating remote sensing and GIS techniques for monitoring and modeling shoreline evolution to support coastal risk management', *GIScience & Remote Sensing*. Taylor & Francis, 0(0), pp. 1–21. doi: 10.1080/15481603.2017.1376370.

Chuvieco, E. *et al.* (2010) 'Development of a framework for fire risk assessment using remote sensing and geographic information system technologies', *Ecological Modelling*, 221(1), pp. 46–58. doi: 10.1016/j.ecolmodel.2008.11.017.

Deleu, J., Tambuyzer, H. and Stephenne, N. (2011) 'Multi Risk preparedness supported by Earth Observation', *Eurosense Gi4DM Conference, 3-8 May, Antalaya, Turkey*.

Delmonaco, G., Margottini, C. and Spizzichino, D. (2007) 'ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map', *ARMONIA PROJECT: Applied Multi-Risk Mapping of Natural Hazards for Impact assessment, Deliverable 3.1.1, Rome, Italy*.

DGT (2013) *Linha de Investigação em Riscos*. Available at: http://www.dgterritorio.pt/ordenamento_e_cidades/ordenamento_do_territorio/prevencao_e_reducao_de_riscos/linha_de_investigacao_em_riscos/ (Accessed: 11 January 2018).

EC (2010) 'Risk Assessment and Mapping Guidelines for Disaster Management', *European Comission staff working paper, 21 December, Brussels, Belgium*.

Grünthal, G. *et al.* (2006) 'Comparative Risk Assessments for the City of Cologne - Storms, Floods, Earthquakes', *Natural Hazards*, 38, pp. 21–44. doi: 10.1007/s11069-005-8598-0.

Leifer, I. *et al.* (2012) 'State of the art satellite and airborne marine oil spill remote sensing: Application to the BP Deepwater Horizon oil spill', *Remote Sensing of Environment*, 124, pp. 185–209. doi: 10.1016/j.rse.2012.03.024.

Lu, D. *et al.* (2004) 'Mapping soil erosion risk in Rondônia, Brazial Amazonia: Using RUSLE, Remote Sensing and GIS', 512, pp. 499–512.

Marzocchi, M. *et al.* (2009) 'Principles of multi-risk assessment - Interation amongst natual and man-induced risks', *Project Report, EUROPEAN COMMISSION, Directorate-General for Research, Directorate I — Environment, Unit I.5—Climate Change and Environmental Risks*, (Research*eu, Brussels, Belgium).

Marzocchi, W. *et al.* (2012) 'Basic principles of multi-risk assessment: a case study in Italy', *Natural Hazards*, 62(2), pp. 551–573. doi: 10.1007/s11069-012-0092-x.

Selva, J. (2013) 'Long-term multi-risk assessment: statistical treatment of interaction among risks', *Natural Hazards*, 67(2), pp. 701–722. doi: 10.1007/s11069-013-0599-9.

de Souza Porto, M. F. and de Freitas, C. M. (2003) 'Vulnerability and industrial hazards in industrializing countries: an integrative approach', *Futures*, 35(7), pp. 717–736. doi: 10.1016/s0016-3287(03)00024-7.

Tralli, D. M. *et al.* (2005) 'Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards', *ISPRS Journal of Photogrammetry and Remote Sensing*, 59(4), pp. 185–198. doi: 10.1016/j.isprsjprs.2005.02.002.

Van Westen, C. J. (2013) 'Remote Sensing and GIS for Natural Hazards Assessment and Disaster Risk Management', in Schroder, J. F. and Bishop, M. P. (eds) *Treatise on Geomorphology*. Academic P. San Diego, USA.: Elsevier Inc., pp. 259–298.