CLIMATE CHANGE REGIONAL VULNERABILITY ASSESSMENT TO SUPPORT INTEGRATED COASTAL RISK MANAGEMENT

S. Torresan [a], J. Rizzi [a,b] , E. Alberighi [b], A. Critto [a,b] and A. Marcomini [b],*

[a] Euro-Mediterranean Centre for Climate Change (CMCC), Division on Impacts on Soil and Coast c/o Consorzio Venezia Ricerche, Viale della Libertà 5-12, Marghera-Venice, Italy, Tel. +39-0415093184, torresan@unive.it, jonathan.rizzi@poste.it

[b] Department of Environmental Sciences, University Ca' Foscari of Venice, Calle Larga S. Marta 2137, I-30123 Venice, Italy, Tel. +39-0412348548, critto@unive.it, marcom@unive.it

KEY WORDS: GIS, Climate, Coast, Hazards, Impact Analysis, Decision Support

ABSTRACT:

Climate change impacts on coastal zones (e.g. increased erosion, inundation, storm surges and water quality variations) are expected to cause increasing risks to natural and human systems worldwide. Accordingly, it is necessary to develop innovative interdisciplinary approaches to effectively cope with climate related risks and support decision making processes. Climate change impacts affecting coastal communities and ecosystems are greatly influenced by regional geographical features, climate and socio-economic conditions. Impact studies should therefore be performed at the local/regional level, taking into account site-specific coastal vulnerability determined by environmental and socio-economic conditions (e.g. land use, geomorphology, vegetation cover, population density).

In order to provide site-specific information about coastal vulnerability to global climate change and assist coastal communities in the assessment of climate related risks and in the development of adaptation strategies, a GIS-based Regional Vulnerability Assessment (RVA) methodology was developed. The main aim of the RVA is to make a ranking of key vulnerable receptors in the considered region (e.g. beaches, wetlands, terrestrial or marine biodiversity) and to define homogeneous vulnerable areas that can be considered as homogeneous geographic sites for the definition of preventive adaptation strategies. The RVA methodology is based on multiple spatial vulnerability indicators that represent coastal sensitivity from a range of climate-related impacts (e.g. erosion, storm surges flooding, changes in water quality) and employ a system of numerical weights and scores that will led to a ranking of vulnerable receptors/areas in the examined coastal territory. By means of GIS tools, the RVA will produce multi-scale maps representing relative vulnerabilities in the considered region and supporting coastal adaptation to climate change and land use planning processes.

Within the Euro-Mediterranean Centre for Climate Change (CMCC, www.cmcc.it) the RVA methodology was applied to the coasts of the North Adriatic Sea in Italy. Based on the available dataset for the case study area, the application of the RVA included the analysis of different physical, ecological and socio-economic indicators (e.g. coastal topography, geomorphology, presence and distribution of vegetation cover, location of artificial protection) and of a subset of key vulnerable receptors (e.g. beaches and dunes, wetlands, estuaries and deltas). The main results and vulnerability maps obtained for the coastal zone of the North Adriatic Sea are here presented and discussed.

1. INTRODUCTION

Nowadays there is new and stronger evidence that global warming is likely to have profound impacts on coastal communities (IPCC, 2007 WGII). Accelerated sea level rise, increased storminess, changes in water quality and coastal erosion as a consequence of global warming, are projected to pose increasing threats to coastal population, infrastructure, beaches, wetlands, and ecosystems. Beyond this, coastal zones represent an irreplaceable and fragile ecological, economic and social resource. Being the result of a dynamic, unpredictable and interdependent set of subsystems, they are under increasing pressure leading to coastal resources depletion, conflicts between use, and natural ecosystems degradation (COM(2007) 308 final). Thus there is a growing claim of preservation, protection, planning and management of coastal zones that requires a specific integrated approach.

Traditionally much work has been done to understand the overall significance of climate change impacts on coastal systems at the global, continental and national scale, (Hoozemans et al. 1993; Baarse 1995; Nicholls and Mimura 1998; Nicholls 2002, Shuang-Ye et al., 2008 Williams et al., 2009). However, only sub-national/regional to local studies can offer detailed information on site-specific impacts and support policy makers in the design of appropriate adaptation strategies. Risk and vulnerability assessment should therefore be performed at the local or at most at the regional level.

A first pass assessment should involve the analysis of the exposure and sensitivity of a system to climate change (e.g., sea-level rise, erosion, etc.), a full vulnerability assessment should incorporate the analysis of adaptive capacity components (Voice et al. 2006). Moreover, vulnerability is a multi-dimensional concept encompassing a wide range of biogeophysical, socio-economic, institutional and cultural factors. Thus, vulnerability assessment requires a trans-disciplinary approach based on the identification of appropriate

* Corresponding author.

indicators representing different properties of the studied system (Fu¨ssel 2007). In relation to the conceptual framework adopted, vulnerability indicators could reflect the outcome of a defined climate hazard (e.g., monetary costs, human mortality, ecosystem damage, etc.) or the state of a system prior to the occurrence of the hazard event (e.g., geomorphological, biological and ecological features, population distribution, land use, economic condition, etc.) (Brooks 2003). As far as coastal systems are concerned, many important indicators were proposed by different authors to assess vulnerability related to climate change and sea-level rise. The report of the Agency for the Assessment of Impacts and Adaptations to Climate Change (AIACC, 2006) provides geophysical indicators considering geological characteristics of the coast (i.e. coastal height, rock typology, morphology and position of the shoreline) and climate driving forces such as sea level, tidal variation, height of wave. These indicators are used in order to orient scientific efforts toward effective management or policy decisions at the regional or national level. Within the category of vulnerability indicators, the U.S. Geological Survey (USGS, 2004) uses a Coastal Vulnerability Index (CVI) to map the relative vulnerability of the coast to future sea-level rise. Finally, Klein and Nicholls (1999) argue that vulnerability indicators should represent both bio-geophysical and economical, institutional and socio-cultural factors.

Climate change is a geographic problem consequently vulnerability indicators rely on GIS for data management and spatial visualization in order to improve the understanding of spatial and temporal distribution of climate change impacts and drive decision making processes.

With the main aim to prioritize potential impacts, targets and vulnerable areas to climate change at the regional scale, GIS-based vulnerability indicators were developed within the Euro-Mediterranean Centre for Climate Change (CMCC, www.cmcc.it) and applied to the coast of the North Adriatic Sea. Vulnerability indicators are part of a Regional Vulnerability Assessment (RVA) methodology that is included in a Decision Support System (DSS), aimed at support decision-makers in managing information on climate change hazard and vulnerability, assessing related impacts and risks, and design adaptation strategies at the regional scale.

After a brief description of the CMCC centre and of the case study area, in the following paragraphs, the main objectives and functionalities of the RVA methodology will be presented and discussed.

2. THE EURO-MEDITERRANEAN CENTRE FOR CLIMATE CHANGE

The Euro-Mediterranean Centre for Climate Change (CMCC) is a national (Italian) research centre devoted to the study of climate change and its impacts, focusing on the Mediterranean region. The Centre main headquarters are located in Lecce and six other satellite offices are distributed in the rest of Italy. The main partners of the Centre are: INGV (National Institute for Geophysics and Volcanology, project leader), CVR (Venice Research Consortium), FEEM (Enrico Mattei ENI Foundation), the Universities of Lecce and Sannio, and CIRA (Italian Centre for Space Research).

The CMCC make use of a new supercomputing centre that was inaugurated in January 2009. It is composed of two last-generation supercomputers that allow to run numerical models of different complexity and realism, in order to study the natural variability of the climate and the climatic changes, with a particular emphasis on the European and Mediterranean region.

With the help of the supercomputing centre, the CMCC run simulations with:

1. a global circulation model (0.5 x 0.5 degrees resolution) based on the coupling of the atmospheric ECHAM and oceanic OPA-ORCA models, to simulate future climate scenarios and study climate temporal variability. Sea ice, terrestrial and marine ecosystems are integrated in the model;
2. a high resolution model for the Mediterranean sea (1/16 degrees resolution);
3. models to simulate the environmental and socio-economic impacts of climate change.

The modelling outputs are then used to assess climate change impacts on the economy, agriculture, on the marine and terrestrial ecosystems, on coastal areas and on human health.

Within CMCC the development of a Decision Support System (DSS) for the integrated assessment of climate change impacts on coastal zones at the regional scale is being coordinated by CVR (Venice Research Consortium), whose partners for this project are the National Research Council (CNR), the Tidal Forecast and Information Centre of the Venice City Council and the Ca' Foscari University of Venice.

According to Torresan et al. (2007), the DSS is based on a framework that integrates tools and methodologies for the identification of potential climate change impacts and the assessment of bio-physical and socio-economic coastal vulnerability, in order to rank relative risks in the considered region. For this purpose, the framework structure is composed of 3 main phases: the *Scenarios Construction phase* which is aimed at the definition of future climate scenarios for the examined case study area at the regional scale, the *Integrated impact and risk assessment phase* which is aimed at the prioritization of impacts, targets and affected areas at the regional scale, and the *Risk and impact management phase* which is devoted to support adaptation strategies for the reduction of the risks and impacts in the coastal zone, according to ICZM principles. Within the aforementioned framework, the main output of the second phase is the development of GIS-based risk and vulnerability maps. Risk mapping is obtained through the integration of Hazard maps representing the exposure to climatic changes against which a system operates (e.g. inundation level); and Vulnerability maps representing the spatial distribution of environmental and socio-economic vulnerability factors.

The DSS include the analysis of coastal vulnerability to climate change at the regional scale and was applied to the case study region represented by the coastal area of the Northern Adriatic Sea (Figure 1). The approach used to characterize coastal vulnerability for the study area is presented and discussed in this paper.

3. CASE STUDY AREA

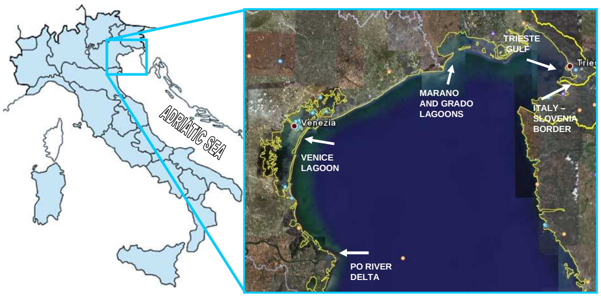

Figure 1:case study area.

The area considered in the Case study involves the coastal zone of Veneto and Friuli-Venezia Giulia regions, bordering the North Adriatic Sea with a overall length of about 286 km (Figure 1). The coast of the case study area runs along the Adriatic Sea from the national border between Italy and Slovenia to the mouth of the southern tributary of the Po Delta system (i.e. Po di Goro). From north-east to south-west, between the Slovenian border and the Timavo river mouth, the coast is high and rocky with few narrow beaches. In the rocky coast there can be found the gulf of Trieste and several bays (e.g. Sistiana bay). Moving southwards, from Monfalcone to the Po river delta the coast consists of low sedimentary shores. The overall continuity of the coast is interrupted by several river outlets (e.g. Tagliamento, Isonzo, Livenza, Piave, Brenta, Adige and Po) and lagoons (i.e. Marano, Grado and Venice lagoons and the lagoons of the Po river Delta). From a morphological point of view the sedimentary shores of the case study area include straight littoral coasts, lagoonal barrier islands, spits, river outlets and salt marshes.

Considering the administrative aspects, the case study area refers to the Friuli-Venezia Giulia Region, including 3 provinces and 8 coastal municipalities from the Slovenian border to Tagliamento river mouth; and to the Veneto Region, including 2 provinces and 10 municipalities from Tagliamento to Po river mouth.

The main coastal activities of the Case study area are petrochemical industry, tourism, fishing, seaport/ port activities and ship traffics.

On the whole, the Northern Adriatic Sea coast, comprises a very precarious coastal environment subject to continuous morphological changes that can be appreciable even over short geological time scales (Gambolati and Teatini, 2002). Moreover, erosion is still active in many areas both on the coastal sea floor and on the beach since the beginning of the 20th century and especially after 1960 (Bondesan et al., 1995). Many areas, particularly around the Po river Delta, are also located below the mean sea level and affected by natural or man-induced subsidence (Pirazzoli, 2005). Furthermore, the municipality of Venice has been experiencing an increase of high tide events with consequent flooding of the city (www.comune.venezia.it). Accordingly the assessment of climate change impacts and vulnerability on this area is an issue of increasing importance.

In the next paragraph the vulnerability assessment methodology adopted to study climate change impacts in the case study area will be described in more detail.

4. CLIMATE CHANGE REGIONAL VULNERABILITY ASSESSMENT TO SUPPORT INTEGRATED COASTAL MANAGEMENT

According to the framework proposed for the integrated assessment of climate change impacts on coastal zones at the regional scale (paragraph 2), the main aim of the RVA is to make a ranking of key vulnerable receptors in the considered region (e.g. beaches, wetlands, terrestrial or marine biodiversity) and to define homogeneous vulnerable areas that can be considered as homogeneous geographic sites for the definition of preventive adaptation strategies.

In order to investigate the potential impacts and risks posed by climate change on coastal zones, the RVA requires the characterization of the territorial vulnerability and involves the development and application of a range of vulnerability indicators and indexes, representing the sensitivity of the coastal communities, systems or assets to the damaging effects of climate change hazards (Torresan et al. 2008). Consequently, in order to identify site-specific targets and areas vulnerable to potential climate change impacts in the considered region, a subset of vulnerability indicators was defined and applied to the coasts of the North Adriatic Sea.

According to Voice et al. (2006) and the Australian society of Coastal Zone Management (www.ozcoasts.org.au), the subset of vulnerability indicators encompass a wide range of biogeophysical and socio-economic factors representing the coastal vulnerability to climate change at the regional scale, and was selected taking into account the availability of environmental and territorial data for the study area.

Available data were provided by various public institutions in graphic format or database, and include a 5 m Digital Elevation Model (DEM) supplied by Veneto Region and a 10 m DEM by Friuli Venezia Giulia Region, the digital Corine Land Cover (CLC2000) database (e.g. wetlands, vegetation cover, hydrological systems, dunes) (http://www.clc2000.sinanet.apat.it/cartanetclc2000/clc2000/prodotti.asp), a list of Natura 2000 sites (i.e. ZPS and SIC areas) supplied by regional authorities, coastal data included in the Geographic Coastal Information System (SIGC) (e.g. coastal morphology, sediment budget, artificial protections) implemented by the Italian Environmental Protection Agency (APAT, now called ISPRA) (http://www.mais.sinanet.apat.it), technical regional maps supplied by the Veneto and Friuli Regions (www.regione.veneto.it /Ambiente+e+Territorio/; www.regione.fvg.it/rafvg/territorioambiente), and administrative boundaries of coastal municipalities and provinces furnished by regional authorities.

Consequently, the proposed set of vulnerability indicators includes various geophysical factors (e.g. geomorphology, elevation), bioecological factors (e.g. vegetation cover, wetlands distribution) and socio-economic factors (e.g. presence of fish-farms, protected areas). Each indicator was divided into vulnerability classes with different scores and was used to construct vulnerability maps, representing the vulnerability of the coastal region to the investigated impacts. These maps allow the visualization and prioritization of vulnerable coastal receptors; the identification of more sensitive areas in the coastal territory and the location of more suitable areas for human settlements, infrastructures and economic activities. Moreover they allow an easy and flexible visualization of vulnerabilities for stakeholders and decision makers.

5. CONCLUSIONS

The proposed RVA approach is an innovative way to study the sensitivity of coastal zones to climate change impacts at the regional scale and support the development of effective ICZM taking into account the increasing issues related to climate change.

In particular the application of the Regional Vulnerability Assessment methodology will led to a ranking of relative vulnerabilities in the examined coastal territory and will allow the identification of the potential for harm from a range of climate-related impacts (e.g. inundation and coastal erosion).

The main issues related to the application of indicators and the construction of maps are the diversity of data sources, formats, and spatial scales that introduced geographical errors in the assessment of vulnerability. Moreover, to deal with numerous and heterogeneous data is often time-consuming and computing demanding. Finally, at the regional/local scale, the geometrical complexity of vulnerability mapping is amplified.

References from Journals:

Bondesan, A., Castiglioni, G.B., Elmi, C., Gabbianelli, G., Marocco, R., Pirazzoli, P.A. e Tomasin, A., (1995). Coastal areas at risk from storm surges and sea-level rise in northeastern Italy. Journal of Coastal Research: 11(4): 1354-1379.

Brooks N (2003) Vulnerability, risk and adaptation: a conceptual framework. Working paper 38, Tyndall Centre for Climate Change Research, Norwich, UK, pp 20

Fu¨ssel HM (2007) Vulnerability: a generally applicable conceptual framework for climate change research. Glob Environ Change 17:155–167

IPCC (2007), “Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for Policymakers”, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Geneva.

Gambolati G. and P. Teatini, (2002). GIS Simulations of the Inundation Risk in the Coastal Lowlands of the Northern Adriatic Sea. Mathematical and Computer Modelling: 35, 963-972.

Klein R.J.T. and Nicholls R.J., 1999. Assessment of Coastal Vulnerability to Climate Change. Ambio, 28, n. 2. Pp 183-187.

Nicholls R.J. and Mimura N., (1998). Regional issues raised by sea level rise and their policy implications. Climate Research, 11: 5-18.

Nicholls R.J., (2002). Analysis of global impacts of sea level rise: a case study of flooding. Phys Chemis Earth. Parts A/B/C 27(32–34):1455–1466

Pirazzoli P. A., (2005). A review of possible eustatic, isostatic and tectonic contributions in eight late-Holocene relative sea-level histories from the Mediterranean area. Quaternary Science Reviews 24 (2005) 1989–2001.

Shuang-YeWu, Raymond Najjar, John Siewert. (2009). Potential impacts of sea level rise on the Mid and Upper-Atlantic Region of the United States. Climatic Change 95. Pp 121–138.

Torresan S., Critto A., Dalla Valle M., Harvey N. e Marcomini A., 2008. Assessing coastal vulnerability to climate change: comparing segmentation at global and regional scales. Sustainability Science, Springer. 3: 45-65.

References from Books:

Baarse G., (1995). Development of an Operational Tool for Global Vulnerability Assessment (GVA)-Update of the Number of People at Risk Due to Sea Level Rise and Increased Flooding Probability. CZM Centre Publication No. 3, Ministry of Transport, Public Works and Water Management, The Hague, The Netherlands.

Hoozemans F.M.J., Marchand M. e Pennekamp H.A., (1993). Sea Level Rise: A Global Vulnerability Assessment for Population, Coastal Wetlands and Rice Production on a Global Scale. Second revised edition, Delft Hydraulics and Rijkswaterstaat, Delft and The Hague, The Netherlands,

USGS, 2004. Coastal Vulnerability Assessment of Olympic National Park to Sea-Level Rise, Open File Report 04-1021, Electronic Book.

Voice M., Harvey N. e Walsh K. (2006). Vulnerability to Climate Change of Australia’s Coastal Zone: Analysis of gaps in methods, data and system thresholds. Australian Greenhouse Office, Department of the Environment and Heritage.

Williams, S.J., B.T. Gutierrez, J.G. Titus, S.K. Gill, D.R. Cahoon, E.R. Thieler, K.E. Anderson, D. FitzGerald, V. Burkett, and J. Samenow. (2009). Sea-level rise and its effects on the coast. In: Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [J.G. Titus (coordinating lead author), K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors)]. U.S. Environmental Protection Agency, Washington DC, pp. 11-24.

References from Other Literature:

AIACC, 2006. Vulnerability and Adaptation of Estuarine Systems of the Río de la Plata. The international START Secretariat 2000 Florida Avenue, NW Washington DC, USA.

COM(2007) 308 Brussels, 7.6.2007. Report to the European Parliament and the Council: An evaluation of Integrated Coastal Zone Management (ICZM) in Europe

Torresan S., Critto A., Dalla Valle M., Harvey N. and Marcomini A., (2007). A regional risk assessment framework for climate change impacts evaluation in a coastal zone management perspective. In Özhan, E. (Editor), Proceedings of the Eighth International Conference on the Mediterranean Coastal Environment, 13-17 November 2007, Alexandria, Egypt, MEDCOAST, Middle East Technical University, Ankara, Turkey, vol 2, pp.741-752

References from websites:

www.ozcoasts.org.au/glossary/def_i-l.jsp (accessed December 2009)

www.comune.venezia.it (accessed November 2009)