Università
Ca'Foscari
Venezia

Corso di Laurea magistrale (*ordinamento ex D.M. 270/2004*) in Scienze Ambientali

Tesi di Laurea

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Development of climate services related to pluvial flood impacts under climate change scenarios in the North Adriatic coast.

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2012 / 2013

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Summary

Climate change has became one of the most important environmental issue both for the scientific community, producing a huge amount of studies, data and projections about future climate scenarios, and for the whole society, showing increasing concern about the potential consequences of climate change on natural ecosystems and human activities. In fact, climate variability and climate change can lead to a variety of impacts on society and the environment (e.g. sea level rise inundation, change in water quality and availability, drought, loss of biodiversity change, increase in vector borne diseases). Particularly, the increase in extreme weather events (i.e. heavy precipitations, storms), together with increasing and changing exposure and vulnerability patterns, is expected to cause an increase in disastrous events such as storms, pluvial floods and coastal flooding. In this context, the development of climate impact and adaptation services transferring knowledge about climate related risks to stakeholders and decision makers is very important to foster the development of national, regional and local adaptation strategies.

For this purpose, the main objective of the thesis is to develop a Regional Risk Assessment (RRA) methodology for the evaluation of pluvial risk in urban areas under future climate change scenarios, and its application to the territory of the municipality of Venice (North Adriatic coast, Italy) in order to produce climate risk services for local stakeholders. Through the analysis of hazard, exposure, vulnerability and risk, the RRA methodology allows to identify and prioritize targets (i.e. residential, commercial-industrial areas and infrastructures) and sub-areas that are more likely to be affected by flood risk due to heavy precipitation events in the future scenario (2041-2050). Moreover, from the early stages of its development and application, the RRA followed a bottom-up approach taking into account the needs, knowledge and perspectives of local stakeholders dealing with Integrated Coastal Zone Management (ICZM) by means of interactive workshops and questionnaires.

The main outputs of the risk assessment methodology are hazard, exposure, vulnerability and risk maps and statistics elaborated trough GIS tools and representing useful climate risk services for the implementation of sustainable planning and management processes aimed at minimizing pluvial flood risks in urban areas.

The hazard map obtained for the pluvial floods impact in the 2041-2050 period allowed to identify that the areas of the municipality of Venice more interested by pluvial flood events are located in

the south-east littoral zone (e.g. Pellestrina and Lido). The hazard scenario of pluvial flood depicts that the major number of potential emergencies (i.e. from 26 to 70 potential emergencies) will take place in the autumn season (i.e. September, October, November). Vulnerability maps highlighted that areas more vulnerable to pluvial floods are characterized by low permeability and slope and by the presence of recently flooded areas and show a percentage of surface interested by very high and high vulnerability classes, ranging from 65% in the residential to 68% in commercial and industrial areas.

Finally, risk maps showed that, for all the receptors, most of the case study area is associated with lower (i.e. low and very low) and medium risk classes with percentage ranging from 90% for residential areas to 65% for commercial and industrial areas; while the receptors surface in the high risk class ranged from 0.25 km^2 for residential areas to 1.19 km^2 for infrastructures which correspond, for all the analyzed receptors, to a percentage of surface less than 1.5%. Specifically, districts with the higher percentage of receptors' surface in the higher risk classes (i.e. very high, high and medium) are Lido-Pellestrina and Marghera with a percentage ranging from 88% for the infrastructures to 66% for residential areas.

Objectives and motivations

Climate variability and change are posing significant challenges to societies worldwide (WMO, 2011). According to IPCC (2007) climate change effects on individual regions will vary over time and with the capacity of different societal and environmental systems to adapt to changes. Coastal zones are considered key climate change hotspots worldwide and according to IPPC (2012) coastal systems are projected to be increasingly at risk over future decades. The major expected climate change impacts will include sea-level rise, coastal erosion, alteration in water quality and increase of flooding due to the increase of extreme events (e.g. heavy precipitations, storms) (Torresan et al., 2012). Subsequently a strong effort is on-going for the identification of risks and impacts related to climate change in coastal zones. Moreover, as result, a very high amount of scientific information is produced in order to minimize and prevent the negative effect of climate change in coastal zones. However, it is necessary to efficiently communicate the appropriate climate information produced by climate experts to stakeholders in order to support decision making and to develop suitable adaptation policy. In this context climate services, defined as "the timely production and delivery of useful climate data, information and knowledge to decision makers" (NRC, 2009), are aimed at bridging the gap between climate forecasters and users (WMO, 2013). Moreover, climate services enable a better management of vulnerabilities and risks related to climate change through the incorporation of science-based climate information and prediction into land planning, policy and practice on the global, regional and local scale (http://www.gfcs-climate.org/). Climate services include a wide variety of different resources (e.g. data, indicators, decision support systems) that can concern different information ranging from basic climate parameters (e.g. precipitation, winds, extreme event frequency and intensity), to derived parameters (e.g. climate change impact and risk assessment on natural and human systems) (Giannini et al., 2011). In particular, climate risk services allow to provide information on climate change-related risks affecting a system considering two main components: climate change hazard (i.e. an event or phenomenon with the potential to cause harm such as loss of life, social and economic damage or environmental degradation (Torresan et al., 2012)) and the vulnerability of the system (i.e. the characteristics of a system that increase its susceptibility to the impact of climate-induced hazards, (Torresan et al., 2012)). Moreover, climate change impacts are very dependent on regional geographical features and environmental and socio-economic conditions, therefore climate risk services should be developed at the local or at most at the regional level.

In addition, the development of climate services should be based on public participation and involvement. Climate services, in fact, should be user-centric and should engage a diversity of user in meaningful ways to ensure their need being met (Jacobs, 2011). A relevant challenge is therefore to develop suitable climate services for climate change risks at the local scale able to respond to the stakeholders request and to be incorporated in policy and decision making.

For this reason the main aim of the thesis is to develop climate impact and adaptation services responding the stakeholders needs in the coastal areas of the North Adriatic sea. In particular, in order to accomplish this general objective the thesis pursues the following specific objectives:

- A description of the state art in the field of climate services focusing on the main indicators and indices used at the international level for the assessment of climate change impacts and vulnerability;
- The analysis of the climate information needs for local stakeholders of the North Adriatic coast by means of workshops and questionnaires;
- The development of a Regional Risk Assessment (RRA) methodology for the assessment of pluvial flood events in urban areas, selected as one of the main concern by local stakeholders;
- The application of the methodology to the selected case study of the municipality of Venice;
- The production of climate risk services (e.g. vulnerability and risk maps, statistics) to communicate the results of the application to the involved stakeholders.

The methodology was developed within the CLIM-RUN Project (Climate Local Information in the Mediterranean region Responding to User Needs) funded by the Seventh Framework Programme of the European Union. The application and the main results of the analysis are presented and discussed in this thesis. The structure of the thesis is outlined in the next paragraph.

Thesis Structure

The thesis is structured in five chapters. Chapter 1 is composed by three main paragraphs which investigate the most commonly used definitions of climate services (Paragraph 1.1); give an overview of the main providers of climate services (Paragraph 1.2); review the state of the art concerning indicators and indexes used for the assessment of climate change impacts and for the development of climate services in different sectors of society (Paragraphs 1.3).

Chapter 2 is structured in three paragraphs introducing the overall research project and the Regional Risk Assessment (RRA) approach on which the thesis is based. Paragraph 2.1 describes the CLIM-RUN Project its objectives and approach. Paragraph 2.2 presents the general concepts of RRA applied for the development of climate impacts and adaptation services. Paragraph 2.3 defines the participatory process applied in the CLIM-RUN project with the public authorities of the North Adriatic coast and used for the development of the bottom-up risk assessment methodology presented in the thesis.

Chapter 3 presents the case study area selected for testing the RRA methodology. Specifically, Paragraph 3.1 gives a geographical description of the case study area highlighting the relevance of the pluvial flood issues. Paragraph 3.2 describes the data used for the application of the methodology including both meteo-climatic and site-specific physical-environmental information.

Chapter 4 is aimed at the presentation of the main steps of the application of the RRA methodology (i.e. hazard, exposure, vulnerability and risk assessment) for the assessment of pluvial flood impacts in the municipality of Venice. Chapter 5 describes the main outputs and results of the application of the RRA methodology which allows to identify and prioritize areas at risk from pluvial floods in the municipality of Venice. Finally, in the conclusions, a discussion of the main strengths and weakness of the proposed methodological approach and application, and possible further investigations and recommendations are presented.

Introduction

The Fifth IPCC Assessment Report (AR5) has recently confirmed that changing in the climate system is unequivocal and that some of the observed climatic changes have established records globally and in Europe in recent years (IPCC, 2013). Moreover, in the last years scientists have increased their understanding of the climate system being able to state with increasing certainty that the Earth's climate has changed beyond historic variability (http://www.eea.europa.eu/themes/climate/intro). Climate change is affecting all regions in Europe, causing a wide range of impacts on society and the environment ranging from sea-level rise, increase in temperature, heat waves, change in ocean circulation, ice melt and increase of extreme weather events (e.g. heavy precipitation, storms, droughts) (IPCC, 2013).

The changes in extreme weather events have been observed since about 1950 (IPCC, 2013). Particularly, the IPCC (2013) sets that there are several land regions where the number of heavy precipitation events has increased (e.g. North America and Europe). Moreover, it is widely being assumed that the increase in heavy precipitation will increase the incidence and severity of pluvial floods (NERC, 2010).

Pluvial floods are rain-related floods which occur when intense rainfall cannot be drained away quickly enough through sewage or rivers. They are usually associated with high intensity pluvial events (typically >30mm/h) but can also occur with lower intensity rainfall where ground is saturated, developed or has low permeability (NERC, 2009; Falconer et al., 2008). In this case drainage systems and surface watercourses may be completely overwhelmed leading to overland flows and pooling, causing damage to buildings, infrastructure and inconvenience to people (Spekkers, 2011). In urban areas the probability of pluvial flood events is particularly high and damages are significant both in economic and social terms due to the presence of many residential and productive activities in those areas (Houston et al., 2011).

The two main aspects that should be considered in the assessment of pluvial flood risk are climate change and the change in land use. Specifically, climate change will lead in an increase of heavy precipitation events (e.g. above 95^{th} percentile) (IPCC 2007, 2012) resulting in an increased risk of localized pluvial floods (Kundzewicz et al.; 2007; Bates et al.; 2008). However, also socio economic factors should be considered. In fact, changes in land use (i.e. transformations from green areas to urbanized ones) result in an increase of urban floods frequency due to poor infiltration and reduction of flow resistance. Moreover, urbanization also leads to changes in the local hydro meteorological regime which facilitates the establishment of micro-climates impacting the extreme rainfall rate (Shepherd et al., 2002; Mote et al., 2007, WMO, 2008).

Numerous pluvial flood events have occurred in the last years around Europe (e.g. United Kingdom, Ireland, Italy, France, Germany) causing infrastructure and building flooding, traffic line interruption and, in some cases, damage to people. Despite in recent years pluvial floods is moving up the policy agenda of local authorities and stakeholders through adaptation measures (e.g. pluvial floods early warning systems, construction of water storage areas, green roofs), knowledge on impacts that climate are likely to have on the extent and pattern of floods and on the associated risks for human activities is still poor.

In order to fill this gap, this thesis is aimed at the development of climate risk services related to pluvial flood impacts under climate change scenarios in urban areas. Specifically, the thesis is aimed at developing a Regional Risk Assessment methodology for the prioritization of pluvial flood risks in urban areas, considering future climate change scenarios and land use patterns as basic input data. The methodology was developed following a bottom up approach involving stakeholders in each step of the process in order to collect their needs with the aim to produce suitable climate risk services for the management of pluvial floods impacts. The main outputs of the methodology are GIS-based maps and statistics which represent useful climate risk products to transfer information about pluvial flood impacts to stakeholders and decision makers, allowing the classification and prioritization of areas that are likely to be affected by pluvial flood risk more severely than others in the same region and the identification of areas more vulnerable to pluvial flood in relation with specific physical and environmental characteristics of the territory supporting land planning and decision making. The produced climate risk services can be used by stakeholders and decision makers for the implementation of adaptation strategies (e.g. improvement of drainage and storage water system, creation of green areas with higher permeability) aimed at increasing the resilience of the urban areas to pluvial floods events and to identify suitable areas for infrastructure, economic activities and human settlements toward the development of regional adaptation plans.

Chapter 1 Indicators and indices of vulnerability, risk and impacts relevant for different systems and sectors of the society

Climate change is one of the most challenging topics that humanity is facing globally during recent years. The temperature and sea level rise, drought and extreme events are only some of the main examples of the important challenges that societies are facing on a global scale and subsequently a strong effort is on-going for the identification of risks and impacts related with climate change. The research around the causes, and potential consequences, of climate change in the weather and the climate of the earth is constantly increasing. As a result there is a very high production of scientific information that can be useful for all kinds of users and stakeholder. A vital question is how this information can be used by different sectors of society to minimize the climate change effect and, specifically, how this information can effectively answer to the stakeholders data needs. The aim of this Chapter is to answer to these questions exploring the range of climate services provided for the study of climate change impact and vulnerability for different sectors of the society. The Chapter is based on the following structure: Paragraph 1.1 presents a thorough and comprehensive, presentation and analysis of the main definitions of climate services that can be found in the literature. Main attributes, principles and guidelines of climate services are presented and shortly described. Paragraph 1.2 presents the main providers of climate services, including the main organizations that are involved in the coordination, creation and dissemination of services and related activities. Paragraph 1.3, after to have identified the main sectors of society affected by climate change and for which climate services are provided, presents a review of indices and indicators for the assessment of climate change impacts for each sectors. Results of the review will be taken into account in Chapter 3 for the development of climate services responding to users needs in the North Adriatic area.

1.1 Climate services definitions and main attributes

In recent times, due to the increase of interest for what concern climate change, a multitude of climate related information has been produced. The need was to organize this information under a globally accepted term of “climate services”. Since that time elaborations of the definitions has been performed by scientists and users from different sectors. In order to define what the term indicate and includes. In the following paragraph a condensed and comprehensive presentation of the main definitions of climate services is provided.

The research on the available literature has shown that the term climate services is generally ambiguous and is used in different contexts and from different organizations. Specifically during the years two main notions have been identified as the most common and have been alternated referring to climate services. A climate service can be described as:

- An organisation/entity;
- An activity/action.

Specifically in the previous decade, there has been a strong connection between the term 'climate service' and the bodies which are held responsible for providing climate data and information, as part of their national weather prediction duties. An example can be found in a definition of the World Bank (2008) referring strongly to climate services as "the National Meteorological Services (NMSs) and the National Hydrometeorological Services (NMHSs)". Therefore, extensive research has been done for assessing the state of the art of 'climate services' as entities which are run on national level, for analysing the possibilities for further improvement of their efficiency and design, and for identifying strategies for creating the right environment for the proper connection with decision makers.

During the last couple of years various other definitions of 'climate services' have been produced and the interest has been significantly switched from the notion of an '*entity*' to the notion of an '*activity*'. Furthermore, it is interesting to notice the evolution of the definition inside a single specific organisation. The National Research Council (NRC, 2001) defines climate services as "*the timely production and delivery of useful climate data, information, and knowledge to decision makers*"and few years later (NRC, 2009) as "*A mechanism to identify, produce, and deliver authoritative and timely information about climate variations and trends and their impacts on built, social-human, and natural systems on regional, national, and global scales to support decision making.*"

The first attempt tried to introduce an inclusive definition after a review of the breadth of useful climate information, from historical analyses to century-scale predictions, whereas the second attempt provides a more detailed idea regarding climate services.

During the same period, the World Meteorological Organisation (WMO, 2009) defines climate services as "*the dissemination of climate information to the public or a specific user. They involve strong partnerships among providers, such as NMHSs, and stakeholders, including government* *agencies, private interests, and academia, for the purpose of interpreting and applying climate information for decision making, sustainable development, and improving climate information products, predictions, and outlooks*".

Adding to these, Bessembinder (2011) define climate services as "*an activity delivering data and information on the past-future climate to a broad range of users/stakeholders standard and tailored information and guidance in the use of climate data/information*".

It can be clearly seen that the latest trends define climate services as one of the 'means' to connect various stakeholders, foster their cooperation and allow a more efficient communication between different users as claim in the International Conference on Climate Services (2011) "Climate services will ensure that the best available climate science is effectively communicated with agriculture, water, health and other sectors, to develop and evaluate mitigation and adaptation strategies".

At the same time, there is an incentive on providing short and simple definitions which are though at the same time very specific, well expressed and easy to understand. An example it is provided by WMO (2011) in the report on the global framework where climate services are simply defined as "*Climate information prepared and delivered to meet a user's needs*". This definition is way shorter than the definitions provided before, though it is very comprehensive and detailed at the same time.

From the large number of definition provided is easy to deduce that there is not a universally accepted one and that each sector use the definition which best fit with its needs and aims however attributes that a climate services should have are clean and well define. According to Jacob (2011) a Climate Service should:

- Provide balanced, credible, cutting edge scientific and technical information;
- Engage a diversity of users in meaningful ways to ensure their needs are being met;
- Provide and contribute to science-based products and services to minimize climate-related risks;
- Strengthen observations, standards, and data stewardship;
- Improve regional and local projections of climate change;
- Identify, quantify and price the direct and indirect risks associated with climate changes. Inform policy options.

In addition, the Board on Atmospheric Sciences and Climate (BASC) of the National Research Council (NRC) assessed the climate service activities in the United States in 2001, compared the state of climate services with the development of weather services and identified the following five guiding principles for climate services:

- The activities and elements of a climate service should be user-centric;
- If a climate service function is to improve and succeed, it should be supported by active research;
- Advanced information (including predictions) on a variety of space and time scales, in the context of historical experience, is required to serve national needs;
- The climate services knowledge base requires active stewardship;
- Climate services require active and well-defined participation by government, business, and academia.

Climate services aims to provide a wide variety of resources (e.g. data, products, decision support) directly used by stakeholders playing the role of an interface between the needs (sphere of stakeholders) and resources (sphere of research). Furthermore, various services can be identified in the literature as they differ not only based on their input data but on their expected outputs as well. A first and useful classification, based on the expected provided outcomes of services is provided by Giannini et al (2011), in the frame of the CLIM-RUN project, who identify services that can provide:

- Basic climate parameters (e.g. precipitations, winds, extreme event frequency and intensity) through the use of climate observations and scenarios and implementation by climate experts;
- Derived parameters (e.g. climate change impacts and risks assessment on natural and human systems) supplied by environmental risk experts.

A graphical representation is provided in Figure 1.1:

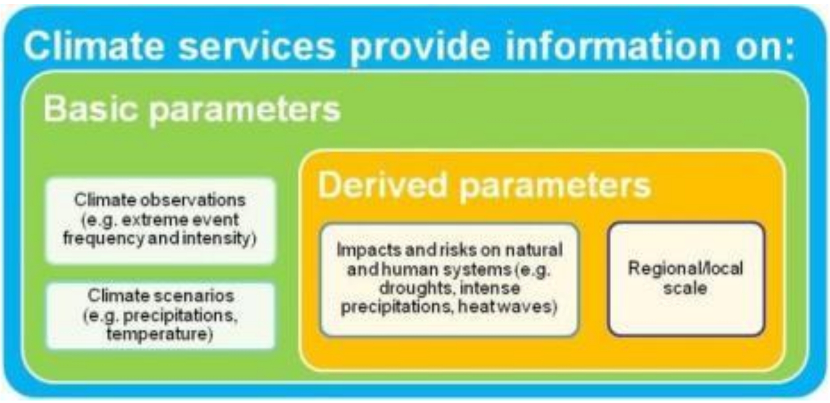

Figure 1.1 Classification of parameters provided by climate services (Giannini et al. 2011)

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1.2 Climate services provides

There is an abundance of entities and organizations, of many different types, that are involved in the production and development of climate services. It can be easily understood that due to the global dimension of the topic, there are numerous organizations which are conducting activities related with weather and climate, and subsequently there are numerous ways these organizations could be classified and clustered. In order to give an overview of the vast range of providers and different kind of activities and information available, a review of the most important climate services provider has been performed. The results are summarized in Table 1.1 which classified providers considering:

- name and the acronym;
- website;
- the scale at which they operate (global, regional, local);
- main activities which they perform;
- sectors in which their activities and data can be used.

It is important to clarify that would be impossible, to identify all the climate related entities existing around the world therefore the content of this review is limited to the most important and influential climate service providers . The first classification which can be performed identify that climate services providers belong to the 4 main categories:

- National Meteorological and Hydrological Services (NMSs and NMHSs);
- Academic and research institutions;
- Governmental institutions;
- Consortia and joint organisations.

For that which concern the scale all providers operate at global scale especially in the case of those organizations whose main activities is connected with the production of climate data and forecasts. Almost all organizations are composed by several units divided according to geographic regions (Europe, Asia, Africa) and therefore are able to provide services also at the regional level. This happens especially for those organizations that lead activities related with impacts and management of climate change for which a regional scale is preferable. There are also a large number of NMSs and NMHSs which mainly operate at local and national scale such as the UK Met Office and the UKCIP.

Looking at the main activities it emerges that a single organization is involved in different activities. Some organizations are mainly involved in the production and monitoring of actual climate data. For example, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) produce and deliver a extended range of weather and climate related data, images and maps 24 hours a day for each day of the year. EUMESTAT provides data on ocean and atmospheric composition used to monitoring and forecasts of air quality.

The World Meteorological Organization (WMO) is a specialized agency of the United Nations. It is the UN system's authoritative voice on the state and behavior of the Earth's atmosphere, its interaction with the oceans, the climate it produces and the resulting distribution of water resources. The main activities and products provide by WMO are Climate Monitoring Products (Global and Regional Monitoring Products) which are systems providing advisories to inform and alert users, especially on natural hazards preparedness, mitigation and response. Climate Data Sets including World Weather Records, Climate Extremes Records, Global Surface Temperature, Global Precipitation, aerosols and ozone. WMO is considered the leader in the development of climate services as it is involved in the development, in 2009, of The Global Framework for Climate Services (GFCS) with the aim to *enable better management of the risks of climate variability and change and adaptation to climate change at all levels, through development and incorporation of science-based climate information and prediction into planning, policy and practice*". Morover in the 1988 the WMO has established, with the United Nations Environment Programme (UNEP), the IPCC which is the leading international body for the assessment of climate change. It reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. It does not conduct any research nor does it monitor climate related data or parameters however its assessment reports (e.g Fourth Assessment Report: Climate Change 2007, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation 2012) are the scientific base for the development of each climate services and climate change policy. The IPCC also operate in the field of climate change communication and raising awareness trough reports, publications, guidelines for users of different sectors.

National Oceanic and Atmospheric Administration (NOAA) aims in providing science and information to help the American (and not only) society in taking decisions on how to manage climate-related risks and opportunities they face. NOAA is a source of timely and authoritative scientific data and information about climate. Its goal is to promote public understanding of climate science and climate-related events, to make data products and services easy to access and use, to provide climate-related support to the private sector and the economy, and to serve people making climate-related decisions with tools and resources that help them answer specific questions. For this it provide a wide range of tools: maps showing where and how climate conditions are changing, climate education resources, reports, decision support tools, datasets, and professional development opportunities all sortable by sectors, topics, and regions.

Other organization are mainly involved in the climate change prediction and climate change impacts risk assessment; these organization used climate data resulting from models and observation to create climate change scenarios and to performed an assessment of its impacts on natural and human systems. It's allows to quantify impacts in socio economic and environmental terms.

The Euro-Mediterranean Center on Climate Change is a non-profit research institution established in 2005, with the main goal of establishing a Center of excellence focused on integrated study of climate change related topics in Italy. CMCC represents at the national and international scale, an institutional point of reference for decision makers, public institutions, as well as private and public companies seeking technical-scientific support. CMCC's mission is to investigate and model our climate system and its interactions with society to provide reliable, rigorous, and timely scientific results, which will in turn stimulate sustainable growth, protect the environment, and develop science driven adaptation and mitigation policies. The main activities of CMCC are related with climate predictions and climate change projections, risk assessment of impacts related with climate change on different systems (e.g. coast, soil, agriculture, natural ecosystem), socio economic analyses of climate change impacts, communication of the results and information obtained to a broad range of users.

The Food and Agriculture Organization of the United Nations (FAO)'s mandate is to "raise levels of nutrition, improve agricultural productivity, better the lives of rural populations and contribute to the growth of the world economy". For this purpose FAO Climate Change Resources study climate change impacts on agriculture sector and related sectors (Biodiversity, Bioenergy, Forestry, Health, Food Security). One of the tools developed by FAO to assess the climate change impact on crops yields is the FAO-MOSAICC (MOdelling System for Agricultural Impacts of Climate Change) – "a system of models designed to carry out each step of the impact assessment from climate scenarios downscaling to economic impact analysis at national level. The four main components of the methodology are a statistical downscaling method for processing GCMs output data, a hydrological model for estimating water resources for irrigation, a crop growth model to simulate future crop yields and finally a CGE (Computable General Equilibrium) model to assess the effect of changing yields on national economies" (Medri et. All., 2012). FAO is involved in the development of mitigation and adaptation policy "Climate-Smart Agriculture practices" for instance are examples of "climate-smart" production systems which can been used by farmers and food producers to reduce greenhouse gas emissions, adapt to climate change and reduce vulnerability. In this context FAO performed also training and activities to support the agricultural sectors stakeholders trough wide range of learning materials and decision support tool (e.g.CROPWAT 8.0, TECA platform - Technologies for Agriculture;)for capacity development on climate change.

Finally organization such as Global Facility for Disaster Reduction and Recovery (GFDRR) and the Red Cross Climate Centre (RCCC) conduct their activities in the field of risk and disaster reduction with particular focus on developing country. Some products and tools developed are, for example, early warning scientific information (publications, guidance, practical implementation examples); information on risk reduction and resilience increase (e.g. guidance note for practitioners to consider climate change in Vulnerability Capacity Assessments in their work with communities) and forecasting tools to use in humanitarian decisions.

Name	**Website**	**Scale**	**Main Activities**	**Sectors**
Word Meteo Organisation (WMO)	http://www.wmo.int/pages/themes/climate/climate_services.php	Global, Regional	▪ Climate data and monitoring; ▪ Climate prediction; ▪ Risk management; ▪ Climate collaboration networks;	Water, Agriculture, Health, Energy,Tourism,Transportation, Humanitarian Sector, Urban planning
Intergovernamental Panel on Climate Change (IPCC)	http://ipcc.ch/	Global, Regional	▪ Review and assessment of the most recent scientific, technical and socio economic information on climate change; ▪ Climate change impacts and vulnerability assessment; ▪ Greenhouse gasses inventory; ▪ Communication	Water resources; ecosystems; food, forests; coastal systems; industry; health, energy, transport.
National Oceanic and Atmospheric Administration (NOAA)	http://www.climate.gov	Global, Regional, Local	▪ Climate data and monitoring; ▪ Education; ▪ Decision support;	Health, fisheries, agriculture, water and air quality, urban planning.
United Nations Environment Program (UNEP)	http://www.unep.org/	Global (Developing Country)	▪ Climate Policy and governance; ▪ Disaster management; ▪ Early warning systems.	Energy, transports, urban planning, health, air and water quality
FAO Climate Change Resources	http://www.fao.org/climatechange/59 898/en/	Global, Regional	▪ Climate data and monitoring ▪ Climate impacts assessment ▪ Climate adaptation and mitigation ▪ Education	Agriculture, Biodiversity, Energy, Climate risk management, Forestry, Fisheries, Soil and Water quality.
European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)	http://www.eumetsat.int/	Global	▪ Climate data(oceans, atmospheric composition); ▪ Weather Forecasting; ▪ Climate prediction; ▪ Data distribution	Health, water quality, civil protection

			and communication	
Red Cross Climate Centre (RCCC)	http://climatelab.org/Red_Cross_Red_Crescent_Climate_Centre	Global (Developing country)	▪ Communication/Raising awareness; ▪ Capacity building; ▪ Disaster management; ▪ Climate policy; ▪ Research in climate risk management;	Health, water quality, food supply, humanitarian sector
Global Facility for Disaster Reduction and Recovery (GFDRR)	https://www.gfdrr.org/	Global, Regional, Local	▪ Disaster management; ▪ Climate change adaptation,	Humanitarian sector, health, risk management
International Research Institute for climate and society (IRI)	http://portal.iri.columbia.edu	Global, Regional	▪ Climate change forecasting; ▪ Climate change scenario construction; ▪ Climate policy; ▪ Education; ▪ Communication	Agriculture, Health, Water Resources, Civil Protection.
Euro-Mediterranean Centre On Climate Change (CMCC)	http://www.cmcc.it/it/	Regional, National, Local	▪ Climate change forecasting; ▪ Climate impacts assessment; ▪ Education; ▪ Communication.	Agriculture, Coastal and marine management, Forestry, Tourism, Civil Protection and environmental security, water management.
UK Met Office MO	http://www.metoffice.gov.uk/services/climate-services	Global, Regional, National, Local	▪ Climate Projections, ▪ Climate Impacts Projections; ▪ Business consulting; ▪ Training; ▪ Education; ▪ Climate Policy	Agriculture, Coastal and marine management, Civil Protection and environmental security, Water management, Energy, Transport.
UKCIP	http://www.ukcip.org.uk/	Global, National, Local	▪ Climate Impact research and assessment; ▪ Economic impacts assessment; ▪ Training.	Health, Agriculture, Civil Protection and environmental security, Water management, Energy, Transport.

Table 1.1 Main European and International climate services providers

1.3 Review of climate change impacts indexes and indicators

The theoretical background on climate services previously provided is necessary for the establishment of a common understanding of the shared terms, in global terms. There exist various organizations, users, groups, classifications, inputs and outputs and other types of information that have been presented in the previous chapters. Though what remains the vital part of climate services is how these services can be efficiently used in our world and how they can contribute significantly in the effort of minimizing the effects of climate variation and impacts on numerous instances of our activities and our societies. In order to answer to these questions and to select the more appropriated climate services to be developed in the thesis, a review of indexes and indicators related which climate change impacts have been performed and will be presented in this Paragraph. As it can be easily understood, the applications of climate services can span among various sectors of our society, therefore, the first step of the analysis was aimed to identify which are the sectors of the society that mostly could benefit from the existence of climate services. Feenstra et al (1998) and EEA (2012) identify the following societal sectors as the ones more closely connected with climate services:

- Agriculture;
- Civil protection and environmental security;
- Coastal zones and management;
- Energy ;
- Financial services and insurances;
- Fisheries and aquaculture ;
- Forests, forestry and land management;
- Human health;
- Oceans and marine environment;
- Soil;
- Terrestrial ecosystems and biodiversity;
- Tourism;
- Transport services and infrastructure;
- Trade and Commerce;
- Water management.

However for the purpose of the thesis only seven out of the sixteen proposed by Feenstra (1998) and EEA (2012) were selected based on the relevance for the case study subject of the present thesis. Each sector was analyzed in order to evaluate how it could benefit from the existence of climate services and which stakeholders needs can effectively be met by climate related services. Table 1.2 presents sectors taken into consideration in the present review and some generic examples of real questions that can be tackled through climate services.

Sector	**Climate change relevance**	**Questions**
Agriculture and Forestry	With a better analysis of climate risks and availability of seasonal forecasts, farmers can plan optimal planting dates, the best mix of crops to grow and which disease- and pest-resilient varieties to choose. This can help to improve food security and reduce poverty. Climate scientists and farmers must develop close partnerships to effectively use seasonal forecasts and develop coping strategies in the event of natural disasters.	• Which crops should a farmer plant? • Should a farmer reduce livestock numbers due to a drought forecast?
Water Management	Water availability can provide or deny life-supporting needs. It can lead to enhanced food production but also to extreme water stress, high levels of poverty and even loss of life. Improved climate predictions give water resource managers the necessary information to plan and operate their systems more efficiently.	• Should new water reservoirs be built?
Human health	Weather and climate conditions have direct and indirect impacts on health. They can increase the risk of epidemics of airborne and waterborne diseases, as well as malnutrition, heatstroke and respiratory problems. Climate prediction and information facilitate early warnings and surveillance, as well as interventions and resource allocation management.	• Where can we expect a disease outbreak? • Where mitigation to heat waves should be built?
Civil Protection	Climate-related disasters such as flooding or drought have great impacts on communities and their socio-economic activities. Early	• Which areas are likely to be affected by disasters? • Where should

	warning systems can prevent loss of life, livelihood and property by alerting people to specific threats.	investments on disaster mitigation measures take place?
Energy	Climate change is likely to both increase electricity demand for cooling in the summer and decrease electricity, natural gas, heating oil, and wood demand for heating in the winter. New infrastructure investments may be necessary to meet increased energy demand, especially peak demand during heat waves. Climate change could impact wind and solar power.	• Where energy infrastructure should be built? • In which energy sectors (solar, wind) should be invested?
Tourism	As a climate sensitive sector, tourism might be highly affected by global climate change due to changes of temperatures, precipitations, wind speed, storm frequency, etc. The impacts on tourism are expected to lead to the reduction of visitors in some destinations and the increase in others.	• Which destination will be most appreciated in the future? • Where should tourism infrastructures be built?
Fishing	Rising ocean temperatures and ocean acidification are radically altering aquatic ecosystems. Climate change is modifying fish distribution and the productivity of marine and freshwater species.	• Which species should be available for fishing? • Which habitat should be including in the protected areas?
Coastal and Marine Management	Changes in climate will affect coastal systems through sea-level rise and an increase in storm-surge hazards and possible changes in the frequency and/or intensity of extreme events.	• Where should investments on defense structures take place?

Table 1.2 Examples of question for climate change information for different sectors of the society

Once that questions raised by different sectors have been identified, the aim was to assess which of the climate services available could actually answer to the questions. A review was performed focusing on climate change impacts indexes and indicators. Indices and indicator are broadly used in the field of environmental sciences where they are used to measure physical, chemical, biological or socio-economic parameters of an ecosystem or environmental issue (http://www.ozcoasts.org.au/glossary/def_i-l.jsp). Specifically, considering the impact of climate change, indicator and indexes are used for monitoring climate variations, characterizing spatial and temporal distributions of stressors and drivers, identifying strategic vulnerability (IPCC, 2007). According to EEA (2003), an indicator is defined as an observed value representative of a phenomenon of study which quantifies information by aggregating different and multiple data. Moreover an index is defined as a set of aggregated or weighted parameters or indicators. On a bottom up approach, a measurement of a specific variable is the basis for the construction/characterisation of an indicator, which in turn can be the basis for the construction/characterisation of an index. Obviously, more than one variable can be used for characterising one indicator and more than one indicator can be used for characterising one index. Indicator and index should have specific attribute in order to provide a science-based representation of the analyzed issue. According to the criteria proposed by Voigt e van Minnen (2007) and EEA (2007) indices and indicators should be:

- **Relevant:** indicators should send a clear message and provide information at a level appropriate for policy and management decision-making;

- **Routinely collected:** indicators must be based on routinely collected, clearly defined, verifiable and scientifically acceptable data.

- **Representative at national scale:** as far as possible, it should be possible to make valid comparisons between countries using the indicators selected;

- **Easily understandable:** the power of an indicator depends on its broad acceptance and on its easy communication; simple indexes and indicators should be preferred;

- **Methodologically well founded**: the methodology should be clear, well defined and relatively simple. Indicators should be measurable in an accurate and affordable way, and constitute part of a sustainable monitoring system. Data should be collected using standard methods.

- **Show cause-effect relationship:** information on cause-effect relationships should be achievable and quantifiable in order to link pressures, state and response indicators.

- **Sensible to changes:** indicators should show trends and be able to detect changes in systems in timeframes and on scales that are relevant to the decision makers.

Following this criteria, relevant climate change impacts and vulnerability indicators have been identified from the existing scientific literature and divided for the sectors of interest described previously in Table 1.2. For each sector the main climate change impacts have been identified and, for each of them, available indicators and indices have been classified based on:

- Name of the index or indicator;
- Variables and parameters measured;
- Scale of application;
- References;

The results of the review for are presented as follow and summarized in Table 1.3.
For the **agricultural sector** three main climate change impacts were identified: drought, change in crops agrophenology and in soil composition. For what concern drought, most of the indicators measure the water availability for crops on the base of precipitations. The Standardized Precipitation Index (SPI) developed by McKee & Doesken (1993) and updated by Heim (2002) is currently use by NOAA to provide monthly maps used in the drought risk assessment. The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount. The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive (http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/spi.html).
NOAA use for the same aim also Palmer Drought Indices (Palmer, 1960); these indices include the Palmer Z Index, the Palmer Hydrological Drought Index (PHDI), the Palmer Drought Severity Index (PSDI) and the Crop Moisture Index (CMI). Palmer's indices are water balance indices that consider water supply (precipitation), demand (evapotranspiration) and loss (runoff). Also this indices provide a value which is negative for drought, and positive for wet conditions, values are then classified in qualitative classes representing low, moderate or elevate drought conditions. Other indices such as Keetch-Byram Drought Index (KBDI) (Keetch & Byram, 1968) and the Available Water (AW) measure

the water content in the soil considering also the pedologic conditions. The Consecutive dry days Index (CDD) developed by Deni & Jemain (2009) assess drought condition measuring the number of dry days between two wet days (Wanders et al., 2010). The higher the number of consecutive dry days, the more severe a drought will be, however it not provide a classification in drought severity classes. The European Environmental Agency in the "Climate change, impacts and vulnerability in Europe" report (EEA, 2012) proposes a set of indicators to apply for the agriculture sector. The first two are related with drought: the Water limited crop productivity, which measure the drought in term of yield reduction; and the irrigation water requirement which measures the increase in the water required for irrigation. Both of them are more related with the socio-economic dimension of agriculture, being used also for a monetary assessment of the drought impacts. EEA (2012) also proposes indicators for assessment of changes in crops agrophenology due to climate change. The agropehenology indicator measures the change in the flowering day. Specific stages of growth (e.g. flowering, grain filling), in fact, are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle (agrophenology) determines the productive success of the crop (EEA, 2012). The Growing season for agricultural crops: Indicator register the change in the duration (days) of the growing season of different crops due to change in temperature.

For the **civil protection sector** the main impact considered was the increase in weather extreme events. The increase in the number of extreme events such as storms and heavy precipitation could increase the occurrence of catastrophic events (e.g. floods, inundations), which can cause loss of life, economic and environmental damages. The Climate Extreme Index (CEI) was developed originally by Karl et al. (1996) with the goal of summarizing a complex set of multivariate and multidimensional climate changes in the United States so that the results could be easily understood and used in policy decisions made by non specialists in the field. It was generated from a composite of three indicators investigating possible extremes in monthly mean temperature, daily precipitation and the Palmer Drought Severity Index (PDSI) on an annual basis. The CEI has been revised by NOAA (2003) and incorporates a new indicator utilizing land-falling tropical storm and hurricane wind intensity data. The revised CEI is calculated based on eight standard seasons (Gleason, K. et al.,2007). It is calculated as the arithmetic average of percentage of territory of a country interested by the extreme events indicators described below. Value of 0% for the CEI, the lower limit, indicates that no portion of the period of record was subject to any of the extremes of temperature or precipitation considered in the index. In contrast, a value of 100% would mean that the entire country had extreme conditions throughout the year for each of the indicators (http://www.ncdc.noaa.gov/extremes/cei/definition). EEA (2012) proposed two indicators to assess the impacts on extreme events on human environment in terms of risk of floods and pluvial flooding. Both of them are socio-economic indices which assess the flood risk looking at the damage and cost related with it.

For what concern **the coastal and marine management**, most of the reviewed indices and indicators are used for quantifying the impacts of climate change on sea level rise and erosion. In particular for sea level rise impacts, Coastal Vulnerability Index (CVI) map the relative vulnerability of the coast to future sea-level rise. The CVI scores different variables in terms of their physical contribution to sea-level rise related coastal change. Considered variables are divided in geological variables (geomorphology, historical shoreline change rate, regional coastal slope) and physical process variables (relative sea level rise, mean significant wave height, mean tidal range). In particular, the geological variables take into account the shoreline's relative resistance to erosion, long-term erosion/accretion trend, and its susceptibility to flooding. The physical process variables contribute to the inundation hazards of a particular section of coastline over time scales from hours to centuries.
Schleupner (2005) proposes a significant approach based on the Coastal Sensitivity Index (CSI) in order to assess the sensitivity of the coast to flooding and erosion caused by climate change and sea level rise. To evaluate the probability of flooding and coastal erosion, four categories that influence vulnerability are chosen: elevation and morphology of the coast, erodibility, coastal exposition to the wind regime, and natural shelter of the coast. Relative elevation, coastal morphology and erodibility represent geological/geomorphological characteristics of coastal zones. Coastal exposition to the wind regime may affect coastal erosion and the withdrawal of the coast. Natural shelter of the coastal segment have the function of natural breakwaters along the coastline (i.e. coral reef, small islands, bays). Relative local subsidence and elevation movements are added to these four categories.
The Eurosion project (2004) proposed a set of 13 indicators based on the DPSIR approach (EEA, 1995) to support the assessment of coastal erosion risk throughout Europe. 9 indicators are sensitivity indicators and referred to pressure and state indicators and they take into consideration parameters as the relative sea level rise and the highest water level, as well characteristics of the coastline (urbanization, geology, elevation, presence of protection structure). The other 4 indicators are impact indicators aimed to evaluate the impacts on coastal zone; they include information on the population

living within the RICE (Radius of influence of coastal erosion and flooding), the coastal urbanization, urbanized and industrial areas within the RICE, areas of high ecological value within the RICE.
Another set of indicators is proposed within the Deduce Project (2007) that aims at monitoring the sustainable development of the coastal zone at different scales. Two indicators are related with sea level rise and erosion impact on coastal zone. The sea level rise and extreme weather conditions Indicator including three measures: number of “stormy days”, rise in sea level relative to land, length of protected and defended coastline and the Coastal erosion and accretion Indicator including three measures: length of dynamic coastline, area and volume of sand nourishment, number of people living within an “at risk” zone. Others indicators proposed in Deduce are more related with the change in water quality and in biodiversity registering the change in coastal and marine habitats and species trough the analysis of their status and trend.

EEA (2012) proposes a set of indicators also for **the energy sector** which take into account the change in energy demand. Climate change, in fact, will lead variations in temperature in many areas causing a change in the demand of energy for heating and electricity. In some areas the number of days with temperature below a defined limit will be reduced and therefore the number of heating days will be reduced. On the other hand during the summer there will be an increase in electricity demand to cooling and air conditioning systems. A 'Heating Degree Day' (HDD) is a proxy for the energy demand needed to heat a home or a business; it is derived from measurements of outside air temperature (EEA, 2012).

The impact of climate change on **fishing** is mainly related with the alteration in terms of species and dimension of the fish stock. EEA (2012) considers two indicators: the change in the phenology and in the distribution of marine species. Phenology is the study of annually recurring life-cycle events of species, such as the timing of migrations and reproduction. Change in phenology is one of the key indicators of the impacts of climate change on biological populations (EEA, 2012) and it is measured recording the day of the year for migrations and reproduction. Climate change also impacts fish stock changing their latitudinal distribution pattern. Within the DEDUCE Project another indicator of fish stock has been developed which involves the observation of the state of the main fish stocks divided by species and sea areas.

Two major indicators have also been found for **the forestry sector**. The Forest growth indicator describes the extent of forests (i.e. their area) as well as the growing stock (i.e. the volume of the aboveground biomass of all living trees) (UNECE and FAO, 2011). The Forest fires indicator monitors the areas burnt by forest fires. Climate change may lead to more forest fires due to warmer and drier weather, and possibly increases in lightning storms (a natural cause of fires). The limit in the application of these indicators is related with the difficulty to separate the impacts of climate change on forests and forestry from non-climate influences in observational data (EEA, 2012).

The climate change impacts **on human health** are mainly related to the increase in the incidence of vector born disease and to the extreme (heat or cold) temperature events. EEA in the Climate change, impacts and vulnerability in Europe 2012 proposed a set of three indicators for the human health sector; the first is defined as “Extreme temperatures and health”. It measures the mortality due to heat and cold waves in term of number of death. This indicator has been recently used in the PESETA Project for the estimation of heat-related mortality in Europe for the 2071-2100 time horizons. The vector born disease indicator evaluates the impact of climate change in increasing the disease trough the measure of the number of people infected by vector borne disease. Other two indices are found for the analysis of climate change impacts on extreme temperatures: the warm spell duration index (WSDI) is defined as the number of days each year which are part of a "warm spell" (i.e. a sequence of 6 or more days in which the daily maximum temperature exceeds the 90th percentile of daily maximum temperature for a 5-day running window, surrounding this day during the baseline period); Likewise (WSDI), the Cold Spell Duration Index (CSDI) is defined as the number of days each year which are part of a "cold spell". Both of them are been applied in the CIRCE Project for the assessment of climate change impact in the Mediterranean environment (www.circeproject.eu/).

The tourism is likely to be deeply affected by climate change mainly for what concern the reduction in attractiveness. Mieczkowski (1985) proposed the Tourism Climatic Index (TCI) merging climatic parameters (temperature, humidity, precipitations, radiation, wind speed) and applicable to tourism sightseeing in order to give indication of a place’s suitability for specific touristic activities (Becken, 2010). The TCI has been further developed and applied in different settings, for example for beach environments (Morgan, 2000, in de Freitas et al., 2008) and for study the impact of climate change on global tourism flows (Amelung et al., 2007). This index allows to assess which touristic localities will loss attractiveness due to changes in the climate and which others will benefit from these changes. A similar index is the Winter Tourism Index (EEA, 2012) which measures the loss of attractiveness of winter tourism localities and winter sports due to the reduction of the snow cover days. Deduce (2007) give a quantitative measure of the reduction in intensity of tourism evaluating the number of overnight stays in tourist accommodation and the rate of occupancy of bed place of specific destinations.

The last sector considered in the review was **the water management sector** which includes impacts on water availability and quality. For what concern water quantity, EEA (2012) use a set of seven indicators: three of them are related with river water flows measuring the mean flow, the maximum flood - as floods indicators - and the minimum flow as river drought indicators; two other indicators are related with the ice and snow cover duration (days) and amount (mm).

The present review was use as starting point for the identification and definition of hazard, exposure and vulnerability indicators to used in the development of the RRA methodology for the production of climate risk services related with pluvial floods impact for the North Adriatic case study which will be presented in the following chapters.

Sector	Impact	Indicator / Index name	Measurement	Scale	Reference
Agricolture	Drought	Water-limited crop productivity	Yield	Local	EEA,2012
		Irrigation water requirement	Increase in water requirement	Local	EEA,2012
		Consecutive dry days, CDD	Number of consecutive day without precipitations	Local / Regional	Deni & Jemain, 2009
		Aridity Index AI	Annual precipitation / Annual Potential evapotranspiration	Local / Regional	UNEP, 1997
		Potential Soil Moisture Deficit, PSMD	Cumulative Precipitation Index needs to the coltural PET of specif crops	Local / Regional	Narasimhan & Srinivasan, 2005
		Available Water; AW	Available water in the soil taking into account precipitations, eavpotranspiration and pedologic conditions	Local / Regional	FAO,1985
		Palmer Z Index	Consider water supply (precipitation), demand (evapotranspiration) and loss (runoff).	Local / Regional	Palmer, 1960
		Palmer Hydrological Drought Index (PHDI)			
		Palmer Drought Severity Index (PDSI)			
		Crop Moisture Index (CMI)			
		Keetch-Byram Drought Index KBDI	Indicate idric deficit condition in the upper part of the soil	Regional	Keetch & Byram, 1968
		Potential EvapoTranspiration; PET	Amount of evaporation that would occur if a sufficient water source were available	Regional	Penman & Monteith, 1965
		Rainfall Anomaly Index,RAI	Distribution of precipitation	Regional	Van Rooy, 1965
		Cumulative Precipitation Anomaly, CPA	The shortage of precipitation compared to the long term mean	Regional	Hayes, 2007
		Standardized Precipitation Index SPI	The cumulative probability of a given rainfall event in a station	Regional	McKee & Doesken,1993
	Crops Agrophenology	Agrophenology	Day of flowering	Local	EEA,2012
		Growing season for agricultural crops	Duration	Local	EEA,2012
	Soil composition	Soil organic carbon	Carbon content	Local	EEA,2012

Forestry	Forest grow	Forest growth	Biomass	Local /Regional	EEA,2012
	Forest fire	Forest fires	Area	Local	EEA,2012
Fishing	Fish stock	Phenology of marine species	Day of the year	Regional	EEA,2012
		Distribution of marine species	Latitude	Regional	EEA, 2012
		Fish stock	State of the main fish stocks by species and sea area	Regional	Deduce Project, 2007
Coastal and marine management	Sea Level Rise	Sea level rise and extreme weather conditions	Number of 'stormy days'	Regional	Deduce Project, 2007
			Rise in sea level relative to land		Deduce Project, 2007
			Length of protected and defended coastline		Deduce Project, 2007
	Coastal Erosion	Coastal erosion and accretion	Length of dynamic coastline	Regional	Deduce Project, 2007
			Area and volume of sand nourishment		Deduce Project, 2007
			Number of people living within an 'at risk' zone		Deduce Project, 2007
		Coastal erosion	Relative sea level rise (best estimate for the next 100 years);	Regional	Eurosion,2004
			Shoreline evolution trend status;		
			Shoreline changes from stability to erosion or accretion;		
			Highest water level;		
			Coastal urbanisation (in the 10 km land strip);		
			Reduction of river sediment supply;		
			Geological coastal type;		
			Elevation;		
			Engineered frontage (including protection structure).		
			Population living within the RICE (Radius of influence of coastal erosion and flooding)		
			Coastal urbanisation (in the 10 km land strip);		

			Urbanised and industrial areas within the RICE;		
			Areas of high ecological value within the RICE.		
	Water Quality	Ocean acidification	Acidity	Local /Regional	EEA,2012
		Ocean heat content	Heat content	Local/Regional	EEA,2012
		Sea surface temperature	Temperature	Local	EEA,2012
		Quality of bathing water	Percentage of bathing waters compliant with the guide value of the European Bathing Water Directive	Local /Regional	Deduce Project, 2007
		Amount of coastal, estuarine and marine litter	Volume of litter collected per given length of shoreline	Local	Deduce Project, 2007
		Concentrations of nutrient in coastal waters	Riverine and direct inputs of nitrogen and phosphorus in inshore waters	Local /Regional	Deduce Project, 2007
		Amount of oil pollution	Volume of accidental oil spills	Local	Deduce Project, 2007
	Vulnerability	Coastal Vulnerability Index (CVI)	Geomorphology	Regional	USGS, 2004
			Historical shoreline change rate		
			Regional coastal slope		
			Relative sea-level rise		
			Mean significant wave height		
			Mean tidal range		
		Coastal Sensivity Index (CSI)	Relative height of the coast	Regional	Schleupner, 2005
			Morphology of the coast		
			Erodibility		
			Coastal exposition to the wind regime		
			Natural shelter of the coast		
			Subsidence		
			Elevation of the area		
			Sediment processes		
	Biodiversity	Change in significance coastal and marine	Status and trend of specified habitats and species	Local	Deduce,2007

		habitats and species			
Tourism	Reduction in attractivity	Tourism Climatic Index	Daytime Comfort Index (CID) maximum daily temperature [in °C] & minimum daily relative humidity [%]	Local	Mieczkowski,1985
			Daily Comfort Index (CIA) mean daily temperature [in °C] & mean daily relative humidity [%]		
			Total precipitation (mm)		
			Avarage wind speed (m/s or km/h)		
			Total hours of sunshine (h)		
		Winter Tourist Index	Winter Tourist Index	Local	EEA,2012
		Intensity of tourism	Number of overnight stays in tourist accommodation	Local	Deduce,2007
			Occupancy rate of bed places	Local	Deduce,2007
Water management	Water Availability	River flow	Mean flow	Local	EEA,2012
		River floods	Maximum flow	Local	EEA,2012
		River flow drought	Minimum flow	Local	EEA,2012
		Water temperature	Temperature	Local /Regional	EEA,2012
		Lake and river ice cover	Duration	Local	EEA,2012
		Snow cover	Duration/Amount	Local	EEA,2012
		Grounddwater	Variation in the groundwater level	Local /Regional	EEA,2012
	Water Quality	Water quality	Variation in the water quality	Local/Regional	EEA,2012
Human health	Heat wawes	Extreme temperatures and health	Number of death due to heat wawes	Local /Regional	EEA,2012
		Warm Spell Duration Index; WSDI	Annual count of days with at least 6 consecutive days when TX > 90th percentile.	Local /Regional	
	Cold wawes	Cold Spell Duration Index, CSDI	Annual count of days with at least 6 consecutive days when TN < 10^{th} percentile.	Local /Regional	
	Disease	Vector-borne diseases	People infected	Regional	EEA,2012
	Pollution	Air pollution by ozone and health	Ozone levels	Regional	EEA,2012
Energy	Change in energy demand	Heating degree days	Energy needed for heating an days at which the temperature falls below a defined limit	Local /Regional	EEA,2012
		Electricity demand	Electricity demand	Regional	EEA,2012

		Electricity production	Electricity production	Regional	EEA,2012
	Greenhouse gasses concentration	Global greenhouses gas emission	Emission	Global	EEA,2012
		Global atmospheric concentration of greenhouse gasses	Concentration (ppm)	Global	EEA, 2012
Civil protection	Increase in extrem events	Floods	People flooded	Regional	EEA, 2012
		Heavy precipitation Index	The average number of days with very heavy precipitation	Local/Regional	
		Pluvial flooding	Damage and cost	Local	EEA, 2012
		Climate Extreme Index (CEI)	Extremes in monthly mean maximum and minimum temperatures	Regional	NOAA, 2003
			Heavy 1-day precipitation events		
			Drought severity		
			Wind intensity of landfalling tropical cyclones.		

Table 1.3 Indicators and indeces used to assess vulnerability and climate change impacts on different sectors of the society

Chapter 2 The CLIM-RUN Project and the participative process applied to the development of climate risk services

The research proposed in this thesis was carried out within the North Adriatic case study of the CLIM-RUN Project (Climate Local Information in the Mediterranean region: Responding to User Needs).It is a 3-year project funded by the 7th Framework Programme for Research in 2011, aimed at the development of a protocol for providing improved climate services to stakeholders in the Mediterranean area. The CLIM-RUN Project is based on a bottom-up approach for the development of climate impact and adaptation services aimed at involving the stakeholders early in the process in order to register their needs and requests. This approach was applied as methodological base also in the development of the pluvial flood risk assessment methodology within this thesis. With the purpose to describe the methodological approach followed for the development of climate risk services, the chapter is structured in three paragraphs: Paragraph 2.1 describes the CLIM-RUN Project, its main objectives and structures; Paragraph 2.2 give a brief introduction of the Regional Risk Assessment (RRA) approach adopted in the project for the development of climate risk and adaptation services in coastal areas. Paragraph 2.3 explains the participatory process involving the North Adriatic stakeholders.

2.1 The CLIM-RUN Project

The CLIM-RUN Project – (Climate Local Information in the Mediterranean region: Responding to User Needs) a three years research funded by the 7th Framework Program of the European Union – was launched on 1st March 2011 and will finish on 28th February 2014. The main aim of the project is to develop a protocol for applying new methodologies and improved modelling and downscaling tools for the provision of adequate climate information at the regional to local scale that is relevant to and usable by different sectors of society (policymakers, industry, cities, etc.)(http://www.climrun.eu/index). The program is based on a bottom-up approach involving stakeholders early in the process in order to identify needs at the regional and local scale and utilize modelling and downscaling tools which respond optimally to these specific needs. The region of interest for the project is the Greater Mediterranean area, which is particularly important for two reasons. First, the Mediterranean is a recognized climate change hot-spot being a region particularly sensitive and vulnerable to global warming. Second, while a number of countries in Central and Northern Europe have already in place well developed climate service networks (e.g. the United Kingdom and Germany), no such network is available in the Mediterranean. The general time horizon of interest for the project is the future period 2010-2050, a time horizon that encompasses the contributions of both inter-decadal variability and greenhouse-forced climate change. The project involves 16 partners including European and International Research Institutes dealing with climate change issues for a total of 11 countries involved and ten different Work Packages (WPs) working in synergy as summarized in Figure 2.1. Specifically, WP1 and WP9 are involved in the climate services analysis and support considering the dissemination of final results. WP2 and WP3 involve climate experts which provide climate information to the other WPs developing new climate modeling, analysis tools and downscaling methods. The remaining WPs (i.e. WP5, 6, 7 and 8) are included in the stakeholders tier and consist of different case studies involving several sectors of the society. Specifically, the WP5 includes tourism case studies which involve Morocco, Cyprus and Savoie (France). The WP6 is the wild fire case study developed in Greece. The WP7 includes three case studies in Spain, Morocco and Cyprus related with energy sector. The last case study is the Integrated Case Study (WP8) which analyzes several systems and sectors (e.g. natural ecosystems, water resources, agriculture, etc.) in the Italian coast of the North Adriatic Sea.

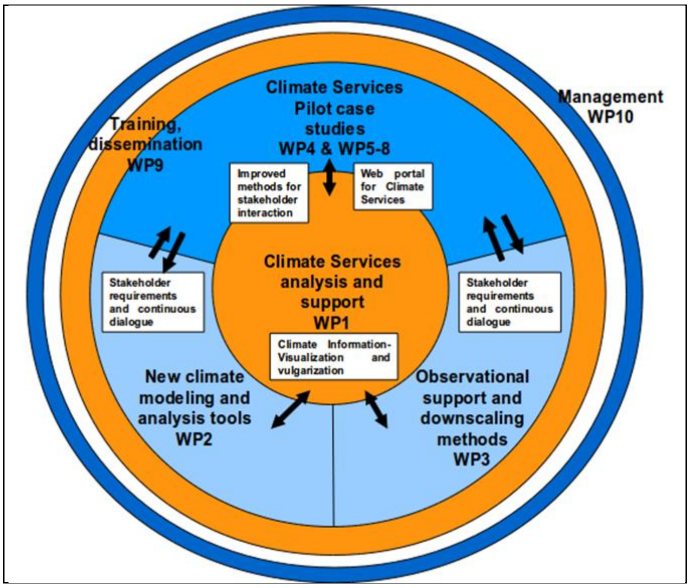


Figure2.1. CLIM-RUN Structure.

The main objective of the Integrated case study is the identification of a subset of climate services to support climate change impact assessment and adaptation in the coastal zones of the North Adriatic sea. Specifically, the case study is aimed at the definition of vulnerability targets and indicators associated to climate change impact for different sectors of interest and at the development of impact and risk indicators based on a wide stakeholder involvement. For this purpose climate modeling and downscaling methods are used and improved for the construction of climate change hazard scenarios. Moreover, GIS-based visualization tools are used to transfer climate information from climate experts to stakeholders involved in the Integrated case study.
In order to achieve these specific objectives the WP8 works on 5 major tasks:

- Organization of periodic meetings and surveys with the stakeholders in order to evaluate their needs, make a comparison between data demand and supply and consolidate the interaction between users and experts;
- Collection of local information on the North-Adriatic coastal case studies, defining a set of climate variables, stressors and hazard metrics to study climate change impacts for each sector of interest at the regional/local scale;
- Evaluation of climate information and estimates of future change performed through the review of climate information (provided by WP2 and WP3). Production of sector-oriented vulnerability matrixes, indicators and indexes and development of GIS-based hazard, vulnerability and risk maps;
- Development of guidelines and information material (fliers, short reports) to distribute to stakeholders;
- Development of a list of relevant parameters to support climate change impact/risk assessment and decision-making processes on Mediterranean coastal zones.

Specifically WP8 is focused on the production of two typologies of climate services: basic climate parameters (e.g. precipitations, winds, extreme event frequency and intensity) implemented by climate experts, and derived parameters (e.g. climate change impacts and risks services) (Giannini et al., 2011) which are developed by climate risk experts. In particular, with the aim to develop climate impact and risk services, it is necessary to integrate three research areas (Figure 2.2) : 1. participative process; 2. climate information; 3. climate impacts and vulnerability information.

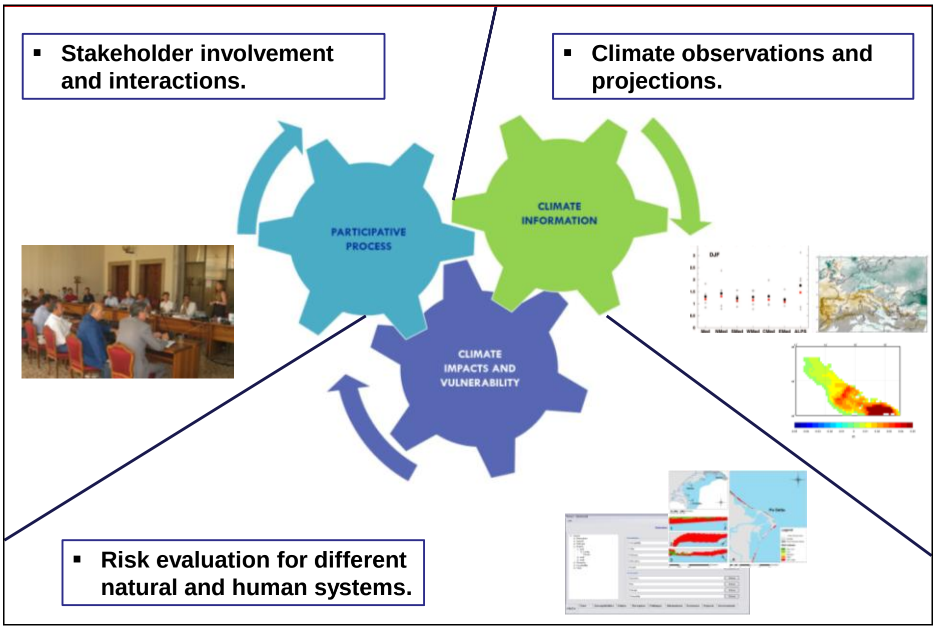


Figure 2.2. Research areas necessary for the development of climate impacts and adaptation services within the WP8 case study.

The first research area is aimed at understanding the needs and requests of the stakeholders for what concern climate services and information. Specifically, the participative process is performed involving stakeholders in different ways (i.e. workshop, thematic group, discussions, questionnaires) with the support of participatory process experts. The second research area represents the climate information which is aimed at provide forecasts and projections on future climate change scenarios. This tier involves climate experts that collect and elaborate climate observations and apply statistical downscaling to climate data at the regional and local scale providing climate information to the final users (i.e. stakeholders and risk experts). The climate information tier aims to support the case study analyzing available climate information and developing new tools to improve the spatial and temporal resolution of climate data. The third research area is the climate impact and vulnerability information which integrates climate data and end-users requests in order to evaluate climate-related risks for different natural and human systems. This is performed by risk experts aimed at bridging the gap between climate experts and stakeholders, using information provided by scientist expertise to responds to the end users' needs. In this context risk experts are both users and providers of climate services. Specifically, in the North Adriatic case study, risk experts provide climate impacts and vulnerability information through the application the Regional Risk Assessment (RRA) methodology. The next paragraph gives a brief introduction about the RRA approach used in the present thesis for the development of climate change impacts and adaptation services.

2.2 The Regional Risk Assessment (RRA) methodology for the assessment of climate change impacts and risks

The Regional Risk Assessment (RRA) is a procedure aimed at providing a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas (Hunsaker et al., 1990). In more detail, the RRA considers the presence of multiple habitats, multiple sources releasing a multiplicity of stressors impacting multiple endpoints (Landis, 2005). Accordingly, the RRA approach concerns the use of Multi Criteria Decision Analysis (MCDA) in order to estimate the relative risks in the considered region, compare different impacts and stressors, rank targets and exposure units at risk, and select those risks that need to be investigated more thoroughly. In order to assess risks related with climate change impacts, the RRA methodology has the following objectives:

1. Identification and prioritization of targets and areas at risk from climate change in the considered region;
2. Identification of homogeneous areas (i.e. homogeneous geographic sites for the definition of adaptation and management strategies) resulting from the aggregation of multiple climate change stressors and vulnerable exposure units;
3. Definition of the consequences (or impacts) of future climate on vulnerable or climate-sensitive exposure units and receptors;
4. Help decision-makers in examining the possible risks and damages associated with uncertain future climate and in identifying where adaptation to climate change may be required.

Specifically with the aim to rank potential impacts, targets and areas at risk from climate change at the regional scale, the RRA methodology integrates the three main pillars of risk defined by UNISDR (2009) and IPCC (2012) (i.e. hazard, exposure, and vulnerability) by mean of a framework composed of four main steps (Figure 2.3).

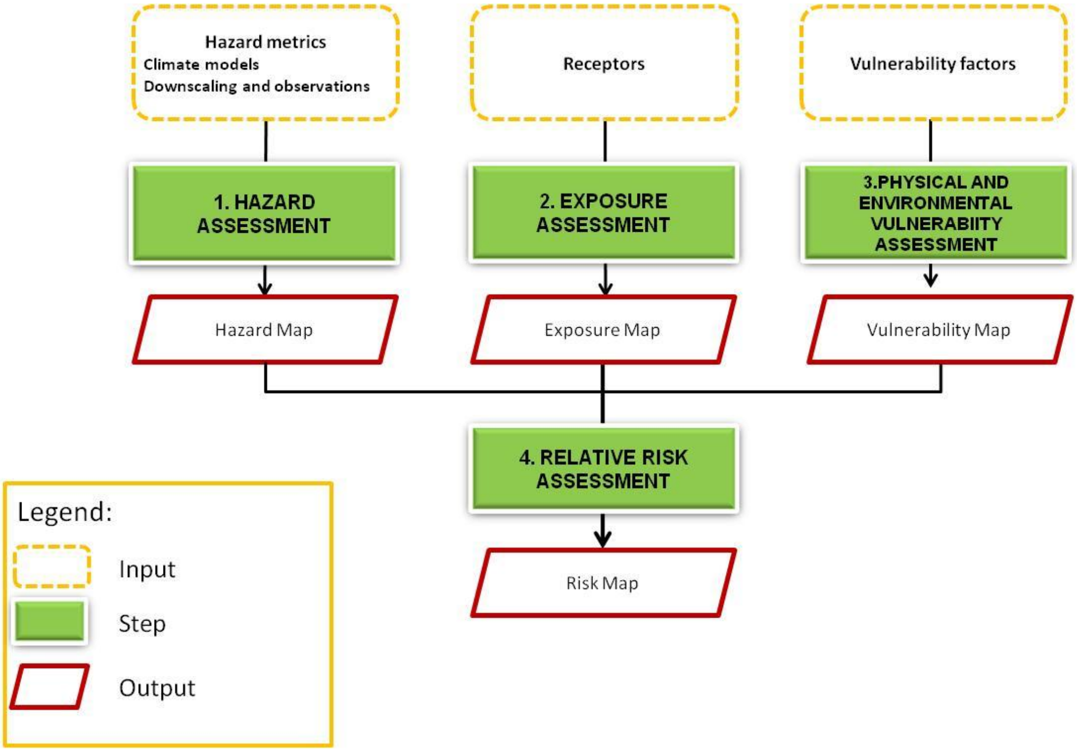


Figure 2.3. RRA conceptual framework.

The hazard assessment step aims at identifying hazard metrics (e.g. sea-level rise, flow velocity, water depth, flood extension) derived from climatic, hydrodynamic and/or hydrogeological models. These models might be implemented from the global to the regional scale, and used as input to develop future climate change hazard scenarios for the case study area.Numerical models simulations used for the characterization of hazards are related to different scenarios of greenhouse gas emissions and aerosol (e.g. IPCC scenarios) that reflect changes in major driving forces of environmental change (e.g. demography, economy, technology, energy and agriculture) (Nakicenovic et al., 2000). Moreover, numerical model simulations are associated to specific time periods (e.g. short or long-term scenarios) reflecting the temporal interval analyzed during the simulation. Finally, useful information in constructing hazard scenarios includes the analysis of observations and time series of climate parameters and extreme events. The hazard assessment allows to produce hazard maps representing the spatial distribution of areas potentially exposed to climate change impacts. The second step of RRA is the exposure assessment, aimed at identifying and selecting the receptors (i.e. elements at risk) that can be affected by climate change. This step requires the analysis of land use/land cover datasets for the localization of people, environmental resources, infrastructures, social, economic or cultural assets that could be adversely affected by climate change hazard. The main outputs of the step are exposure maps showing the presence and the localization of elements potentially affected by climate change impacts. The bio-physical and environmental vulnerability assessment is the third step of the RRA and it is aimed at evaluating the degree to which the receptors could be affected by a climate change hazard. This step requires the analysis of vulnerability factors which determine the susceptibility of a receptor to climate change hazards. Vulnerability factors are represented by geo-physical or ecological factors (e.g. geomorphology, slope, vegetation cover, land use) and are used to measure the degree to which a receptor is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2007). Finally, the relative risk assessment step is aimed at identifying and classifying areas, receptors and hotspots at risk. This phase combines the information about the climate change hazard scenario with the exposure and the physical and environmental vulnerability of the examined receptors through a Multi Criteria Decision Analysis (MCDA) function. Risk assessment provides a relative classification about areas and targets that are likely to be affected by climate change impacts more severely than others in the same region.

The main outputs of the RRA are GIS-based maps (i.e. hazard, exposure, vulnerability, risk maps) useful to communicate the potential implications of floods in non-monetary terms to stakeholders and administrations. These maps can be a basis for the management of climate change impacts. Moreover, they can provide suitable information for setting priority for prevention measures and for land use planning and land management.

The RRA methodology applied within the CLIM- RUN project for the production of climate impacts and adaptation services were developed adopting a bottom-up approach involving the stakeholders of the North Adriatic Sea The next paragraph briefly describes the participatory process applied in the case study area for the development of the RRA methodology for pluvial floods.

2.3 Participative Process for the development of climate risk services in the North Adriatic sea

As described in paragraph 2.1 the participative process is essential in the development of climate impacts and risk services as it allows the identification of requests and needs of the stakeholders and the provision of climate information useful to improve the decision-making process. For this purpose the RRA methodology provided in this thesis for the assessment of pluvial flood impacts on urban areas was developed following the bottom-up approach adopted by the CLIM-RUN

Project. The approach is aimed at involving stakeholders since the first step of the development of climate impact and adaptation services, in order to identify their needs and to provide climate services that optimally address these specific needs. Based on this, the participative process in the integrated case study was performed following the general CLIM-RUN protocol trough five main phases:

1. Stakeholder identification;
2. Stakeholder analysis and selection;
3. First workshop;
4. Iterative Consultation;
5. Second workshop: delivering of climate services.

Preliminary phases allowed to identify and select the stakeholders which should take part in the participative process. Specifically a list of authorities and public offices involved in the Integrated Coastal Zone Management (ICZM) in the North Adriatic sea was identified and finally 40 offices were selected to participate to a first workshop organized in Venice on 13th of September 2011.
The main aim of the first workshop was to identify specific needs and requests of the stakeholders in terms of climate parameters, resolution and scale to be adopted in the development of climate impact and adaptation services (Giannini et al., 2011). A total of 20 offices from different sectors participated to the first workshop (the full list of participant can be found in Annex A) showing great interest for future involvement in activities and meetings with the climate and risk experts. Moreover, after the workshop a questionnaire was administrated to all the participants and 13/20 stakeholders fulfilled it. The workshop allowed to identify the perspectives that stakeholders have on climate services. Most of them described as essential the provision of observed climate and weather data and tools for analyzing climate data. Stakeholders asked for climate services for assessing impacts and vulnerability derived from climate change, developing adaptation strategies, education, and awareness rising within their professional field. Specific needs and requests to take into account in the climate change impacts and risk assessment were highlighted in the discussion. Specifically, stakeholders asked information on specific climate change impacts

including coastal flooding, coastal erosion, drought, salinization and water quality, hydrogeological disturbance (Figure A2, Annex A) .Great importance was given to the extreme events issue. All the stakeholders selected extreme climate/weather events (e.g., heavy rainfall, high temperature, heat waves, low temperature, drought, flood, hail) as the most important climate-related impact and specifically they required heavy rain forecasts as they are necessary for the development of effective early warning flood systems.

Moreover, for what concerns elements at risk stakeholders identified the coastal receptors that should be analysed with priority in climate change impacts, risks and vulnerability assessment studies: beaches, deltas and estuaries, wetlands, hydrological systems, agricultural areas, keystone species habitats, lakes, infrastructures for tertiary sector (Figure A3, Annex A).

Stakeholders also gave information about the scale and the resolution of the climate data they need. High resolution climate data with local/regional scale ranging from a medium (50 km) to a fine (1 km) scale were required by the majority of stakeholders (Figure A4, Annex A). All possible temporal resolutions were required (annual, seasonal, monthly, daily, sub-daily) (Figure A5, Annex A) while the time scale mainly required ranges from last 10 years to last 50+ years (Figure A6, Annex A). Looking at the time horizon stakeholders asked projections for the next 10 or 20 and by 30 to 50 years. Only few asked for projection over 50 years (Figure A7, Annex A).

The main result of the first workshop, describe as tables and statistics, can be found in Annex A.

As results of the discussion three thematic groups (Figure 2.4) were individuated as interesting for the development of climate impacts and adaptation services.

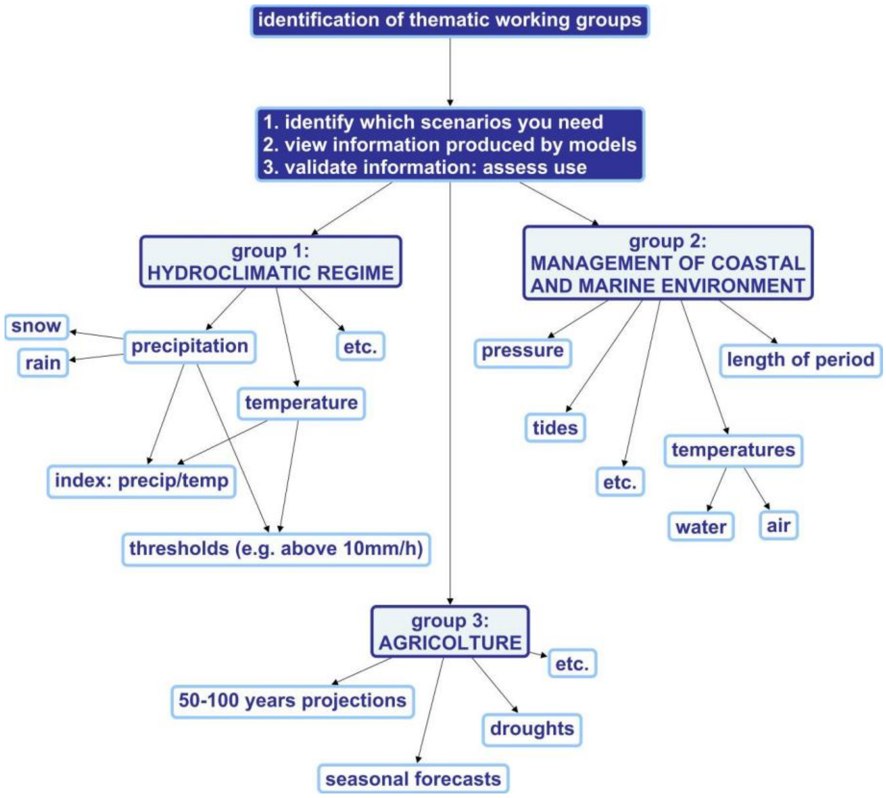


Figure 2.4 Thematic group (Giannini et al., 2011).

Based on the result of the previous consultation with stakeholders (i.e. first workshop, discussions, feedbacks, thematic groups) risk experts identified main sectors and critical climate variables for the North Adriatic and proposed preliminary climate risk services adopting the RRA approach.

Therefore, a second workshop was organized in Trieste on 28th May 2013 with the aim to present the preliminary climate risk services developed to the stakeholders and to evaluating the relevance of the analysis, simulations and tools produced to address user's needs, and to improve adaptation decision-making. All the participants of the First Workshop were invited but only 11 participate to the event (Figure C1, Annex C).The full list of participants can be found in Annex C. During the workshop the preliminary climate impact and risk services produced were presented by the climate risk expert team and discussed. Moreover, a questionnaire was proposed to collect stakeholders' feedbacks about the presented products and particularly about: testing areas for product's application; input data (i.e. receptors, vulnerability factors, dataset and timescale of the analysis); output data (i.e. typology of risk maps and statistics). Due to time constraints during the event, all the participants agreed to fulfill the questionnaire by e-mail after the workshop; however, only 5 out of 11 definitely fulfilled the questionnaire. The results of the questionnaire were considered by the risk expert team in the development of the RRA methodology for two impacts (i.e. pluvial flood and sea-level rise) and in the final production of climate risk services and products.

The original questionnaire developed for the pluvial flood impact can be found in Annex B while specific result can be found in Annex C. In general, stakeholders gave positive feedbacks about the proposed RRA methodology. Specifically, for what concern the pluvial flood risk assessment methodology risk experts suggested the municipality of Venice as a testing area and it was considered appropriate by the majority of stakeholders (Figure C2, Annex C), while 1 stakeholder was interested to include also urban and extra-urban areas of Udine and Pordenone (Friuli Venezia Giulia provinces). Moving to the exposure and vulnerability assessment, the majority of stakeholders considered the proposed receptors and vulnerability factors as appropriate for the analysis (Figure C3 e Figure C4, Annex C) and 1 stakeholder suggested a more detailed analysis of the slope influence on inundated areas. Finally, for the hazard assessment, the decade 2041-2050 was considered as appropriate time scale (Figure C5, Annex C), however 2 stakeholders suggested a more detailed analysis of the outputs (i.e. monthly, annual or seasonal number of events) (Figure C6, Annex C). Other general issues highlighted in the second workshop were the need of higher data resolution and the necessity of data and information on impacts and risk of climate change.

The results of the participative process involving the North Adriatic stakeholders were taken into consideration since the first step of the development of the RRA methodology for pluvial flood risk assessment which will be describe in Chapter 4.

Chapter 3 Description and characterization of the case study area

The Regional Risk Assessment (RRA) developed within this thesis was applied to the case study of the Municipality of Venice for the assessment of pluvial floods risks in urban areas. The municipality of Venice has been chosen following the request of the stakeholders which indicate this area as very sensible to floods due to heavy rain events. Numerous events of pluvial floods, in fact, have been registered in the past years, one of the most intense example was the one occurred on 26th September 2007 in Mestre which caused flooding of infrastructures and buildings with consequent traffic lines interruption and discomfort to people (Barbi et al., 2007).

In order to present the study area and to contextualize the relevance of pluvial floods issue, this chapter provides an overview of its main characteristics. Specifically, in Paragraph 3.1 the investigated area is described focusing on its geographic, administrative and socio-economic aspects highlighting the relevance of pluvial floods issue. Paragraph 3.2 describes input data available for the case study area including climate model outputs and GIS-based geographical data. All these information were used in the thesis for the construction of pluvial flood risk maps described in Chapter 5 following the methodology proposed in Chapter 4.

3.1 Description of the case study area

According to stakeholder needs, the case study area selected for the application of the pluvial flood risk assessment methodology is the municipality of Venice, which is the capital of the Veneto region in the North East coast of the Adriatic Sea. The study area is located in the Venetian Plane on the Northern part of the Venice Lagoon (Figure 3.1). The municipality of Venice have an overall extension of about 416 km^2 and a population of 226.856 inhabitants (ISTAT,2012) mainly concentrated around the two major urban areas of Mestre and Venice. It includes both island territories located within the Venice Lagoon, such as Venice historical centre, Lido, Burano, Murano, and mainland territories including Mestre and Marghera in which reside about 2/3 of total inhabitants of the entire municipality. Moreover, Venice is divided into six administrative districts: Venezia-Murano-Burano, Lido-Pellestrina, Favaro Veneto, Mestre-Carpenedo, Chirignago-Zelarino, Marghera.

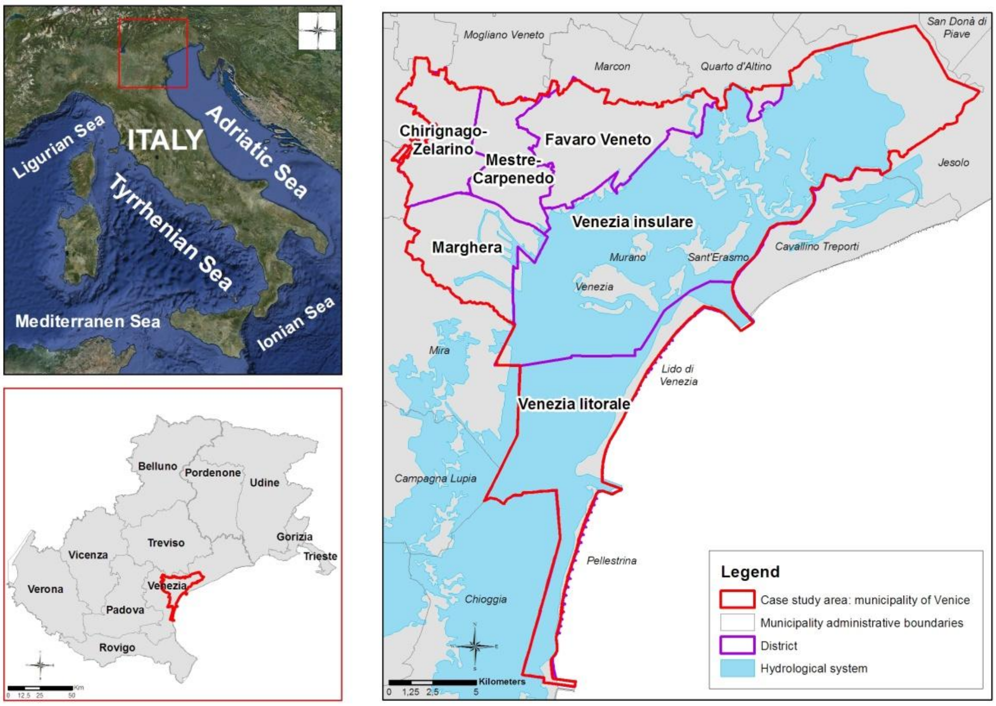


Figure 3.2 Case study area of the municipality of Venice

In the case study area numerous economic activities are located ranging from petrochemical industry in Mestre and Marghera districts to tourism, sea port activities, shipping and fishing in island territories such as Venice-Burano-Murano and Lido districts. The study area, especially with regard to urban centers of Mestre and Marghera, have a very high percentage of urbanization which started after the World War II (50s) when, following the development of the petrochemical plant of Porto Marghera, large numbers of people from the countryside and from Venice's historic center, moved to urban areas on the coast. In a few years Mestre, turned from a small village of 20,000 inhabitants in the 50s, into a city of about 200,000 inhabitants in the 70s (Municipality of Venice, 2013). The rapid development led a growing demand of residential spaces and infrastructure in a restricted coastal area which was built in absence of planning. Radical changes of entire areas of the city occurred with the conversion of green areas in to urban zones. The chemical industry crisis in the late 80s and 90s, along with the general reorganization of the great cities of northern Italy (e.g. Milan, Turin) have caused a considerable decline in residents due to emigration, but Mestre and its suburbs, with more than 200.000 inhabitants, remain one of the most urbanized cities counting more than 66% of the population of the entire municipality. Although in recent years many environmental restorations have occurred with the creation of green areas such as Via Bissuola Park, St. Giuliano Park and Mestre Wood, the study area has still numerous structural criticalities caused by the excessive urbanization and the inappropriateness of drainage and sewer systems.

These criticalities have become more visible in the past decade when, in conjunction with heavy rainfall concentrated in a short period, different urban areas have been flooded (e.g. Mestre, Chioggia). The most evident example for intensity and damages was the flooding event occurred in September 26th 2007 in the city center of Mestre (Figure 3.3) with 260 mm of precipitation in 24 hours (Barbi et al., 2007).

Figure 3.3 Pluvial flood event 26.09.2007 in Mestre via Costa and via Corridoni. Province of Venice, 2011.

Others many similar events have occurred from 2000 and 2009 in the study area as depicted in Figure 3.4 showing events of pluvial flooding caused by collapses of drainage systems occurred in the province of Venice (the study area is indicated by the red box).

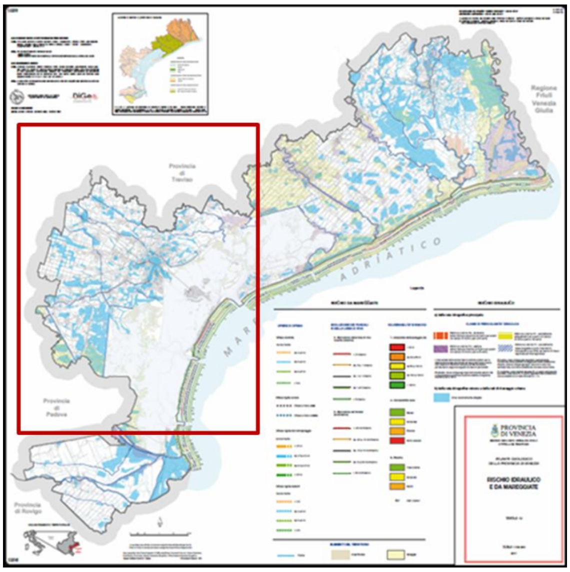


Figure 3.4 Recently Flooded areas map. Province of Venice, 2011.

According to Sartori (2012), these pluvial floods events can be attributed to extreme rainfall events which are increasing in the whole Veneto region. However, the social and structural components (e.g. percentage of urbanization, growing population and lack of appropriately localized and dimensioned drainage systems) play a crucial role in increasing the vulnerability to pluvial floods events reducing the soil absorption rate and increasing the water runoff (Huong, 2013). Therefore, the issue of pluvial floods is of particular relevance in the study area in which climate variability and socio-economic aspects can make this area more prone to the investigated issue in the future, also according to projected climate change scenarios.

3.2 Data used for the assessment pluvial flood impacts in the case study area

The application of the regional risk assessment methodology requires the definition of hazard scenarios and metrics related to climate changes and the collection of site-specific socio-economic and bio-geo-physical information to develop vulnerability indicators. Data used to represent potential hazard scenarios come from a regional climate model developed by ICTP within the CLIM-RUN project (Paragraph 3.2.1). Moreover, the subset of bio-geo-physical and socio-economic data used for the construction of vulnerability indicators is described in Paragraph 3.2.2.

3.2.1 Numerical model output

A Regional Risk Assessment (RRA) methodology needs high resolution data projections to represent potentially significant hazards that could affect receptors at the regional and local scale (Torresan, 2012). In this thesis, data provided by the Regional Climate Model (RegCM4) (Giorgi et al., 2012) developed by ICTP (*International Centre for Theoretical Physics)* were used for the construction of the pluvial hazard scenario.

The Regional Climate Models (RCMs) are obtained by downscaling or nesting techniques applied to Global Climate Models. These techniques consist in the use of initial, time-dependent lateral meteorological and surface boundary conditions to drive high-resolution RCMs. The driving data are derived from GCMs (or analyses of observations) and could include greenhouse gasses and aerosol forcing (Salomon et al., 2007). The main advantage of using a Regional Climate Model (RGM) instead of a Global Climate Model (GCM) is the optimization of computing resources with the possibility to increase the spatial resolution and the description of the interaction between atmospheric and surface; considering both air-sea interactions and interactions with the topography and the land use (Calmanti & Dall'Aquila, 2011).

The RegCM4 is derived from an evolution of previous version of the model the RegCM (Giorgi et all.2012) which was originally developed at the National Center for Atmospheric Research (NCAR) and actually is maintained in the Earth System Physics (ESP) section of the ICTP. The RegCM is the first limited area model which has been developed for long-term regional climate simulation. The model it has been used in numerous projects and applied to a wide range of regional studies related to climate change from different communities (Qian 2008, Quian et all. 2010). The mains advantages of the model are to be easy to use and flexible; accordingly, it can be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit) (Giorgi et al., 2012). The model applied allows to provide data on a wide range of climate variables including precipitations, evapotranspiration, temperature, winds measured with a time resolution of 3 hours for a time horizon going until 2100. The model allows to work at 12 km and 50 km spatial resolution; an example of the output of the model is represent by Figure 3.4 showing a 24 hours precipitation series registered for the 28th November2041.

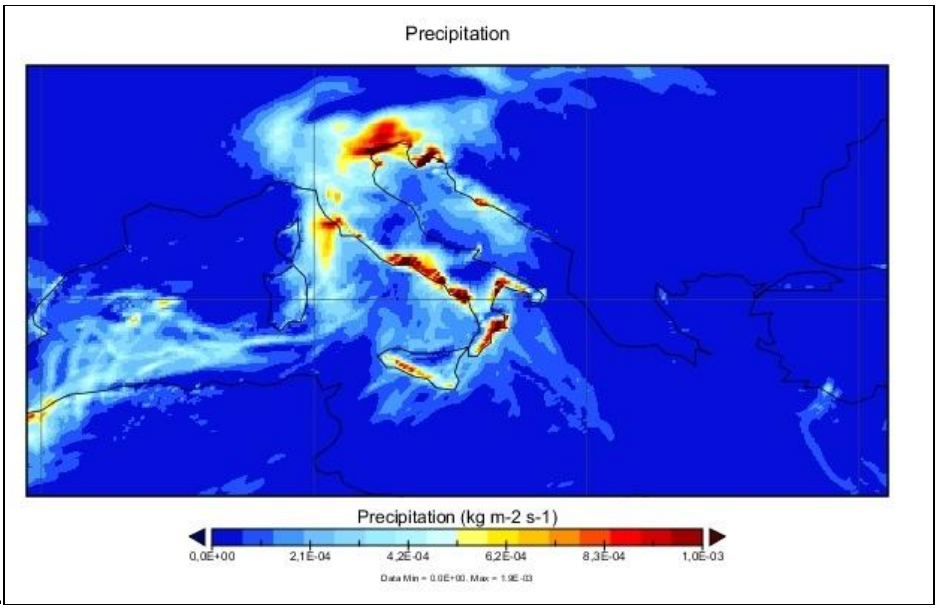


Figure 3.4 Output of RegCM4 model. ICTP, 2013.

The following Table (3.1) summarizes the main characteristics of the numerical model simulation produced at ICTP and used within this thesis for the characterization of climate change hazard scenarios.

Model	Project	Main variable provided	Spatial scale	Reference period	Time horizon	Forcing scenario
REGCM4	MED-CORDEX	Evapotranspiration Temperature Precipitation Wind Solar fluxes Soil moisture	12 km	1970-2005	2006-2100	RCP 8.5

Table 3.4 Main characteristic of the numerical model simulation available for the hazard scenario construction (ICTP,2013)

As shown in Table 4.1 the model is forced by the new IPCC scenario RCP8.5 (Representative concentrations Pathways 8.5) which provides the climate forcing in terms of atmospheric concentrations of greenhouse gases (GHGs). Representative Concentration Pathways (RCPs) adopted by IPCC (2013) for its Fifth Assessment Report (AR5) consist in a set of greenhouse gas concentration pathways designed to support research on impacts and potential policy responses to climate change (Moss et al. 2010; van Vuuren et al. 2011). The RCP 8.5 corresponds to the highest greenhouse gas concentration pathway compared to the total set of RCPs (Fisher et al. 2007; IPCC 2008). The RCP8.5 combines high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term, with absence of climate change policies, to an increasing energy demand and GHG concentration (Riahi et al., 2011). The greenhouse gas emissions and concentrations in this scenario increase considerably over time, leading to a radiative forcing of 8.5 W/m2 by the end the century. The RCP8.5 climate forcing represents the input for RCMs. The RegCM4 output, together with others site-specific information (Paragraph 3.2.2), will be used for the application of the RRA methodology to the case study area as will be describe in Chapter 5.

3.2.2 Data used for the assessment of the vulnerability

The assessment of pluvial floods impacts by means of regional risk assessment involves the collection of a large amount of bio-geo-physical and socio-economic data (e.g. slope, permeability, land use) in order to characterize the targets of the analysis (e.g. element at risk) and define the vulnerability factors to be analyzed in the exposure and vulnerability assessment. Therefore, in order to identify site-specific targets and indicators of vulnerability to pluvial floods impacts in the studied area available territorial and environmental data were investigated and collected. Available data were provided by various public institutions with different spatial resolution ranging from the regional scale to the local scale; they include a 5 m Digital Elevation Model and a land cover map supplied by Veneto Region, a permeability map and a recently flooded areas map extracted by the Geologic Atlas of the Province of Venice, administrative unit boundaries supplied by regional authorities and a municipal technical map provided by the Venice Municipality. Table 3.2 shows the available data used for exposure and vulnerability assessment in the Venice area, organized in the following fields: dataset, spatial domain and source.

Dataset	**Spatial Domain**	**Source**
Infrastructures map, 1:5000	Municipality of Venice	Municipality of Venice, 2008
Municipal tecnical map 1:5000	Municipality of Venice	Municipality of Venice, 2008
5 m Digital Elevation Model (DEM)	Veneto	Veneto, 2007
Permeability Map 1:100.000 extracted from Geologic Atlas of the Province of Venice	Province of Venice	Province of Venice, 2011
Recently flooded areas Map 1:100.000 extracted from Geologic Atlas of the Province of Venice	Province of Venice	Province of Venice, 2011
Land Cover Map for the Veneto region 1:10000	Veneto	Veneto, 2012
Administrative boundaries	Municipality of Venice	Municipality of Venice, 2011

Tabella 3.2 Dataset used for vulnerability and exposure assessment of the case study area (i.e. municipality of Venice)

For the assessment of pluvial flood vulnerability, it would be better to use higher spatial resolution and high vertical accuracy topographic datasets (i.e. high resolution data obtained by Light Detection and Ranging techniques (LIDAR). However, this was not feasible for the study area of concern, because of the lack of LIDAR data. Consequently, the present analysis was done using the most detailed digital topographic dataset available for the Municipality of Venice (i.e. DEM with a horizontal resolution of 5). With future improvements of available topographic data, a revised estimation of the potential impacts of pluvial floods would be possible and necessary. The available datasets will be used in Chapter 4 for the application of the pluvial floods methodology to the case study area.

Chapter 4 Regional Risk Assessment methodology for the assessment and prioritization of pluvial floods risk in urban areas

The RRA methodology developed within this thesis aims to assess the risk of flood caused by heavy precipitation events in urban areas. Specifically, the objective of the methodology is the individuation and prioritization of urban areas which are likely to be affected by pluvial floods more severely than others in the analysed region, in relation with future climate change scenarios. The final results allow relative classifications of risk that are easily communicated to non-expert users and stakeholders in order to set priorities for the implementation of adaptation options.

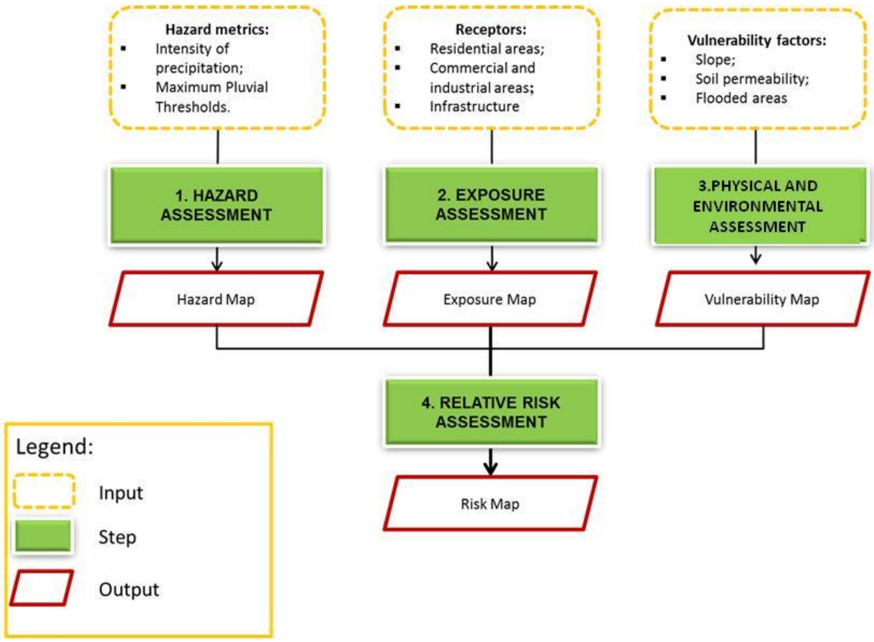


Figure 4.1. Methodological framework for the RRA for pluvial flood impact.

Accordingly, the RRA methodology for the pluvial flood assessment includes 4 main steps:

– Hazard assessment;

– Exposure assessment;

– Bio-physical and environmental vulnerability assessment;

– Relative risk assessment.

The first step (hazard assessment) is aimed at identifying pluvial flood metrics (e.g. intensity, duration, frequency of precipitation) coming from regional climate models and useful to construct climate change hazard scenarios according to different timeframes (e.g. medium or long term scenarios) and emission scenarios (e.g.RCP8.5, RCP4.5).The exposure assessment step is aimed at identifying and selecting the receptors (i.e. elements at risk) that can be affected by potential losses in flooded zones. This step requires the analysis of land use/land cover datasets for the localization of people, environmental resources, infrastructures, social, economic or cultural assets that could be adversely affected by a pluvial flood event. After the selection of the receptors, the physical and environmental vulnerability assessment is aimed at evaluating the degree to which the receptors could be affected by a pluvial flood hazard based on physical/environmental site-specific information (e.g. slope, permeability, drainage system characteristics).

Finally, the relative risk assessment step is aimed at identifying and classifying areas, receptors and hotspots at risk in each case study. This phase combines the information about pluvial flood hazard scenarios with exposure and physical and environmental vulnerability of the examined receptors trough Multi Criteria Decision Analysis (MCDA) which provides a relative classification about areas and targets that are likely to be affected by pluvial floods more severely than others in the same region.

The steps of the RRA methodology applied to the study area will be described in detail in the following paragraphs while the outputs and results of the application of the methodology to the case study area will be described in Chapter 5.

4.1 Hazard Assessment

The first step of the RRA is the hazard assessment that is aimed at identify and prioritize areas that will be affected by pluvial flood events in relation with precipitation scenarios for the 2041-2050 period. For this purpose it is necessary to identify hazard stressors and metrics (e.g. intensity and duration of precipitations) related to pluvial flood events and to define pluvial flood hazard scenarios taking into account the effects of climate change in the hydro-climatic regime. The definition of hazard scenarios requires the identification of those stressors that can contribute to determine pluvial floods. In fact, each natural hazard is caused by one or more stressors that can be defined as the cause of environmental hazard impacting large geographic areas (Hunsaker et al., 1990). Each stressor can be characterized by one or more metrics that are quantitative measures of climate variables deriving from statistical analysis of past measurement of weather, models based on observed data or forecasts derived from numerical models (UKCIP, 2003). According to Abhas K Jha (2011), three main hazard metrics should be considered for pluvial flood impacts: intensity, duration and frequency of precipitation. Furthermore, according to the IPCC (2012), the intensity and the frequency are the parameters of a rainfall which are likely to be altered in future by climate change and therefore are essential metrics to take into consideration for the study of climate change impacts on pluvial flood events. However, the daily intensity of precipitation is used for the characterization of extreme rainfalls events and it is crucial in the design of storm water management structures avoiding pluvial floods (Haan, 2002). Accordingly, for the case study the intensity was considered the most relevant hazard metric for the hazard assessment phase (Table 4.1). The intensity (mm/h or mm/day) represents the volume of precipitation falls over the time in a specific area. This parameter was provided as output of the RegCM4 model (Chapter 3) with 13 grid cells of 12 km and in the temporal period 2041-2050. The temporal period was chosen considering a compromise between the stakeholder's requests (Annex A) asking for a short term period of analysis (i.e. 20, 30, 50 years) and the significant period in which the climate change signal is observed.

Climate Change Impacts	Stressor	Hazard metrics
Pluvial Food	Precipitations	Precipitation (mm/day)

Table 4.5. Hazard metrics for the pluvial flood hazard assessment.

After the identification of the hazard stressors and metrics, the hazard scenario construction was performed with the aim to produce an hazard map showing the number of potential emergencies in the 2041-2050 timeframe. The number of potential emergencies was identified comparing future precipitation scenarios with Maximum Pluvial Thresholds (MPT) for the case study area following the procedure proposed by ARPA (2004) in the early warning pluvial flood system.
The MPT identifies the critical values of precipitation over which negative effects to the systems are expected (e.g. traffic line interruptions, flash floods due to failure of the drainage system). The MPT is representative of each geographical site (e.g. warning areas) as it depends on bio-physical characteristics such as the soil permeability and saturation, slope and capacity of the drainage system and can be define on the basis of historical events occurred in the same area.

In a Cartesian plane (P, d), in which P represents the cumulative precipitation and d the duration of the pluvial event, the MPT are represented as a curve which delineates two possible states: the situation above the curve can be considered potentially critical, below the curve the pluvial event does not have the characteristics to trigger a state of emergency (ARPA, 2004). Figure 4.2 provides an example of three different MPTs above which ordinary, moderate and elevate flood emergency state is defined respectively.

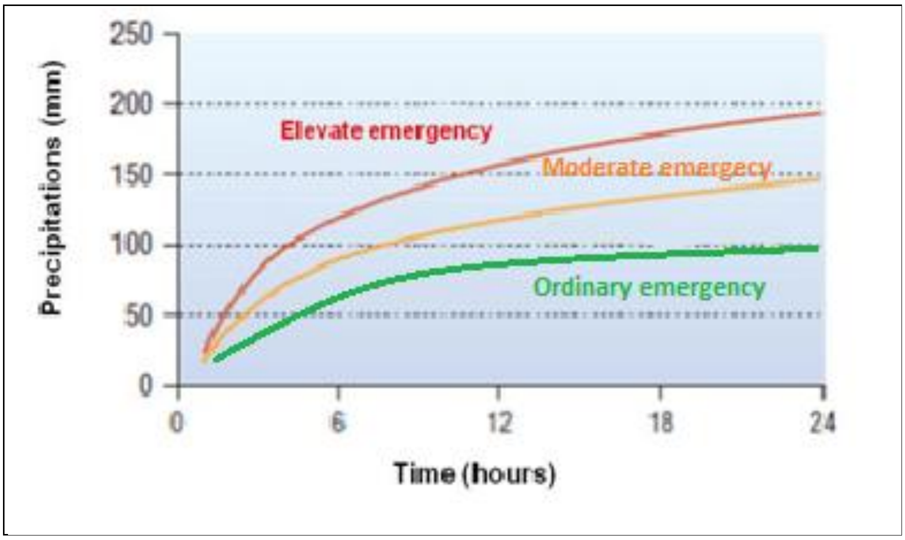


Figura 4.6 Examples of Maximum Pluvial Thresholds. ARPA, 2004.

The ordinary emergency is caused by hydraulic phenomena which involved the secondary hydraulic system (i.e. drainage and sewage system) causing difficulties in the water drainage with consequent localized flooding of infrastructures, urban surface and discomfort to people (Civil Protection, 2007). Moderate and elevate emergency are mainly related with the principal hydrographic system (i.e. rivers and other water streams) causing, respectively, limited and extended floods with damage to residential and commercial building, infrastructures, agricultural areas and people (Civil Protection, 2007). Therefore according to the Civil Protection (2007) in the present research only the ordinary emergency threshold is considered as it is related with pluvial floods events. The total daily precipitation for the 2041-2050 period in the case study area was identified using the output of the RegCM4 model elaborated trough a software which provides the total daily precipitations for the center point of each cell of the model grid (Figure 4.3). The center point is defined by some geographical attributes (i.e. longitude, latitude).

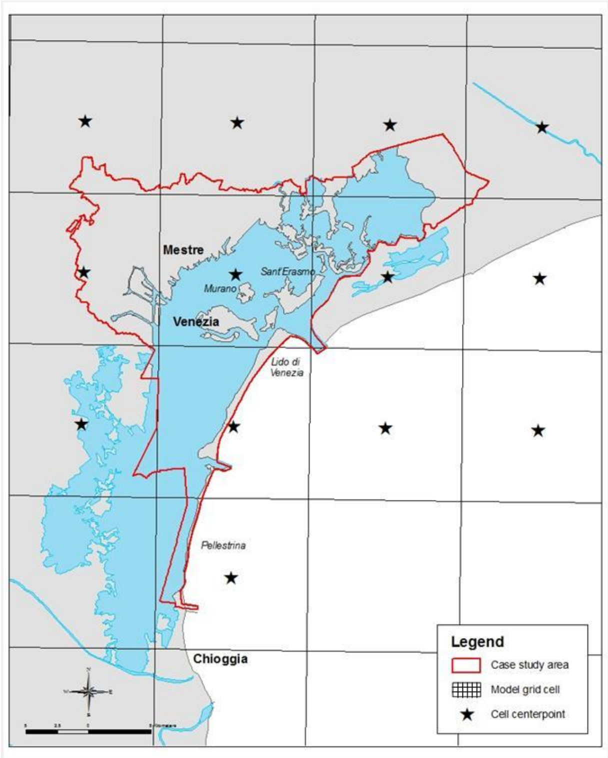


Figure 4.7 Center point of each model grid cell of the study area

According to ARPA (2004), the cumulative precipitation of each of the 15th days before the pluvial flood event was calculated as the sum of the precipitation of the day and the cumulative precipitation of the previous day as explained in Box 1.

Box 1 Calculation of the cumulative precipitation.

Cumulative precipitation day 1 (Cp1)= precipitations day 1;

Cumulative precipitation day 2 (Cp2)=Cp1 + precipitations day 2;

…;

Cumulative precipitation day 15 (Cp3)=Cp3 + precipitations day 15.

Therefore, the cumulative precipitations calculated for each of the consecutive 15 days (i.e. Cp1, Cp2, …, Cp15) were compared with the correspondent soil humidity threshold proposed in Table 4.4 using a software developed in R environment in order to identify the state of the soil (i.e. wet or dry).

Humidity thresholds															
Day	**Hp1**	**Hp2**	**Hp3**	**Hp4**	**Hp5**	**Hp6**	**Hp7**	**Hp8**	**Hp9**	**Hp10**	**Hp11**	**Hp12**	**Hp13**	**Hp14**	**Hp15**
mm	84	98	107	114	120	124	129	133	136	139	142	145	147	150	152

Table 4.4 Soil humidity thresholds (Civil Protection, 2007)

According to ARPA procedure (2004), if just one of the 15 cumulated values calculated in any center point of the model grid cell within the case study area exceeds the correspondent soil humidity threshold, the soil was considered wet in all the study area, while if it does not occur the soil was considered dry in the whole area. This procedure was done for each center point associated to the selected grid cells of the climate model providing precipitation scenarios for the 2041-2050 period in the study area. Once the state of the soil was identified, following the procedure proposed by the ARPA (2004), the appropriate ordinary Maximum Pluvial Threshold (MPT) for the selected area was chosen. The ordinary MPTs for the case study area were chosen according to Civil Protection (2007) and are listed in Table 4.5.

	DRY	**WET**
Maximum Pluvial threshold	76,0 (mm)	58,4 (mm)

Table 4.5 Maximum Pluvial Threshold (Civil Protection, 2007).

Each pluvial event expected in the analysed future scenario was compared with the appropriate ordinary MPT (Table 4.5) using the aforementioned software. The software allows to evaluate the threshold that should be used for each pluvial event, applying the analysis of the soil state and to evaluate if the pluvial event exceeds the ordinary MPT or not. The output indicates the number of events of ordinary emergency in the 2041-2050 for each day and geographical site (i.e. center point associated with each model grid cell). The number of ordinary emergency events was normalized, dividing the total number of events by the maximum number of events obtaining a score from 0 to 1, in order to allow the integration process of the hazard scores in the relative risk assessment step. Specifically, 0 represented the class with no emergency events where the hazard is considered null, while 1 represent the class with higher number of emergency events in the study area. Intermediate values were assigned to intermediate hazard classes using the Natural

Breaks classification method (Zald et al., 2006), which allows to reduce the variance within classes and maximizing the variance between classes. The normalized values (number of emergencies) associated with each center point of the model grid was interpolated applying an Inverse Distance Weighted (IDW) technique in order to obtain an hazard map with a spatial resolution comparable with the spatial resolution used for exposure and vulnerability assessment (i.e. 5m). The resulting flood hazard maps represent the spatial distribution of areas potentially exposed to ordinary hydraulic emergency events under climate change scenarios.

4.2 Exposure Assessment

The second step of the RRA Methodology is the exposure assessment which is aimed to identify, select and localize receptors (i.e. elements potentially at risk) that could potentially be in contact with the pluvial floods hazard and be exposed to losses in flooded zones. Receptors can be chosen in relation with the objectives of the study, the spatial scale and the available dataset. In the municipality of Venice three receptors were identified as presented in Table 4.6: residential areas, commercial and industrial areas, infrastructures. However other relevant receptors could be considered for pluvial floods in urban areas such as people, agriculture, natural systems (e.g. natural or protected areas), cultural elements (e.g. historic site or buildings), according to stakeholder needs.

Receptor	Description
Residential areas	This receptor includes continuous or discontinuous urban fabric made by residential buildings, urban centre types and dense ancient suburbs, roads and artificially surfaced areas associated with vegetated areas and bare soils which occupy more than 80% of surface area. It includes also green spaces, parking areas, adventure playgrounds and public utilities http://sia.eionet.europa.eu/CLC2000/classes. This receptor is high sensible to pluvial floods impacts being highly permeable (80 % of the total surface is impermeable) and being characterized by a high population density.
Commercial and industrial areas	The receptor includes artificially surfaced areas (e.g. cement, asphalt) mainly related with commercial and industrial functions which can also contains building or vegetation. It includes large shopping centers, agricultural, energy plants, military barracks, biological waste water treatment plants, abandoned industrial sites and by-products of industrial activities where buildings are still present. In the receptor are also comprise: port and its infrastructures, including quays, dockyards and marinas, airports including runways, buildings and associating lands and train stations http://sia.eionet.europa.eu/CLC2000/classes. These receptor is important because are areas where the majority of economic activities are located.
Infrastructures	The receptor includes roads, motorways and railways, including associated installations (stations, platforms, embankments) (Büttner et al., 2006) . Infrastructure are highly vulnerable to pluvial flood events due to the low permeability of theirs surfaces which increase the water runoff

Table 6.6 Definition of receptors considered for the municipality of Venice.

In order to keep the highest feasible detail, according to the available dataset, the exposure assessment was based on spatial units (i.e. grid cells) of 5 m. In the exposure assessment an exposure score equal to 1 was assigned to cells where the receptor is located and equal to 0 in case of absence of the receptor. The main output of this step is the exposure map (Paragraph 5.2) showing the presence and the localization of elements potentially at risk from pluvial floods.

4.3 Physical and environmental vulnerability assessment

The physical and environmental vulnerability assessment aims to evaluate the degree to which a specific receptor could be affected by a pluvial flood hazard based on physical and environmental site-specific information (e.g. land use, slope, soil type, percentage of urbanization) (Gallina et al., 2013). Accordingly, this step does not consider the analysis of aspects related to the human dimension of vulnerability (i.e. adaptive and coping capacity (IPCC, 2007)).

Vulnerability factors are represented by physical and ecological indicators which can influence the vulnerability of a receptor to pluvial flood impacts. Vulnerability factors applied in the methodology for each of the three receptors (i.e. residential areas, commercial and industrial areas, infrastructures) are described in Table 4.7 and were selected based on the dataset available for the case study area (Paragraph 3.2.2). Moreover, vulnerability factors proposed were presented and discussed with stakeholders during the second CLIM-RUN workshop (Annex C).

Vulnerability factor	**Definition**	**Data source**
Slope (degree)	Average topographic slope of the land.	5 m Digital Elevation Model (DEM) provided by Veneto Region, 2007.
Soil permeability	Soil permeability due both to geological characteristics and land use (urbanized areas)	Permeability Map 1:100.000 extracted from Geologic Atlas of the Province of Venice provided by the Province of Venice, 2011.
Flooded areas	Areas where in recent years have occurred floods due to heavy precipitations and consequent overflowing of the sewage and drainage systems .	Recently flooded areas Map 1:100.000 extracted from Geologic Atlas of the Province of Venice provided by the Province of Venice, 2011.

Table 4.7 Vulnerability factors for the municipality of Venice.

Once vulnerability factors were identified, they were classified and scored according to Table 4.8, in order to allow the process of integration of vulnerability scores (ranging from 0 to 1) in the relative risk estimate and provide a ranking of areas more sensitive to pluvial floods.

Factor	Class		Score
Slope (degrees)	0°-2.7°		0,8
	2.7°-10.4°		0,4
	10.4°-49.2°		0,2
Soil permeability	Areas occupied by building and infrastructure (Impermeable)		1
	Stratified clays	$<10e^{-8}$	0,8
	Mixture of sand, silts and clay	$10e^{-8}$ - $10e^{-7}$	0,6
	Sands with silts	$10e^{-7}$ - $10e^{-6}$	0,4
	Very fine sands	$10e^{-6}$ - $10e^{-5}$	0,3
	Clear sands and gravel	$>10e^{-5}$ (permeable)	0,2
Flooded areas	Not flooded areas		0
	Flooded areas		0,8

Table 4.8 Classes, score and weight associated with vulnerability factors in the municipality of Venice.

In fact, the definition of classes and scores allows the normalization of physical and environmental vulnerability factors that is a necessary step for the application of MCDA functions for the aggregation of risk factors.

Classes and scores were assigned involving a team of environmental risk experts of the CLIM-RUN Project, following the linguistic evaluations reported in Table 4.9.

Linguistic Evaluation	Scores
Most important class	1
Weakly less important class	0.8
Rather less important class	0.6
Strongly less important class	0.4
Demonstratively less important class	0.2
Absolutely less important class	0

Table 4.9 Linguistic evaluation supporting the expert in the assignation of relative scores to vulnerability classes

As shown in Table 4.8 the slope factor was subdivided in classes using the Natural breaks classification method (Zald et al., 2006), which allows to reduce the variance within classes and maximizing the variance between classes. Plan lands are more susceptible to pluvial floods due increasing water stagnation (Preston et al., 2008) therefore the higher vulnerability score was assigned to lower slope values (i.e. 0°-2.7°) while the lower score was assigned to steeper lands (i.e. 10.4°-49.2°).

Moreover, permeability classes were identified base on of the permeability map of the province of Venice extracted by the geological atlas of the Province of Venice (Province of Venice, 2011). Specifically, the vulnerability to pluvial floods increases if the soil is characterized by low permeability (Abhas et al.,2012; Pan,2012) therefore the higher score was assigned to the lower permeable areas (areas occupied by building and infrastructure) while the lower score was assigned to area characterized by the presence of clear sands and gravel which are highly permeable. Intermediate scores were assigned to intermediate permeability classes (i.e. sand with silts, very fine sands).

Finally, areas were pluvial floods have occurred in the past, were considered more susceptible because it is assumed that these areas are more likely to be affected by the same events in the future (Cheong et al.,2013). Therefore, the higher score were assigned to recently flooded area while score were assigned to not flooded area class.

After the normalization, vulnerability factors were aggregated through a Multi-Criteria Decision Analysis (MCDA) function named "probabilistic or" (Kalbfleisch J. G., 1985), in order to provide a single normalized score of physical and environmental vulnerability for each cell of the study area following the Equation 1

$$V_{pe} = \quad \otimes_{i}^{n} [vf_i] \qquad \text{Equation 1}$$

where:

V_{pe}= physical and environmental vulnerability score associated to the cell for the pluvial flood;

$\otimes$= "probabilistic or" function;

Vf_i = i^{th} physical and environmental vulnerability factor score (already classified in [0,1]).

In detail, the "probabilistic or" operator can be evaluated, due to the associative and commutative proprieties, as explained in the following example where it is applied to 4 vulnerability factors:

$$\otimes_{i=1}^{4} [f_i] = f_1 \otimes f_2 \otimes f_3 \otimes f_4$$

$$f_1 \otimes f_2 = f_1 + f_2 - f_1 \; f_2 = F_1$$

$F_1 \otimes f_3 = F_1 + f_3 - F_1 f_3 = F_2$
$F_2 \otimes f_4 = F_2 + f_4 - F_2 f_4 = \otimes_{i=1}^{4}[f_i]$

Since the vulnerability factors are the same for each receptor (i.e. residential areas, commercial and industrial areas, infrastructures) (Table 4.7) the applied vulnerability function is the same for all the cells of the case study area.

Vulnerability score vary in a range from 0 (i.e. minimum vulnerability) to 1 (i.e. maximum vulnerability). Applying the “probabilistic or” function (Equation 8), if just a vulnerability factor (vf) assumes the maximum value (i.e. 1) then the vulnerability score will be 1. On the other side, different vf with lower scores contribute in increasing the final vulnerability score: the more is the number of low vulnerability factor scores, the greater is the final vulnerability (Gallina et al, 2013).

The results of the physical and environmental vulnerability assessment applied for each receptor of the case study area are described in Paragraph 5.3. Vulnerability maps can be used by stakeholders and decision makers in the choice of the localization of adaptation strategies (e.g. improvement of drainage and storage water system, creation of green areas with higher permeability) aimed at increase the resilience of the urban areas to pluvial floods events.

4.4 Relative Risk Assessment

The last step of the RRA Methodology is the Risk assessment which is aimed to integrate information about the pluvial flood hazard of a given climate change scenario, with the territorial exposure and vulnerability assessments in order to identify and prioritize receptors and areas at risk of flooding in the case study area.

Risk scores are not absolute predictions about the risks related to flood. Rather they provide relative classifications about areas and targets that are likely to be affected by pluvial floods more severely than others in the same region.

The risk is calculated as the product between hazard, exposure (i.e. element at risk) and physical and environmental vulnerability. The general function for the estimation of the pluvial flood risk (R) follows Equation 2:

R= H x E x Vpe Equation 2

where:

R= pluvial flood related risk;

H= hazard score;

E= exposure score (i.e. in presence of element at risk is equal to 1, in absence of element at risk is equal to 0);

Vpe= physical and environmental vulnerability score, calculated according to Equation 1

Risk score varies from 0 to 1, in which 0 means that in the area the risk is null (i.e. there is no hazard or no physical and environmental vulnerability) and 1 means maximum risk for the considered target/area in the considered region. The risk assessment allows to produce risk maps showing the areas affected by different risk classes in the case study for each receptor. Risk maps produced through the application of the methodology to the municipality of Venice will be presented in Paragraphs 5.4. These maps identify areas that will be affected by pluvial flood events and provide a support for decision makers to establish relative priorities for intervention and to identify suitable areas for infrastructure, economic activities and human settlements.

Chapter 5 Results and discussion

The results of the RRA procedure described in Chapter 4 were classified and processed in GIS in order to obtain maps representing the spatial variability of hazard, exposure, vulnerability and risk for pluvial flood impacts in the considered case study. Moreover, through GIS tools, several statistics (e.g. percentage and surface of each receptor associated to each hazard, vulnerability, risk class, percentage and surface of receptors at risk for each administrative unit) were calculated in order to synthesize relevant information coming from the RRA outputs. All these outputs represent suitable climate risk services useful for stakeholders to establish relative priorities for intervention, to identify suitable area for human settlements, infrastructures and economic activities and provide a basis for land use planning. Resulting maps and statistics from the application to the case study area will be presented and discussed in the following paragraphs. Specifically, paragraph 5.1 aims at present the hazard map produced to localize hazard metrics in the study area; paragraph 5.2 is aimed at describe the exposure map showing the localization of the receptors which can be subject to loss due to pluvial flood events; paragraph 5.3 presents vulnerability maps and the related statistics produced for each considered receptor; finally, paragraph 5.4 describe the risk maps obtained from the aggregation of hazard, exposure and vulnerability maps which allow to identify and prioritize areas at risk from pluvial floods impact in the study area.

5.1 Hazard map

The hazard map, representing the number of potential pluvial floods emergency in the 2041-2050 period, results from the aggregation of hazard metrics (i.e. precipitation projections calculated from the RegCM4 model for the 2041-2050 timeframe according to RCP8.5 scenario) and maximum ordinary pluvial thresholds (MPT) described in paragraph 4.1.1. Figure 5.1 shows the hazard map for the municipality of Venice and allows to identify the numbers of potential ordinary hydraulic emergencies in the different grid cells of the case study area.

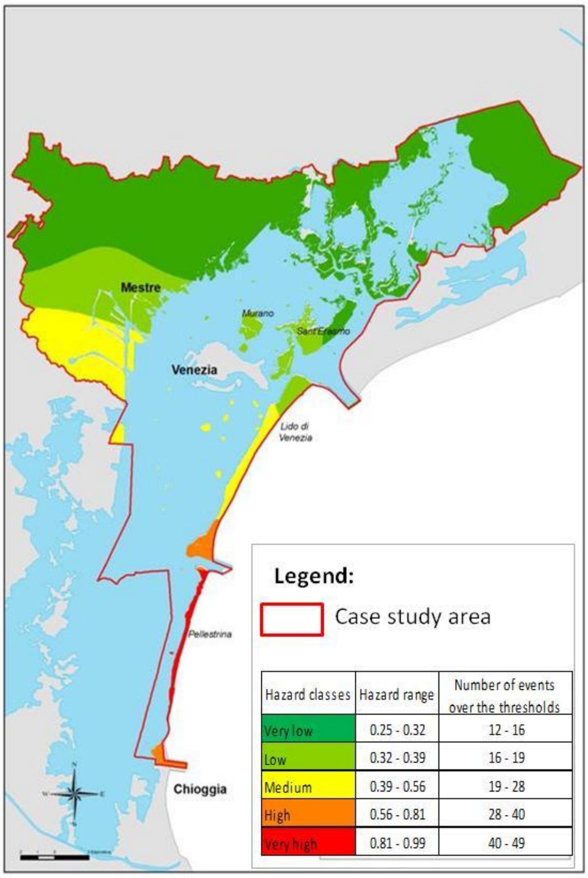


Figure 5.8 Hazard map for pluvial flood impact in the municipality of Venice.

Hazard classes represented in the hazard map were obtained using the Natural breaks classification method. The Natural breaks method (Zald et. Al., 2006) is designed to determine the best arrangement of values into different classes. The main aim of the method is to reduce the variance within classes and maximize the variance between classes and was used in order to obtain a clear visualization.

The hazard map (Figure 5.1) shows that all the territory is interested by potential ordinary emergencies and that the hazard increases moving from north to south-east: higher hazard classes are located in Pellestrina with a number of potential emergencies ranging from 40 to 49 in the 2041-2050 period while decreasing classes are located in the area of Mestre - Carpenedo where the number of potential emergencies ranges from 12 to 19.

Based on the hazard map, a statistic was calculated representing the total number of potential ordinary emergency in each cell of the case study area for each month of the 2041-2050 decade. Figure 5.2 shows the total distribution of the potential emergency for each months and highlights that the higher number of emergencies is concentrated in autumn with a maximum peak in October (70 potential emergencies). In the other months the hazard is homogeneously distributed with emergencies ranging from 7 to 19 with the exception of July where no emergencies occur.

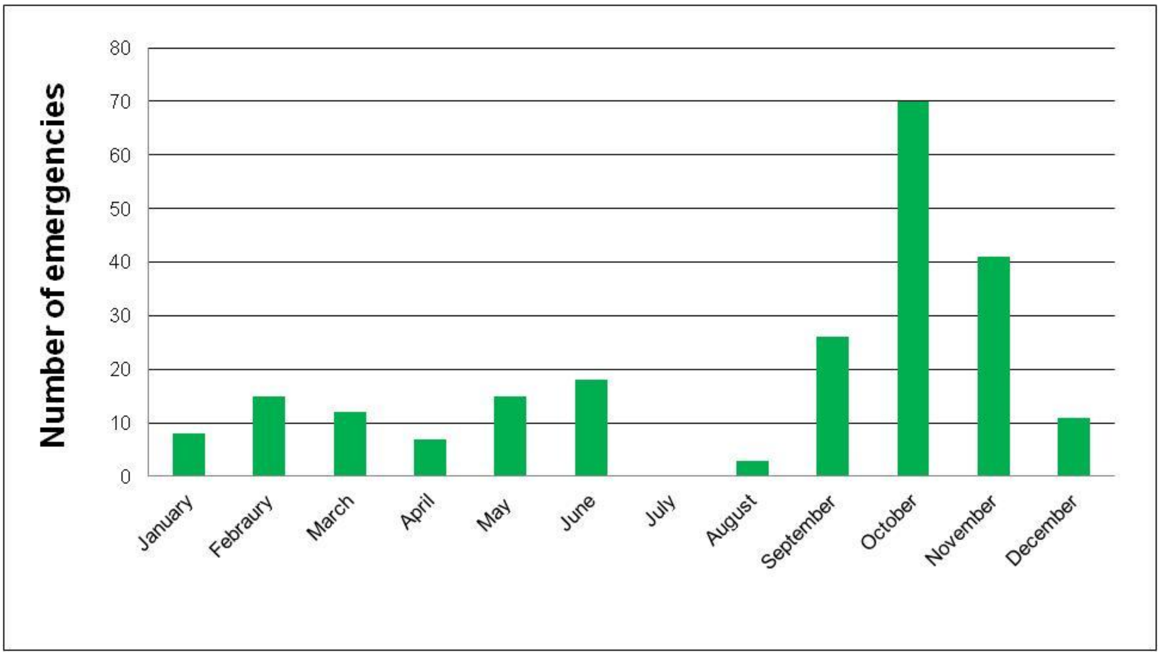


Figure 5.9 Total number of potential ordinary emergency in each cell of the case study area for each month of the 2041-2050 decade .

5.2 Exposure map

The exposure map identifies and localizes the receptors (i.e. element at risk) that can be subject to potential losses in the case study area due to pluvial floods events. Figure 5.3 presents the exposure map produced for the municipality of Venice considering residential areas (red spots), commercial and industrial areas (violet spots) and infrastructures (grey segments) as receptors. Figure 5.3 highlights that the residential areas and infrastructure are spread on all the territory of the case study with an higher density in Mestre, Marghera and Lido. Whereas, commercial and industrial areas are mainly localized in correspondence of the industrial plane of Porto Marghera and in the north-east part of the case study area in correspondence of the Marco Polo airport. The zoom highlights the merging of the three receptors and specifically the localization of the most important infrastructures in the city of Mestre.

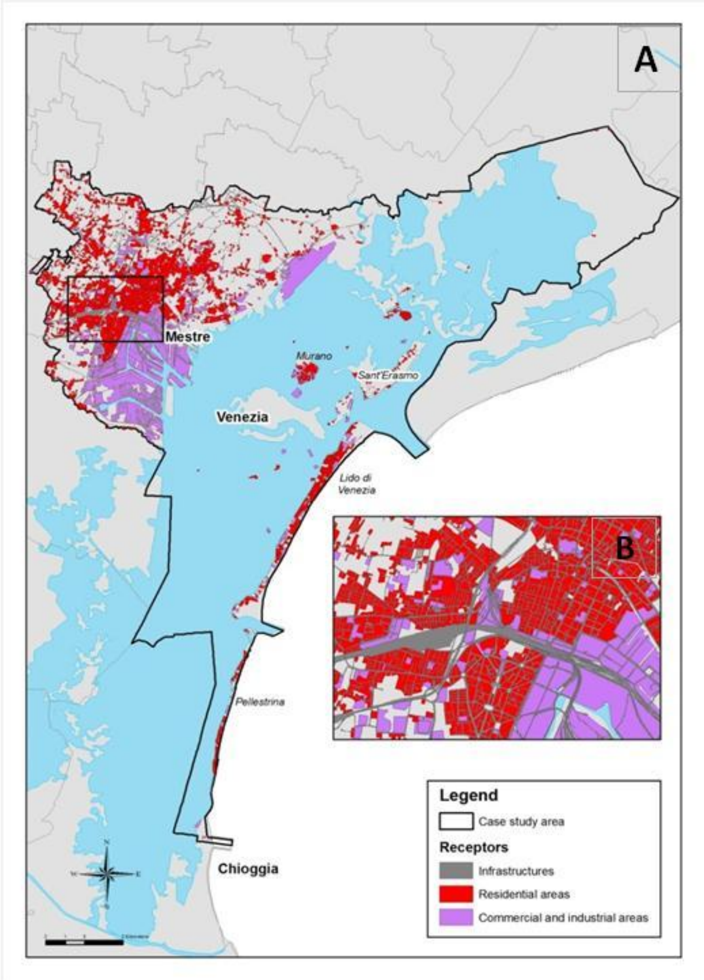


Figure 5.10 Exposure map for infrastructures, residential an commercial-industrial areas for the case study area (A) and for the area around Mestre (B)

5.3 Vulnerability maps

Vulnerability maps represent the spatial distribution of physical and environmental vulnerability factors (e.g. slope, permeability) and are derived from the aggregation of vulnerability factors for each analysed receptor according to Equation 1 (Paragraph 4.1.3). Vulnerability scores were classified using the Natural breaks classification method obtaining the vulnerability scores represented in the vulnerability maps. Figure 5.4 show the distribution of the vulnerability of residential areas within the municipality of Venice. Figure 5.4 shows that areas with higher vulnerability scores (very high, high, intermediate vulnerability classes) are located in the northern part of municipality of Venice while the low and very low vulnerability classes are located only in littoral areas in the south-east of the study area.

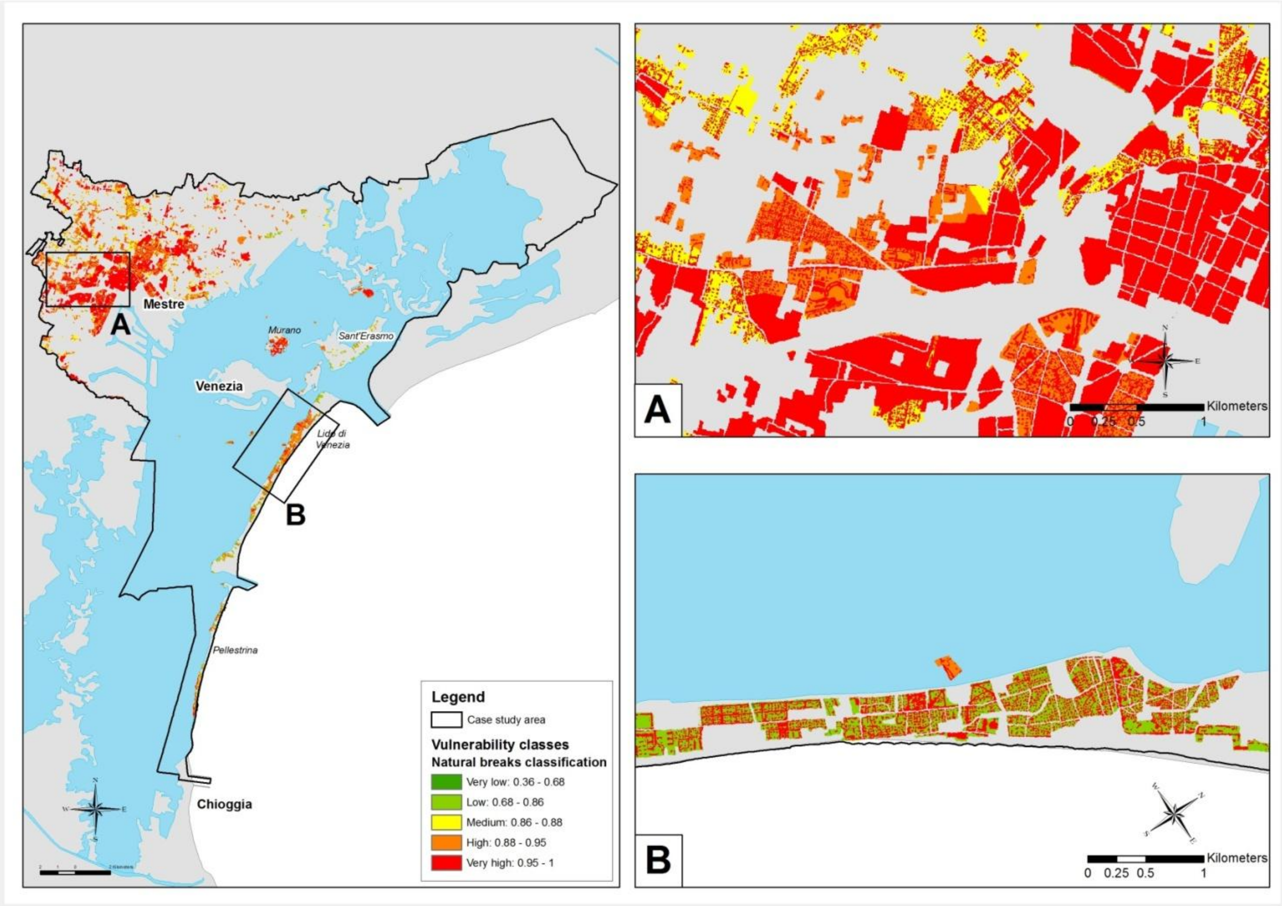


Figure 5.11 Vulnerability map of residential area for pluvial flood impact in the municipality of Venice.

Specifically, Figure 5.4A show that areas with the higher vulnerability scores are Mestre and Chirignago areas due to the high density of urbanization which confers low permeability to the soil. Another factor that increases the vulnerability is the occurrence of past pluvial flood events in these areas. However, in these areas also high and medium vulnerability classes are represented associated with moderate permeability soils (i.e. sand with silts, mixture of sand,silt and clay) with intermediate vulnerability scores (i.e. 0.4. 0.6).

Lido and Pellestrina (Figure 5.4B) are mainly associated with lower vulnerability classes due to the presence of soil with moderate permeability (i.e. sand with silts and very fine sands) associated with lower vulnerability score (i.e. 0.3, 0.4) however, also in this areas higher vulnerability classes are located in correspondence with buildings which have the higher vulnerability scores (i.e. 1) being totally impermeable. Moving to the second receptor, Figure 5.5 shows the vulnerability associated with commercial and industrial areas within the case study area.

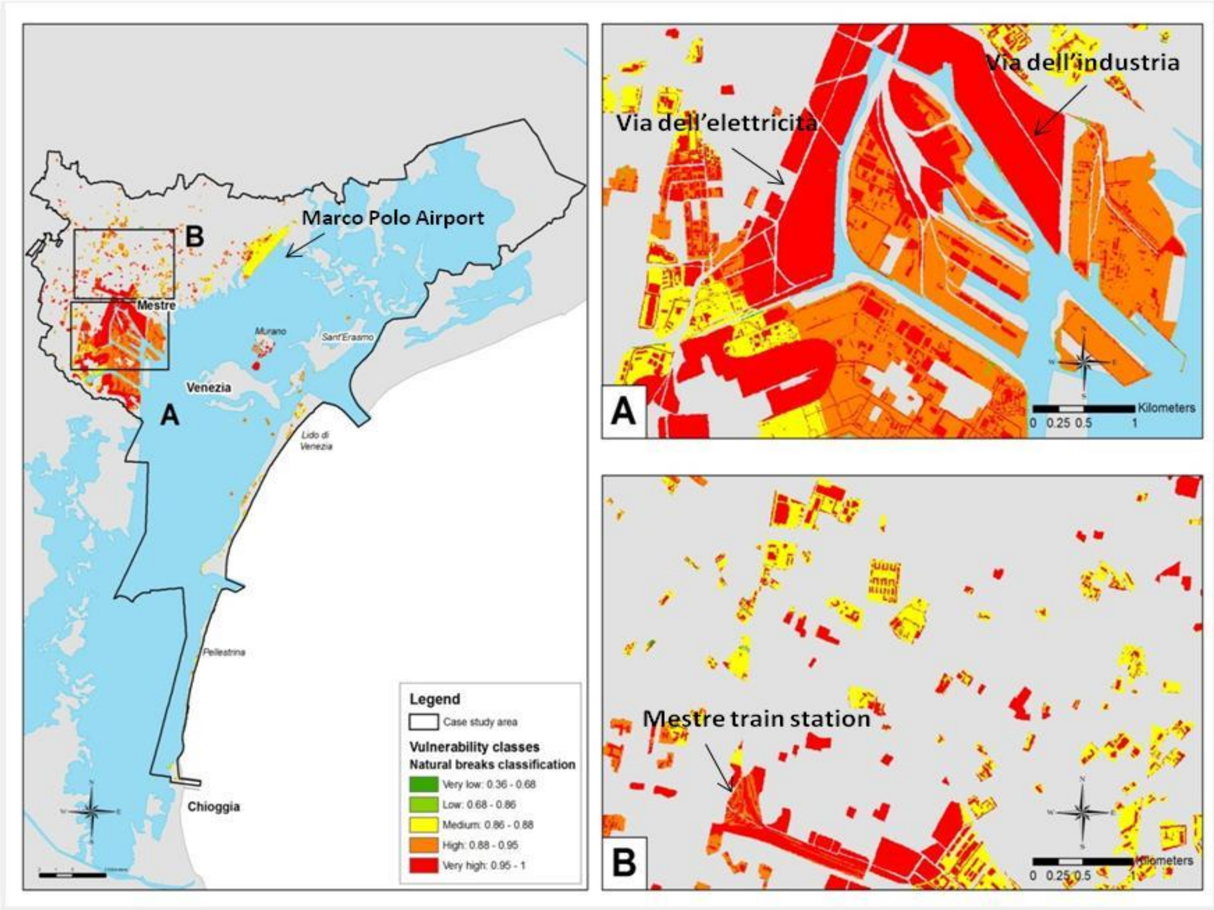


Figure 5.12 Vulnerability map of commercial and industrial areas for pluvial flood impact in the municipality of Venice.

Figure 5.5 shows that higher vulnerability classes (i.e. very high and high) are mainly located in the north-west of the case study area while lower vulnerability classes (i.e. low and very low) are not represented. Specifically, Figure 5.5A highlights the industrial area of Porto Marghera which is interested by higher vulnerability classes which are located in territories composed by medium permeable soils (i.e. mixture of sand, silts and clay) that have an intermediate vulnerability score (i.e. 0.6). The transition to the very high vulnerability class (Figure 5.5A) occurs moving to areas interested by recent floods (i.e. Via dell'industria, Via dell'eletricità) with high vulnerability score (i.e. 1). The Figure 5.5B shows the Mestre train station which is associated to the very high vulnerability class. The station is highly vulnerable to pluvial floods events because of the high impermeability of the surface due to urbanisation and because is located in an area interested by pluvial floods in recent years. By contrast another significant infrastructure, the Marco Polo airport of Venice, is located in an area with medium vulnerability class as it is interested by medium permeable soil (i.e. sands with silts) with a intermediate vulnerability score (i.e. 0.4). For what concern the third receptor Figure 5.6 show the distribution of vulnerability classes for infrastructures.

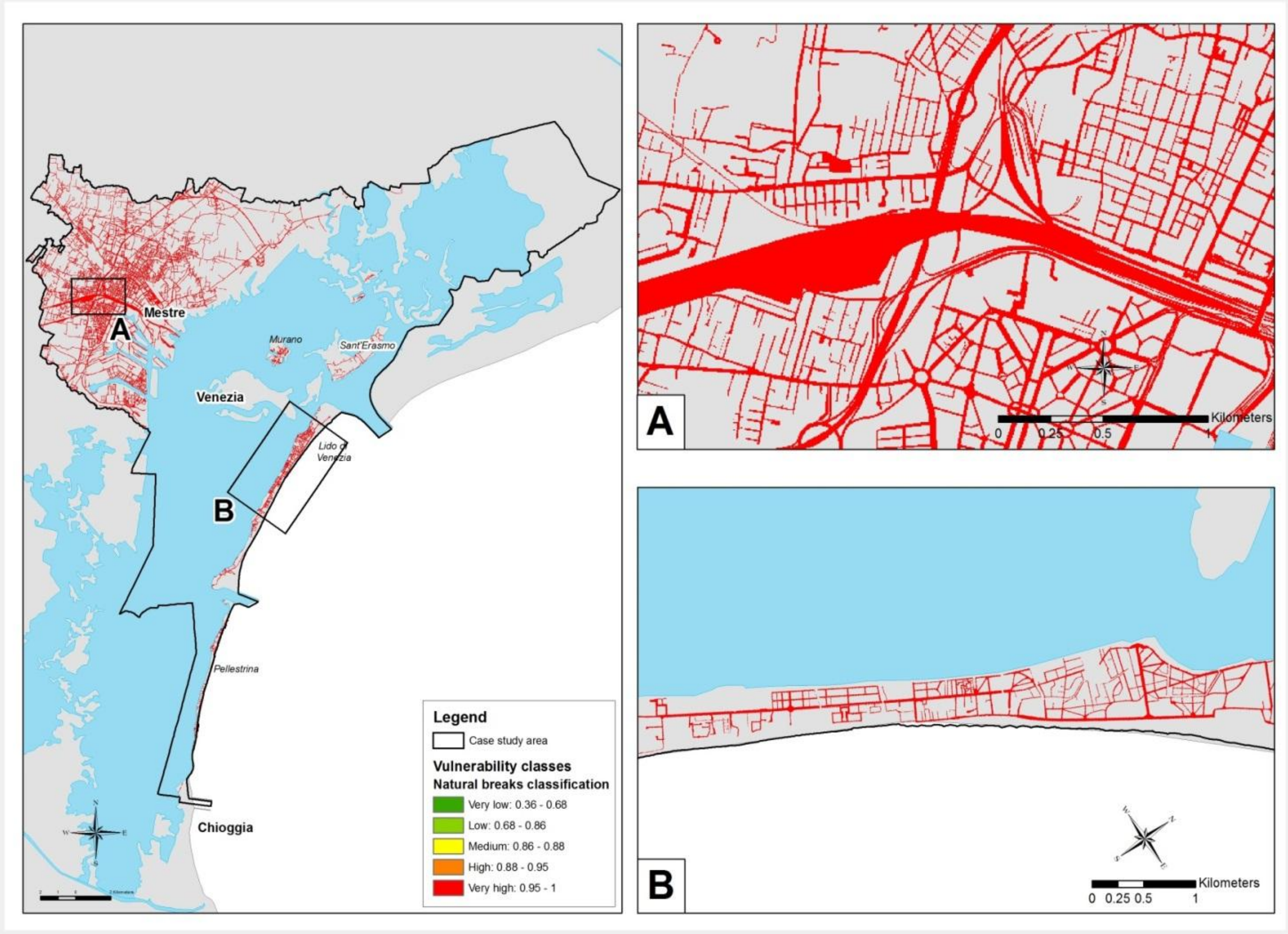


Figure 5.13 Vulnerability map of infrastructure for pluvial flood events in the municipality of Venice

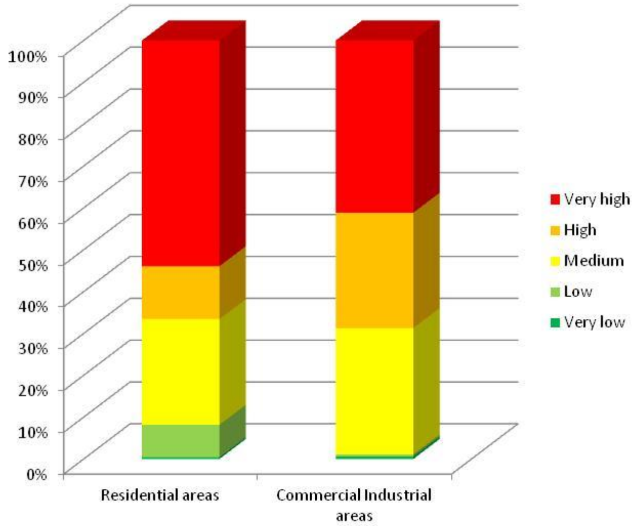
Figure 5.6 shows that infrastructures are totally associated with very high vulnerability scores. This is due to the total impermeable nature of infrastructures which confers to the receptor an high vulnerability score equal to 1. Specifically, Figure 5.6A highlight infrastructures associated with the Mestre train station which are highly vulnerable to pluvial flood due to the high urbanized surface, while Figure 5.6B shows the infrastructural system of Lido.

In order to consider how pluvial flood events affect the use of infrastructures locally (e.g. loss of service) other relevant vulnerability factors should be included at the micro-scale (e.g. infrastructure material construction, localization and dimension).

Based on the vulnerability maps, several statistics representing the territorial surface (km^2) and the percentage (%) of the case study in each vulnerability class for residential and commercial and industrial areas were calculated.

Class	Residential areas (km^2)	Commercial and industrial areas (km^2)
Very low	0,11	0,15
Low	2,04	0,13
Medium	6,67	7,94
High	3,34	7,24
Very high	14,25	10,82
Tot	26,49	26,28

a)



b)

Figure 5.14 Distribution the territorial surface (km^2) a) and of the percentage of surface b) associated with each vulnerability class for the investigated receptors in the municipality of Venice.

Figure5.7 shows the surface in km^2 (Figure 5.7a) and the percentage (Figure 5.7b) of the municipality of Venice in each vulnerability class for residential and commercial-industrial areas. The residential areas are more vulnerable to pluvial floods impacts with 53% and 12% of the territory in the very high and high vulnerability classes and the 25% of the territory with a medium vulnerability classes, while lower vulnerability classes (i.e. very low and low) represents the 7% of the investigated receptor. The vulnerability of commercial and industrial areas is more heterogeneous with a percentage of the territory ranging between 41% and 27% in the very high, high and medium classes while less of than 1% of the territory is interested by a very low vulnerability.

5.4 Relative risk maps

Risk maps aggregate hazard, exposure and vulnerability according to Equation 2. Figure 5.8, Figure 5.9 and Figure 5.12 provide the risk maps obtained for the three different receptors considered in the case study area. Figure 5.8 shows the distribution of risk classes for residential areas within the municipality of Venice. The relative risk classes represented in the maps were defined using the Natural breaks classification method.

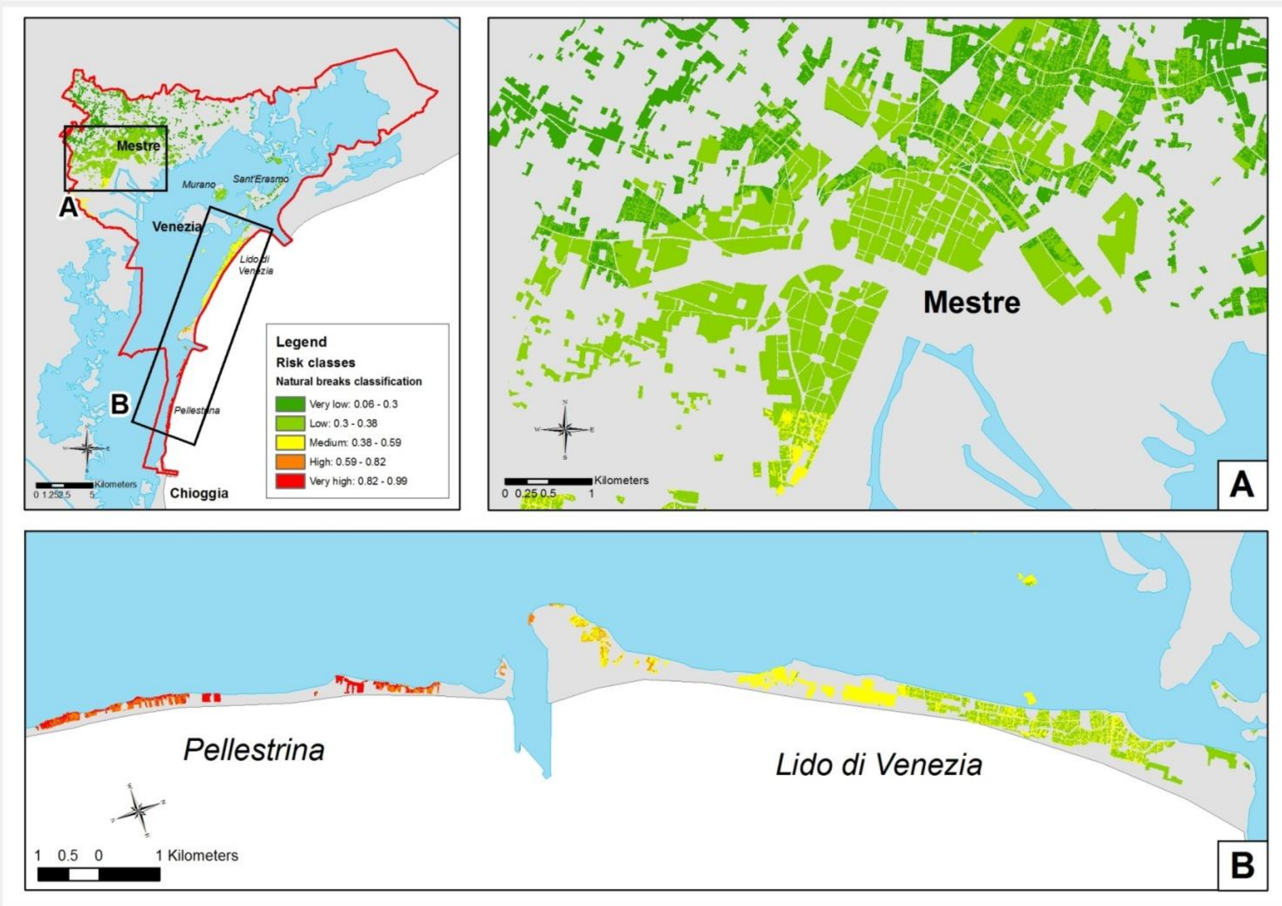


Figure 5.15 Risk map for residential areas.

Figure 5.8 shows how the higher risk classes (i.e. very high and high) interest the south-east part of the case study area and mainly insular areas in correspondence with very high hazard score while the lower risk classes (i.e. low and very low) are located in the northern part of the municipality of Venice. Medium classes are located both inland and in the littoral zones in correspondence to medium hazard scores and medium vulnerability scores. The residential area of Mestre (Figure 5.8A) is interested by risk classes comprised between very low and intermediate risk scores mainly due to low and medium hazard classes (i.e. 12 to 28 number of potentially ordinary emergencies in the 2041-2050) and the presence of moderate permeable soils (i.e. sand, mixture of sand, silts and clays). Specifically, in the south part of Mestre the transition between low risk class to intermediate risk class follows the main increase of hazard classes from low to medium (e.g. 19 to 28 number of potentially ordinary emergencies in the 2041-2050). In the northern part, instead, the increase of the risk from very low to low is also due to the increase of vulnerability associated with the presence of recently flooded zones. The southern littoral areas (Figure 5.8A) are

interested by the higher risk classes even if Pellestrina and Lido present quite different risk scores. In particular the risk increases moving to south-east from medium to very high. This increase is mainly due to the increasing pluvial hazard scores (e.g. 0.81 to 0.99) from north to south-west as the vulnerability is similar and generally low both for Pellestrina and Lido.
Figure 5.9 shows the spatial distribution of risk classes for commercial and industrial areas within the municipality of Venice.

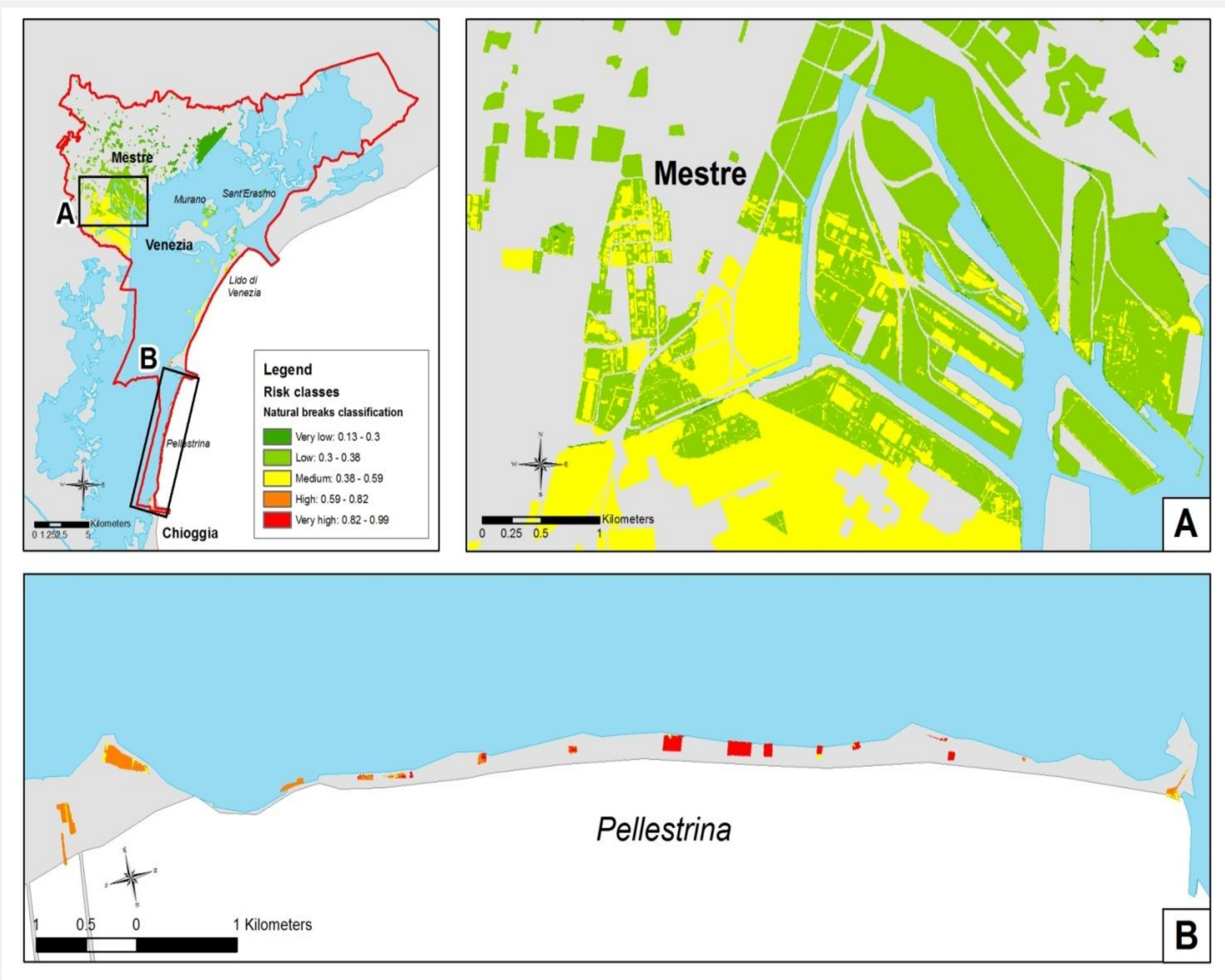


Figure 5.16 Risk map for commercial and industrial areas

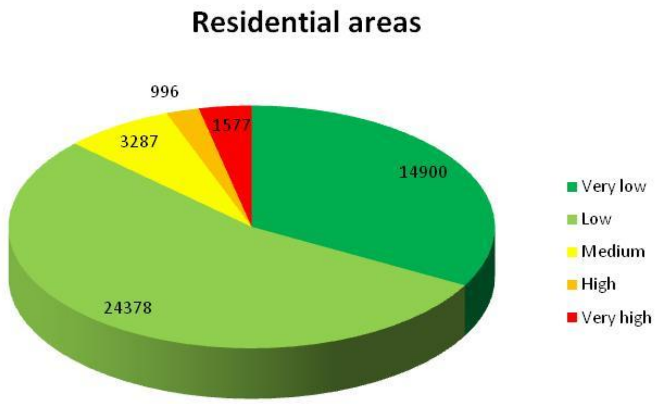
The higher risk classes (i.e. very high and high) interest the south-east part of the case study area and mainly littoral zones while the lower risk classes (i.e. low and very low) are located in the northern part of the municipality of Venice around the city of Mestre. Medium classes are located prevalently in the west part of the inland territories in correspondence with the industrial plan of Porto Marghera.

Specifically, Figure 5.9A shows that commercial and industrial areas of Mestre and Marghera are located in areas interested by intermediate and low risk classes. Medium risk class is due both to the increase of the hazard score (i.e. 12 to 29 ordinary potential emergency in the 2041.2050) and to the increase of vulnerability due to with the presence of recently flooded areas and impermeable soils. The Figure 5.9B show the very high risk class which interests commercial and industrial buildings of Pellestrina. This relative high risk class is in accordance with the very high hazard class (i.e. 40 to 49 ordinary potential emergency in the 2041.2050) associated with the area while the vulnerability, being relative low, doesn't contributed significantly in increase the risk.

A more specific statistic was calculated considering the number and the percentage of buildings in the different risk classes for residential and commercial industrial areas. Figure 5.10 shows that the majority of the residential buildings are located in areas with low (54%) and very low (33%) risk classes, while only 3.5 % are located in very high risk class.

	Residential areas	
Class	Number of buildings	%
Very low	14900	33%
Low	24378	54%
Medium	3287	7.3 %
High	996	2.2 %
Very high	1577	3.5 %
Total	45138	100

a)



b)

Figure 5.17 Distribution of risk classes for residential buildings considering the number a) and the percentage b)

A similar situation is provided in Figure 5.11 where commercial and industrial buildings are mainly located in area interested by the low risk class (49.8 %). However, for this receptor, also the buildings located in intermediate risk classes are considerable high (33.8 %). Moreover only a small number of commercial and industrial buildings are located within areas at high (103 buildings) and very high (119 buildings) risk.

a)

Class	Commercial and industrial areas	
	Number of buildings	%
Very low	1366	14.2%
Low	4777	49.8%
Medium	3245	33.8%
High	103	1.1%
Very high	119	1.2%
Total	9610	100

b)

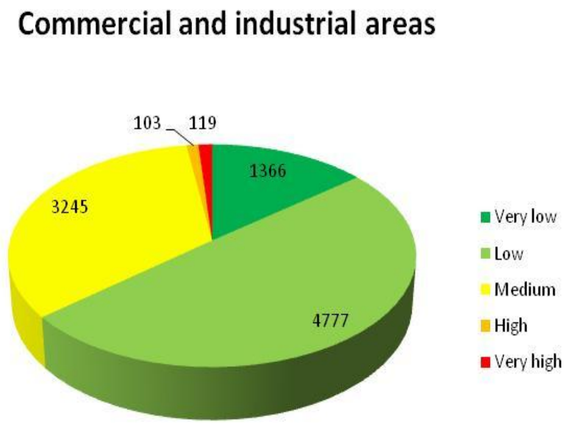


Figure 5.18 Distribution of risk classes for commercial and industrial buildings considering the number a) and the percentage b)

Moving to the third receptor, Figure 5.12 describes the distribution of risk classes for infrastructures within the municipality of Venice. Figure 5.12 show that lower risk classes (i.e. very low, low, medium) are distributed in the northern part of the case study area while higher risk classes (e.i. high and very high) are located in the south-east of the municipality of Venice. Generally we can see that, being the vulnerability very high for all the infrastructures, increasing risk classes are due to the increase of the hazard score which increase moving from north-west (0.2-0.4) to south-east (0.8-1).

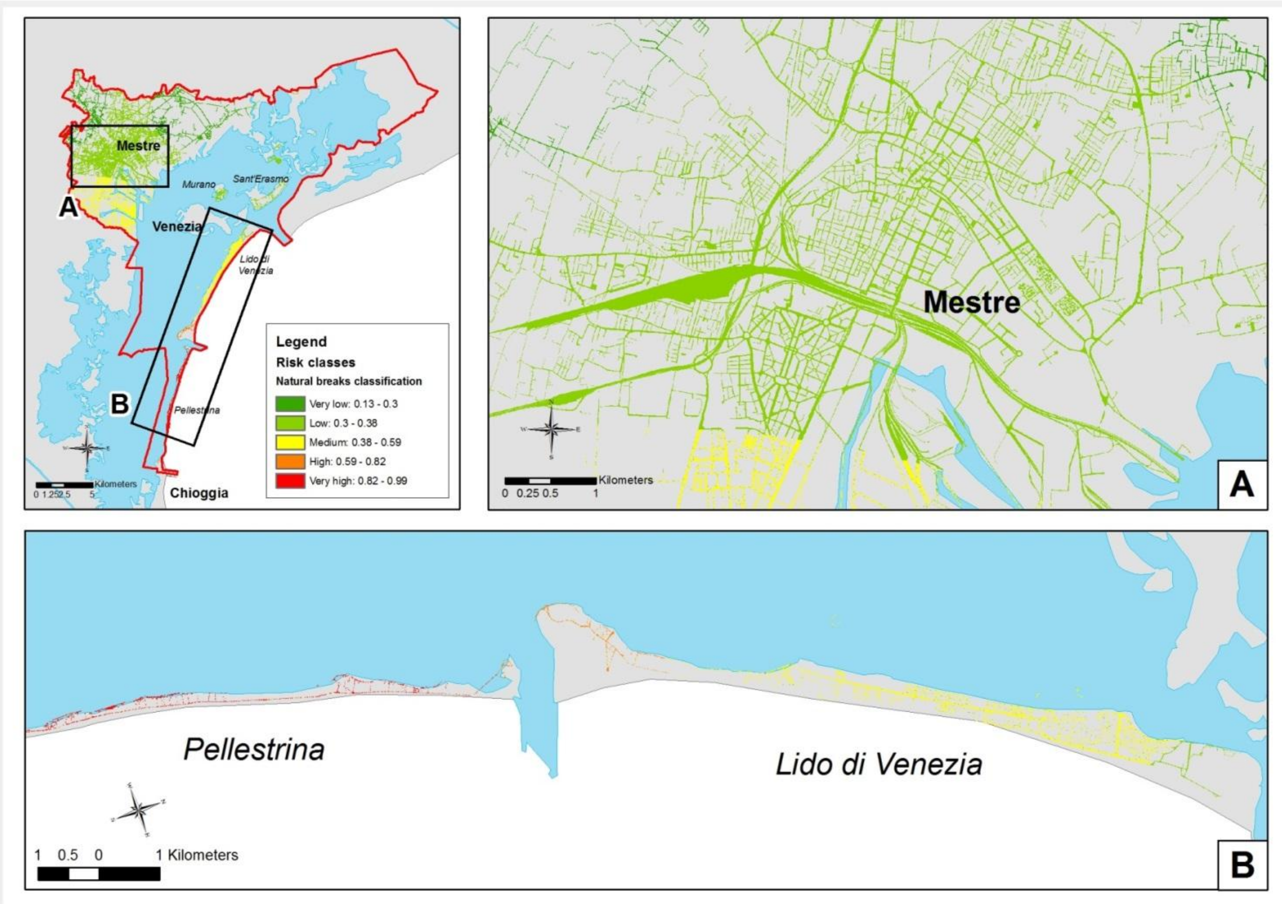


Figure 5.19 Risk map for infrastructures

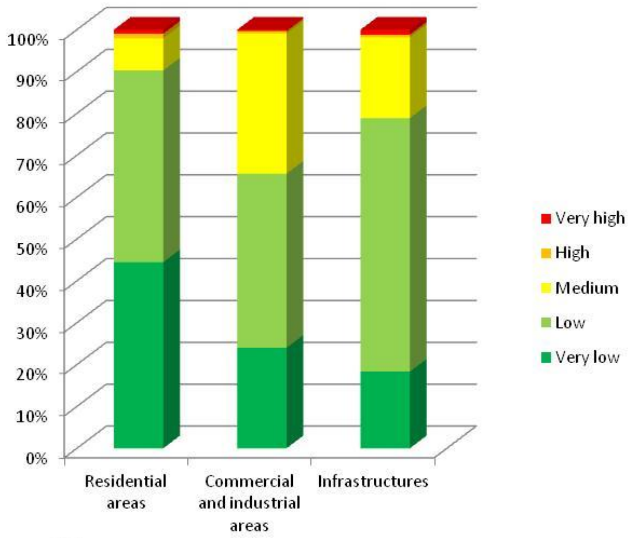
Specifically, Figure 5.12A highlights that the infrastructures of Mestre, comprising the train station, are associated to the lower risk classes while in Marghera infrastructures are located in the intermediate risk class. This distribution is due to the hazard score that increases from 0.39 to 0.56 in Marghera. Figure 5.12B show the infrastructure of the littoral zones of the case study area which are located in the very high risk classes in Pellestrina and in the high, medium and low in Lido. Also in this case the risk reflects the hazard score which increase from 0.81 to 0.99 moving from Lido to Pellestrina being the vulnerability relative low.

Based on the pluvial flood risk maps produced for the case study area, further relevant statistics were also calculated for each investigated receptor. Figure 5.13 shows that for all the receptors the percentage of surface in the higher risk classes (i.e. very high and high) is low (less than 1%) while most of receptors territories are associated with intermediate and low risk classes (i.e. low and very low) with percentage ranging from 90% for residential areas to 65% for commercial and industrial areas. Specifically, all the receptors present considerable surface of territories in the medium risk classes: commercial and industrial areas present 33% of the territories in the medium risk classes for a total surface of 8.80 km^2 while the infrastructures in the medium class are the 19% for a total surface of 2.04 km^2. Finally, in the residential areas even if the percentage is only 7%, the surface interested by medium classes is 2.0 km^2.

On the other hand, the lower risk classes are well represented in the totality of receptors. In the residential area the percentage of areas with very low risk class is 44% (11 km^2) while areas with low risk are about 45% (6.3 km^2); infrastructures present the higher percentage of the territory in the lower risk classes (78%) compared with the totality of the receptor.

	Receptors (km^2)		
Class	Residential areas	Commercial and industrial areas	Infrastructures
Very low	11,75	6,31	1,94
Low	12,11	10,93	6,40
Medium	2,04	8,80	2,04
High	0,28	0,15	0,07
Very high	0,26	0,09	0,17
tot.	26,47	26,29	10,57

a)



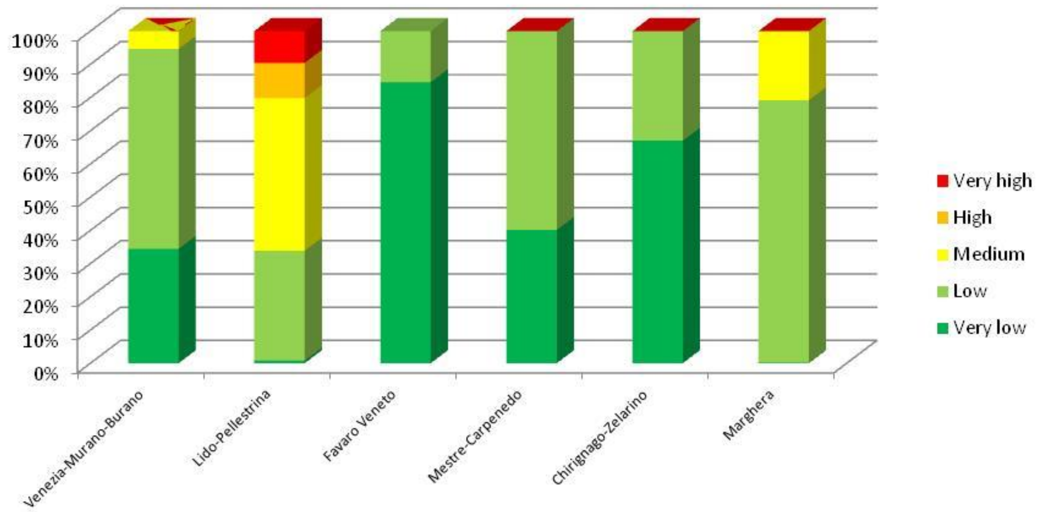
b)

Figure 5.20 Distribution of risk classes considering the territorial surface a) and the percentage b) of each receptors in the municipality of Venice

Others specific statistics where calculated considering the percentage and the surface of receptor interested by different risk classes for each administrative unit (i.e. districts) of the municipality of Venice. Figure 5.14 shows the distribution of risk classes for residential areas and highlights that Lido-Pellestrina is the district more at risk with a 9% of area in very high risk class, 10% in the high and 45% in the medium risk class for a total surface of 1.2 km^2. The municipality of Marghera follows with a percentage of 20% and a surface of about 0.73 km^2 in the medium risk class. Then, Venezia-Murano-Burano municipality shows about the 5% of the total surface in the medium risk class. Other districts are mainly affected by low and very low risk classes and specifically, the district with lower risk is Favaro -Veneto with almost the total of the surface in lower classes (99%).

a)

Class	Districts (km^2)					
	Venezia-Murano-Burano	Lido-Pellestrina	Favaro Veneto	Mestre-Carpenedo	Chirignago-Zelarino	Marghera
Very low	0,48	0,02	3,60	3,20	4,43	0,01
Low	0,84	0,89	0,65	4,77	2,18	2,78
Medium	0,07	1,23	0	0	0	0,73
High	0	0,28	0	0	0	0
Very high	0	0,26	0	0	0	0
Total	1,39	2,67	4,25	7,97	6,62	3,51



b)

Figure 5.21 Distribution of risk classes considering the territorial surface a) and the percentage of surface b) of residential areas for administrative district

Figure 5.15 show the distribution of risk classes for commercial and industrial areas for each district of case study area. The district most affected by the risk is Lido and Pellestrina with 9% of area in very high risk class, 15% in the high and 41% in the medium risk class for a total surface of 1.2 km^2. However, looking at the total surface of territories at risk, Marghera is the district with the higher surface associated with medium risk class presenting 8.16 km^2 in the medium risk classes. This is mainly because the majority of commercial and industrial areas are located in Marghera district. Favaro Veneto, although presenting a considerable surface of commercial and residential buildings (4.2 km^2), is the district at lower risk with the 99% of territorial surface in the lower risk classes (i.e. low and very low).

a)

Class	Districts (km^2) Venezia-Murano-Burano	Lido-Pellestrina	Favaro Veneto	Mestre-Carpenedo	Chirignago-Zelarino	Marghera
Very low	0,09	0,01	4,11	1,33	0,66	0,10
Low	0,70	0,32	0,17	2,02	0,55	7,2
Medium	0,24	0,40	0	0	0	8,16
High	0	0,15	0	0	0	0
Very high	0	0,09	0	0	0	0
Total	1,02	0,98	4,26	3,35	1,21	15,47

b)

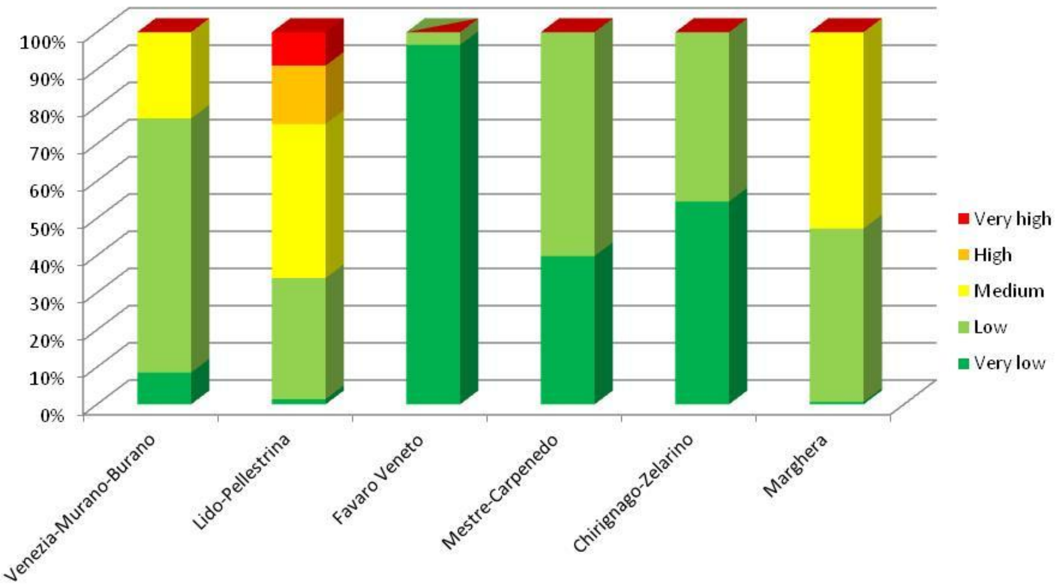


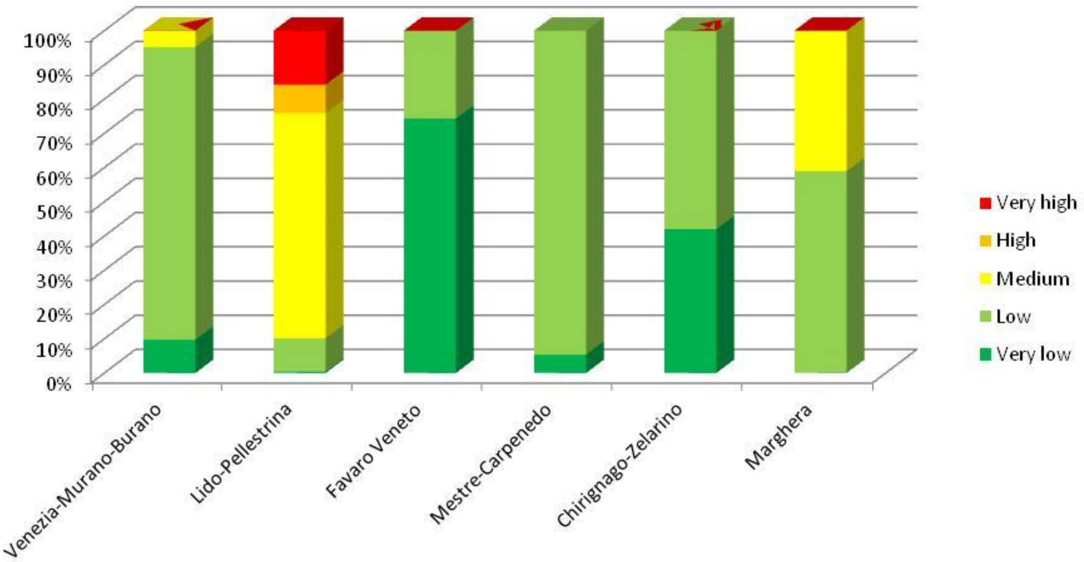
Figure 5.22 Distribution of risk classes considering the territorial surface a) and the percentage of surface b) for commercial and industrial area for administrative district

The same statistics were calculated for infrastructures as presented in Figure 5.16 which shows the distribution of the different risk classes for the receptor in each district of the municipality of Venice.

In general most of the districts (e.g. Favaro Veneto, Chirignago-Zelarino, Mestre Carpenedo) are not at risk for infrastructures presenting high percentage in the low and very low risk classes. However, in term of percentage of surface, Lido-Pellestrina is the district most at risk with the 15% of infrastructures surface in very high risk class, 8% in the high and 65% in the medium risk class. However, looking at the total surface (km^2) of infrastructure at risk, Marghera present the higher area in the medium risk classes for a total surface of 1,5 km^2 which is the 41% of its territory.

a)

Class	Districts (km^2)					
	Venezia-Murano-Burano	Lido-Pellestrina	Favaro Veneto	Mestre-Carpenedo	Chirignago-Zelarino	Marghera
Very low	0,02	0	1,06	0,15	0,69	0
Low	0,20	0,08	0,36	2,64	0,96	2,15
Medium	0,01	0,53	0	0	0	1,50
High	0	0,07	0	0	0	0
Very high	0	0,13	0	0	0	0
Total	0,24	0,80	1,43	2,79	1,66	3,66



b)

Figure 5.23 Distribution of risk classes considering the territorial surface a) and the percentage of surface b) for infrastructure for administrative district

Conclusions

The thesis was aimed at the development of climate impacts and adaptation services in the North Adriatic coastal area responding to the needs of stakeholders dealing with Integrated Coastal Zone Management (ICZM) at the local and regional level. Specifically, the thesis focused on the development of a RRA methodology for the assessment of pluvial floods risks in urban areas. The proposed methodology was applied to the territory of the municipality of Venice considering a climate change scenario for the 2041-2050 period allowing to identify and prioritize areas and targets at risk by pluvial flood events (i.e. residential areas, commercial and industrial areas, infrastructures). The regional risk classification should not attempt to provide absolute predictions about the impact of climate change. Rather, it considered relative indices which provide information about sub-areas that are more likely to be affected by climate change risks in the investigated region. The elaboration with Geographic Information Systems (GIS) tools allowed a detailed analysis of the results and the estimation of several indicators and statistics for the analyzed receptors and administrative units (e.g. km^2 of infrastructures at higher risk, percentage of residential buildings and commercial buildings interested by higher risk in the considered region).

The strength of the proposed methodology consist in the involvement of stakeholders and decision makers early in the process, in order to identify needs and data gaps at the regional to local scale, and in the application of a bottom-up interdisciplinary approach, requiring the exchange of knowledge among climate experts, risk experts and stakeholders about pluvial flood risks.

Information about stakeholders needs was collected by analyzing the results of a participatory process developed in different ways (questionnaire, workshop, focus groups) within the CLIM-RUN project, and at different steps of the methodology development (i.e. choice of the case study areas, choice of receptors and vulnerability factors), with the aim to create a product tailored to the stakeholders' requests and that could be easily incorporated in policy and decision making processes.

The RRA approach is flexible and therefore the methodology could be improved considering other hazard scenarios (e.g. using the outputs coming from different climate models) and extending the analysis to longer term timeframes (e.g. 2070-2100). Moreover, methodology can be easily upscaled to evaluate the consequences of pluvial flood impacts at a broader region/sub-national scale (e.g. for Veneto and Friuli Venezia Giulia Regions) or can be applied for the analysis of more detailed local impacts, by using more detailed datasets for the characterization of exposure and vulnerability (e.g. high resolution data obtained by Light Detection and Ranging techniques LIDAR, information about the capacity, structure and localization of the urban drainage system). Finally, the proposed approach can also be in principle applicable to other receptors of interest for the stakeholders (e.g. people, cultural buildings, agricultural areas).

On the whole, the methodology outputs (i.e. hazard, exposure, vulnerability and risk maps) and the related indicators can be considered as a first-pass assessment for the spatial identification of areas and targets at higher risk from pluvial flood impact. Specifically, they can be used to support coastal authorities in the implementation of sustainable planning and adaptation processes aimed at minimize climate change impacts. In addition, further synthetic indexes and statistics of the results could be developed with the aim to propose innovative climate risk and adaptation services which, integrating different research areas (i.e. climate information and climate risk assessment), could meet stakeholders needs and be incorporated in decision making and land planning to manage and minimize climate change impacts.

Bibliography

Abhas K.Jha, Bloch R.,Lamond J., 2011.Cities and Flooding. A Guide to Integrated Urban Flood Risk Management for the 21st Century.GFDRR.

Amelung, B., Nicholls, S. & Viner, D. (2007). Implications of Global Climate Change for Tourism Flows and Seasonality. Journal of Travel Research, 45, 285-296.

ARPA Piemonte, 2004. Convenzione tra il dipartimento per la protezione civile e l’Arpa per l’assistenza alla gestione delle situazioni di rischio idrometeorologico sul territorio nazionale. Soglie pluviometriche.

Barbi A., Formentini G., Monai M., Rech F., Zardini F.,2007. Analisi meteo-climatica dell’evento pluviometrico del 26 settembre 2007 nel veneziano. ARPAV.

Bates, BC, Kundzewicz, ZW, Wu, S and Palutikof, JP. (Editors). 2008. Climate Change and Water: IPCC Technical Paper IV. Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva.

Becken S.,(2010).The importance of climate and weather for tourism. Literature review. LEaP background paper. Lincoln.

Bessembinder J., 2011. Climate services in the Netherlands: interaction with impact researchers and policy makers – Workshop on the "Processes for improving the interface between climate research and its application: sharing experiences on climate services development in Europe", 08-09 November 2011, Bologna, Italy.

Büttner, G. and Kosztra, B. 2006. CLC2006 Technical Guidelines.

Centro Decentrato Protezione Civile,2007. Aggiornamento delle modalità di funzionamento del Centro Funzionale Decentrato della Regione Veneto.

Cheong T.S., Xiaotao C., 2013. Guidelines on urban flood risk management (UFRM).

CLUVA research project, 2011. Deliverable 2.11: Review and evaluation of existing vulnerability indicators in order to obtain an appropriate set of indicators for assessing climate related vulnerability.

De Freitas, C.R. (2005). The climate-tourism relationship and its relevance to climate change impact assessment. In: Tourism, Recreation and Climate Change: International Perspectives. C.M. Hall and J. Higham (eds). Channelview Press,UK. 29-43.

DEDUCE consortium, 2007. Indicators Guidelines - To adopt an indicators-based approach to evaluate coastal sustainable development.

Deni S.M., Jemain A.A., 2009. Mixed log series geometric distribution for sequences of dry days – Atmospheric Research, 92, 236 – 243.

EEA, 2003. Environmental Indicators: Typology and Use in Reporting – EEA internal working paper.

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

Eurosion, 2004. Living with coastal erosion in Europe:Sediment and Space for Sustainability. PART III – Methodology for assessing regional indicators.

Falconer R., Smyth P., Maani L.,2008. Pluvial extreme event risk appraisal techniques with recent applications in Ireland and the Uk. Irish National Hydrology Conference 2008.

FAO, 1998. Crop Evapotranspiration Guidelines for computing crop water requirements – FAO Irrigation and Drainage Paper No. 56.

Feenstra J., Burton I., Smith J., Tol R. (eds.), 1998. Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies – United Nations Environment Programme, Nairobi, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam. (Version 2.0).

Fisher B., Nakicenovic N., Alfsen K., Corfee Morlot J., De la Chesnaye F., Hourcade J.C., Jiang K., Kainuma M., La Rovere E., Matysek A., Rana A., Riahi K., Richels R., Rose S., van Vuuren D.P., Warren R., 2007. Climate change 2007: Issues related to mitigation in the long-term context. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change .Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Gallina V., Gallina V., Torresan S., Critto A., Zabeo A., Semenzin E., Marcomini A., 2013. Development of a risk assessment methodology to estimate risk levels, Part A.

Giannini V., Torresan S., Gallina V., Critto A., Giupponi C., Marcomini A., 2011. Deliverable 8.1 Workshop report: context and objectives, comparison of data supply and demand, simulation results, feedback and discussion. Integrated case study: Veneto and Friuli Venezia Giulia, Northern Adriatic Sea, Italy – CLIM-RUN project report.

Giorgi F., Coppola E., Solmon F., Mariotti L., Sylla M.B., Bi X., Elguindi N., Diro G.T., Nair V., Giuliani G., Turuncoglu U.U., Cozzini S., Güttler I., O'Brien T.A., Tawfik A.B., Shalaby A., Zakey A.S., Steiner A.L., Stordal L.C., Brankovic C., 2012. RegCM4: model description and preliminary tests over multiple CORDEX domains.CLIMATE RESEARCH Clim Res, Vol. 52: 7–29, March 2012.

Giove S., A. Brancia, F. K. Satterstrom, I. Linkov, 2009. Decision Support Systems and Environment: Role of MCDA. A. Marcomini et al. (eds.), Decision Support Systems for Risk-Based Management of Contaminated Sites, DOI 10.1007/978-0-387-09722-0_3. Springer ScienceþBusiness Media, LLC 2009. Pp. 53-73.

Gleason K.L., Lawrimore J.H, Levinson D.H., Karl R.T.,2008.A Revised U.S. Climate Extremes Index. Climate, 21, 2124–2137.

Haan, C. 2002. Statistical methods in hydrology. 496 p. Iowa State Press, Ames, Iowa, USA.

Hayes M.J. (ed), 2007. Drought Indices. Intermountain West Climate Summary. Western Water Assessment.

Heim R.R., 2002. A Review of Twentieth-Century Drought Indices Used in the United States. Bull. Amer. Meteor. Soc., 83, 1149–1165.

Houston D., Werritty A., Basset D., Geddes A., Hoolachan A., McMillan M., 2011. Pluvial (rain related) flooding in urban areas: the invisible hazard.

Hunsaker C. T., R. L. Graham, G. W. Suter II, R. V. O'Neill, L. W. Barnthouse, R. H. Gardner,1990. Assessing ecological risk on a regional scale. *Environmental Management* 14: 325-332.

Hunsaker, C. T., R. L. Graham, G. W. Suter, R. V. O'Neill, B. L. Jackson, and L. W. Barnthouse,1990. Regional ecological risk assessment: Theory and demonstration. ORNL/TM-11128. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Huong, H. T. L. and Pathirana, A., 2013. Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrol. Earth Syst. Sci., 17, 379-394,2013.

IPCC, 2008. Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies. Report of the IPCC Expert Meeting, held on 19-21 September, 2007, in Noordwijkerhout, the Netherlands.

IPCC, 2012: Summary for Policymakers. 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. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

IPCC, 2013. Climate change 2013: the physical science basis. Summary for policy makers. Working Group I contribution to the IPCC Fifth Assessment Report, Stockolm.

Jacob D.,2011. Regional climate information and services – UNFCCC, Workshop of the Subsidiary Body for Scientific and Technological Advice (SBSTA), Thirty-fourth session, 6-16 June 2011, Bonn, Germany.

Kalbfleisch J. G, 1985. Probability and Statistical Inference: Volume 1: Probability.Springer Texts in Statistics-Sep 9, 1985.

Karl T.R., Knight R.W., Easterling D.R., Quayle R.G., 1996. Indices of Climate Change for the United States.Bull. Amer. Meteor. Soc.,77, 279–292.

Keetch J. J., Byram G.M., 1968. A drought index for forest fire control. USDA Forest Service Research Paper SE-38, Southeastern Forest Experiment Station, Asheville, NC, 33 pp.

Kundzewicz, ZW, Mata, LJ, Arnell, NW, Döll, P, Kabat, P, Jiménez, B, Miller, KT, Oki, T, Sen, Z and Shiklomanov, IA. 2007. Freshwater resources and their management.In Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge, United Kingdom

Landis W. G., 2005. Regional scale ecological risk assessment. Using the relative risk model. Edited by W. G. Landis. CRC PRESS.

Matzarakis, A., 2007. Assessment method for climate and tourism based on daily data. In: A. Matzarakis, C. R. de Freitas, D. Scott (Eds.), Developments in Tourism Climatology, 52-58.

McKee T.B., Doesken N.J., Kleist J., 1993. The relationship of drought frequency and duration to time scales. Preprints, Eighth Conf. on Applied Climatology, Anaheim, CA, Amer. Meteor. Soc., 179–184.

Mieczkowski Z., 1985. The tourism climate index: A method for evaluating world climates for tourism– The Canadian Geographer 29: 220-233.

Miles E. L., Snover A. K., Whitely Binder L. C., Sarachik E. S., Mote P. W., Mantua N., 2006. An approach to designing a national climate service – PNAS, vol. 103, no. 52, p. 19616–19623.

Moss R.H., Edmonds J.A., Hibbard K.A., Manning M.R., Rose S.K., 2010. The next generation of scenarios for climate change research and assessment. Nature .463(7282):747-56.

Narasimhan B., Srinivasan R., 2005. Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. Agricultural and Forest Meteorology, 133(July), 69 – 88.

NOAA,2013. U.S. Climate Extremes Index (CEI). Accessed online June 2013. http://www.ncdc.noaa.gov/extremes/cei/introduction.

NRC, 2001. A Climate Services Vision: First Steps Toward the Future.

NRC, 2009. Restructuring Federal Climate Research to Meet the Challenges of Climate Change.

Palmer W. C., 1965. Meteorological drought - U.S. Weather Bureau Research Paper 45, 58 pp.

Preston B.L., Smith T.F., Brooke C., Gorddard R., Measham T.G., Withycombe G., Mcinnes K., Abbs D., Beveridge B. and Morrison C., 2008. Mapping Climate Change Vulnerability in the Sydney Coastal Councils Group. Prepared for the Sydney Coastal Councils Group.

Provincia di Venezia, 2011. Atlante geologic della Provincia di Venezia. Cartografie e note illustrative. Edited by Vitturi A., Provincia di Venezia.

Qian J.H., Robertson A.W., Moron V., 2010: Interactions among ENSO, the Monsoon, and Diurnal Cycle in Rainfall Variability over Java, Indonesia. J. Atmos. Sci., 67, 3509–3524.

Qian JH (2008) Why precipitation is mostly concentrated over islands in the maritime continent. J Atmos Sci 65: 1428–1441.

Riahi K., Shilpa R., Krey V., Choc., Chirkov V., Fischer G., Kindermann G., Nakicenovic N., Rafaj P., 2010. RCP 8.5—A scenario of comparatively high greenhouse gas emissions.. Climatic Change. November 2011, Volume 109, Issue 1-2, pp 33-57,

Sartori G.,2012. Eventi meteorologici estremi. Dati e valutazioni sulla radicalizzazione del clima in Veneto. Consiglio Regionale del Veneto.

Schleupner C., 2005. Spatial Analysis As Tool for Sensitivity Assessment of Sea Level Rise Impacts on Martinique – Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science. Working paper FNU-71.

Solomon,S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M., Miller H.L., 2007. The physical sciences basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Spekkers M.H., Veldhuis J.A., Clemens F.H.L.R, 2011. Collecting data for quantitative research on pluvial flooding. 12nd International Conference on Urban Drainage, Porto Alegre/Brazil, 11-16 September 2011.

Torresan S.,2011. Development of a Regional Risk Assessment methodology for climate change impact assessment and management in coastal zones. Doctoral thesis. Cà Foscari University.

UKCIP, 2003. Climate adaptation: risk, uncertainty and decision-making. Robert Willows, Richenda Connell (ed.). Pp166.

UNISDR, 2009. Global assessment report on disaster risk reduction 2009. United Nations.

Van Rooy M.P., 1965. A Rainfall anomaly index (RAI) independent of time and space. Notos, 14, 43– 48.

Van Vuuren D.P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G.C., Kram T., Krey V., Lamarque J.F., Matsui T., Meinshausen M., Nakicenovic N., Smith S.J., Rose S.K .,(2011). Representative concentration pathways: An overview. Climatic Change , 109, 1-2, 5-31.

Wanders N., van Lanen H.A.J., van Loon A.F., 2010. Indicators for drought characterization on a global scale – Wageningen University, Hydrology and Quantitative Water Management Group.

WMO, 2009. Global Framework for Climate Services – Concept Note.

WMO, 2011. Climate knowledge for action: a global framework for climate services – empowering the most vulnerable, WMO report No 1065.

World Bank, 2008. Weather and Climate Services in Europe and Central Asia: A Regional Review – World Bank Working Paper no.151, Washington DC, USA.

Zald A. E., Shelly S. and Wade T.,2006. A to Z GIS: An Illustrated Dictionary of GeographicInformation Systems. Articles (Libraries). Paper 144.

Annex A
Results of the first CLIM-RUN workshop

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	Consorzio di Bonifica Delta Po	Ing. Stefano Tosini	stefanotosini@bonificadeltadelpo.it
	Consorzio di Bonifica Veneto Orientale	Graziano Paulon	graziano.paulon@bonificavenetorientale.it
	Port Authoritiy of Venice	Erika Rizzo	erika.rizzo@port.venice.it
Provinces	Venezia: Servizio geologico e difesa del suolo	Valentina Bassan	valentina.bassan@provincia.venezia.it
Municipalities	Venezia	Sandro Caparelli	sandro.caparelli@comune.venezia.it
	Venezia: Istituzione Centro Previsioni e Segnalazioni Maree	Alessandro Tosoni	alessandro.tosoni@comune.venezia.it
Friuli Venezia Giulia Region	Servizio geologico	Antonio Bratus	antonio.bratus@regione.fvg.it
	ARPA	Pietro Rossin	pietro.rossin@arpa.fvg.it
	ARPA	Isabella Scroccaro	isabella.scroccaro@arpa.fvg.it
	ARPA OSMER	Stefano Micheletti	stefano.micheletti@meteo.fvg.it
Parks	Area Marina Protetta di Miramare	Roberto Odorico	roberto.odorico@shoreline.it

Figure A24. Stakeholders participating at the first CLIM-RUN workshop (Giannini et al., 2011)

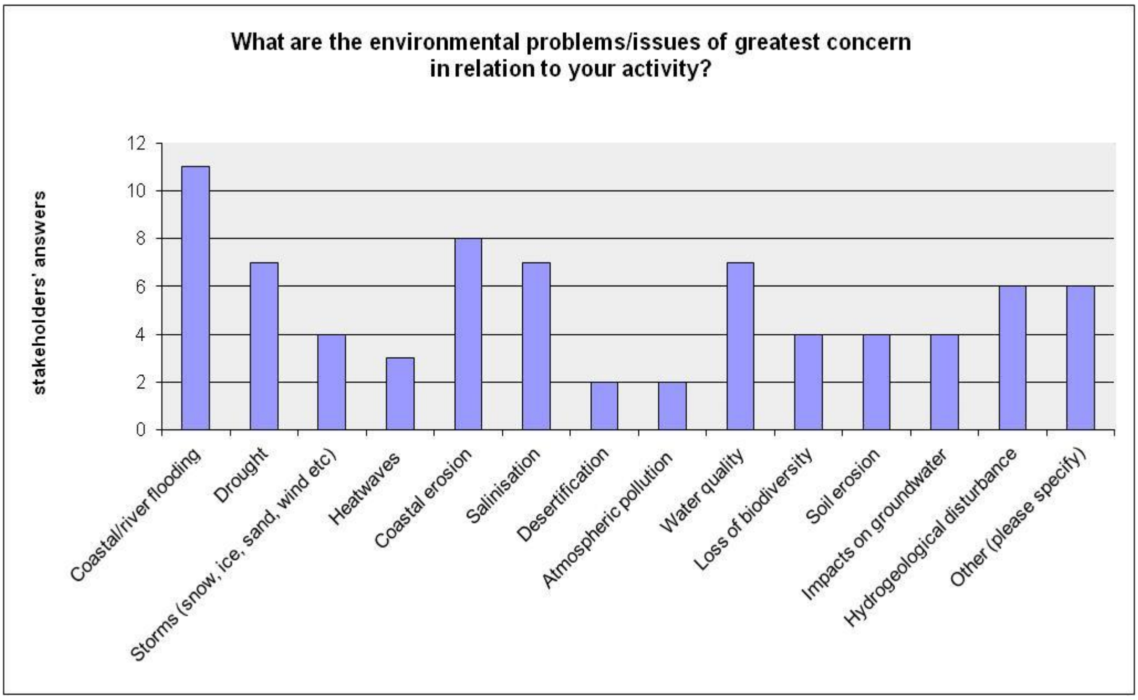

Figure A25. Ranking of the environmental issue to be considered in climate change impacts, risk and vulnerability studies (Giannini et al., 2011)

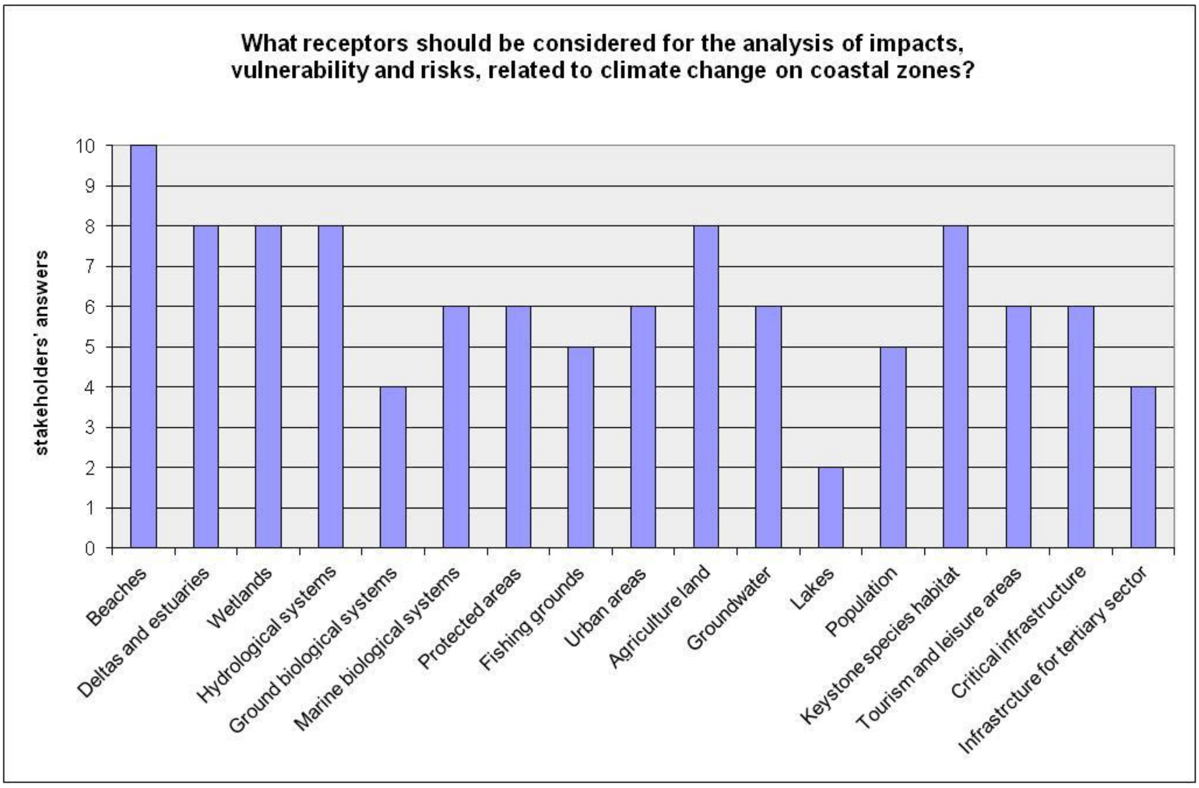

Figure A26. Ranking of the relevance of coastal receptors to be considered as target in the climate change impact, risk and vulnerability studies (Giannini et al., 2011)

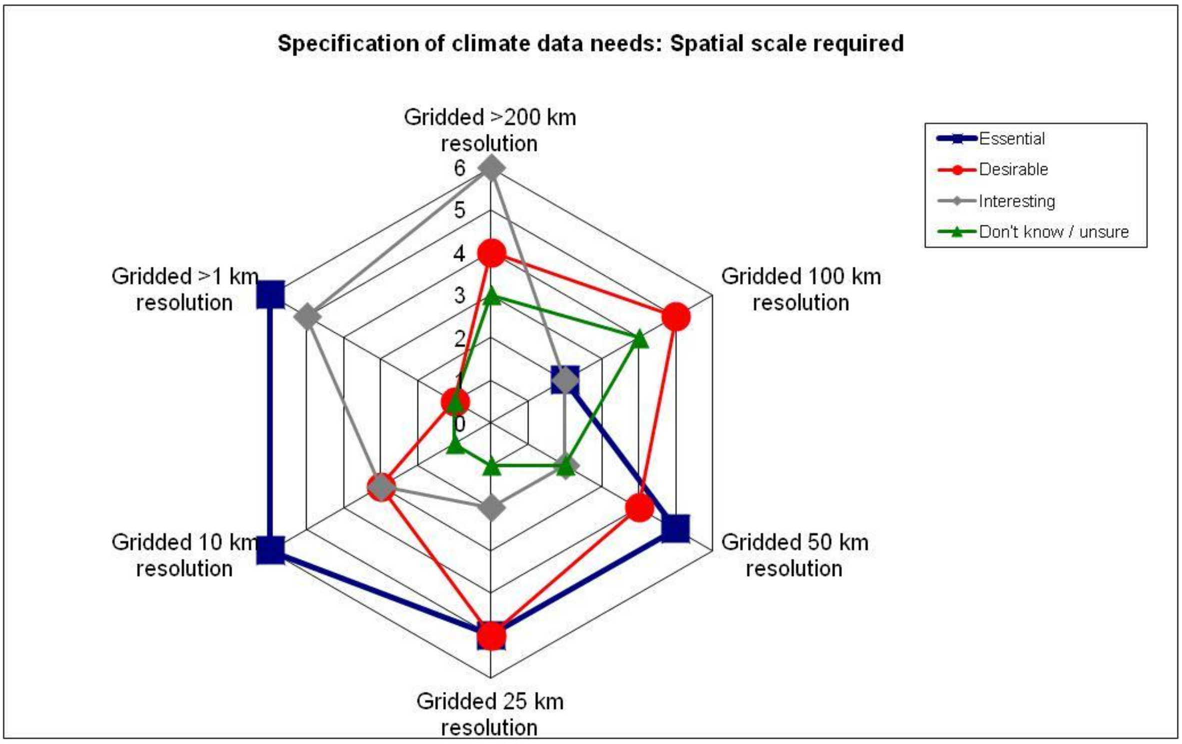

Figure A27. Spatial scale required for climate change impact, risk and vulnerability studies (Giannini et al., 2011)

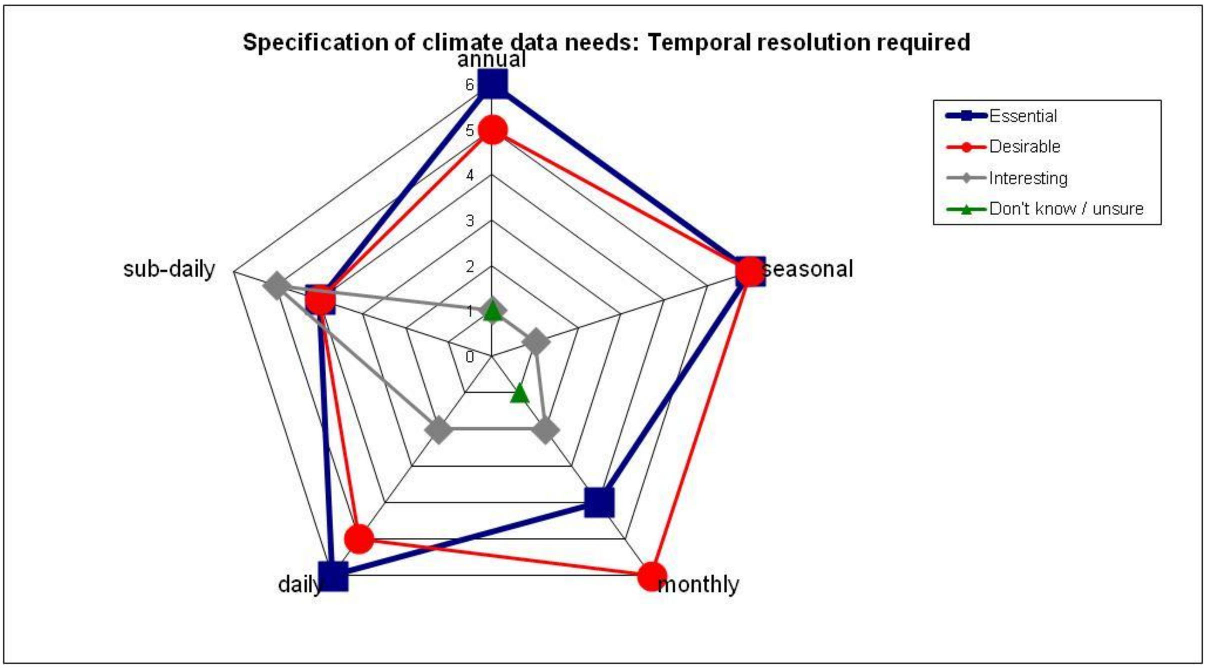

Figure A28. Temporal resolution required for climate change impact, risk and vulnerability studies (Giannini et al., 2011)

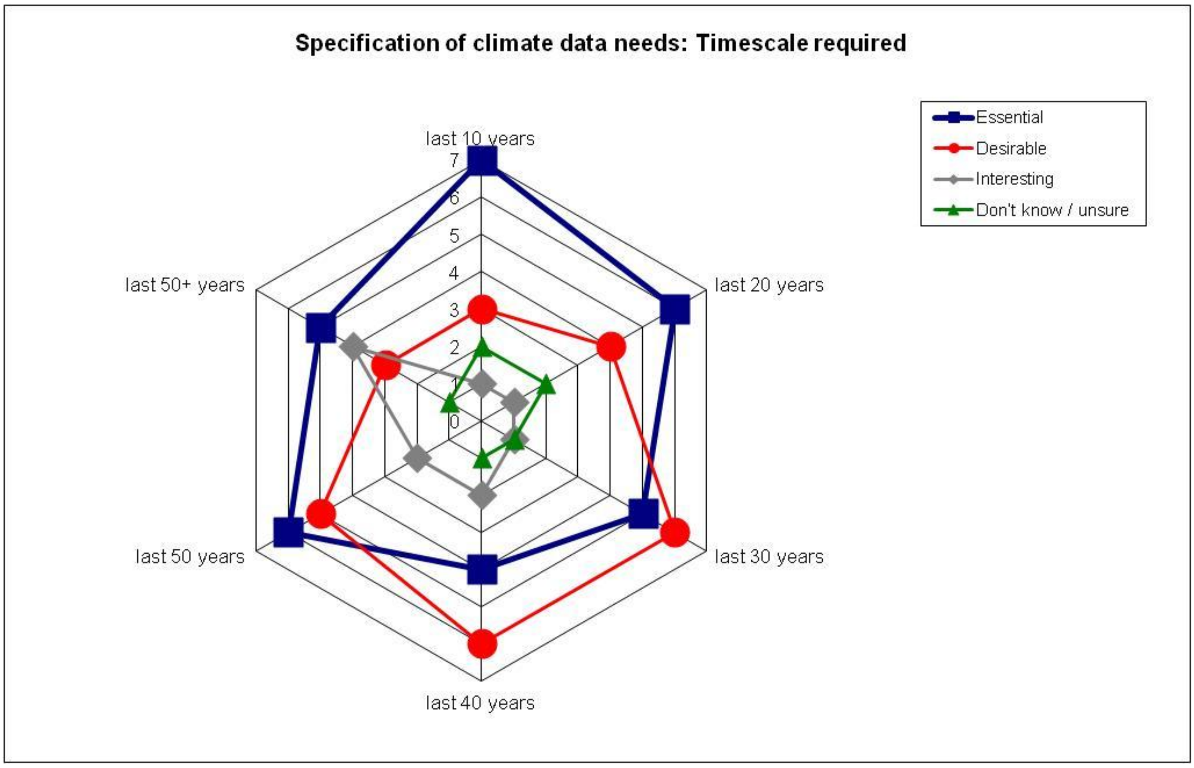

Figure A29. Timescale required for climate change impact, risk and vulnerability studies (Giannini et al., 2011)

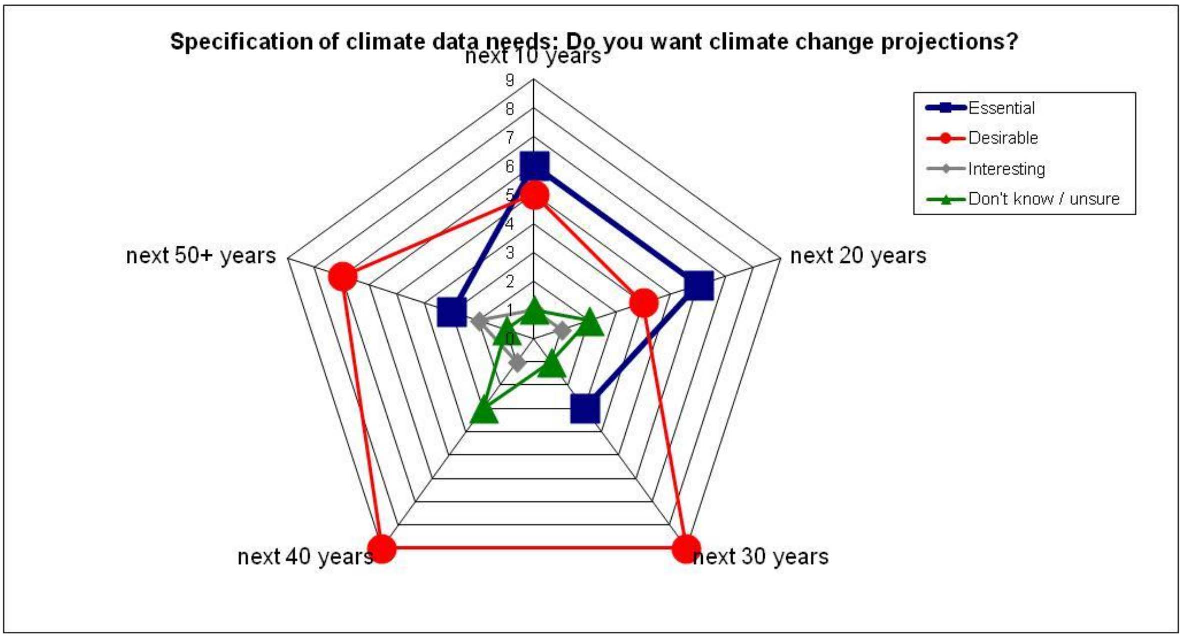

Figure A30. Time horizon required for climate change impact, risk and vulnerability studies (Giannini et al.,2011)

Annex B
Questionnaire for stakeholders

Product Pluvial flood inundation in urban areas

Name ____

Surname____

Affiliation____

INPUT DATA

1. Is the proposed area (Province of Venice) appropriate for the study?

□Yes

□No

2. If not, which areas should be included?

____

____

3. Are the proposed receptors (Tab.1) appropriate for the study?

Receptors	**Source**
Population	ISTAT,2010
Infrastructure	Corine Land Cover, 1:100000, Land use, 1:25000 ISPRA, 2006
Buildings	Corine Land Cover, 1:100000, Land use, 1:25000 ISPRA, 2006

Tab.1. Receptors considered for the pluvial flood risk assessment.

4. If not, which other receptors would you suggest to include?

____

____

5. Are the proposed vulnerability factors (Tab.2) appropriate?

Bio physical and environmental vulnerability factors
Slope
Land use
Recently flooded areas

Tab.2. Bio physical and environmental vulnerability factors considered.

6. If not, suggest which others factors should be included

____

____

OUTPUT DATA

7. Is the time scale proposed (number of events in the decade 2041-2050) appropriate?

□Yes

□No

8. Which should be the most appropriate time scale for the study?

□ Monthly number of events;

□ Annual number of events;

□ Seasonal number of events;

Other:____

Annex C
Results of the second CLIM-RUN workshop

Veneto	
Regional Met office	Adriano Barbi
Municipality of Venezia: urban sustainability	Sandro Caparelli
Municipality of Venezia: PAES and C40	Irene Gobbo
Municipality of Venezia: energy agency	Simone Tola
Friuli Venezia Giulia	
Regional geologic service	Antonio Bratus
Regional environmental agency	Giorgio Mattassi
Regional environmental agency	Isabella Scroccaro
Regional environmental agency	Dario Giaiotti
Regional Met office	Andrea Cicogna
Extension service Ledra Tagliamento	Damiano Furian
Marine Protected Area of Miramare	Carlo Franzosini

Figure C1. Stakeholders who participated in the second CLIM-RUN workshop (Giannini et al., 2013)

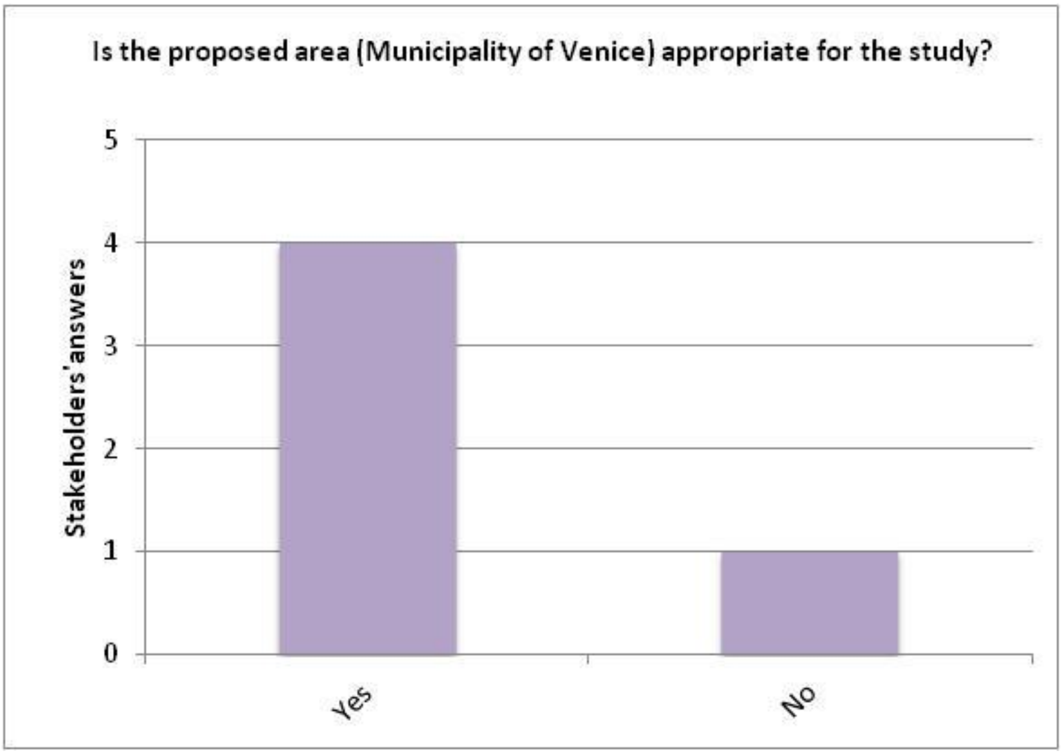

Figure C2. Case study area that should be considered for the application of the pluvial flood risk assessment.

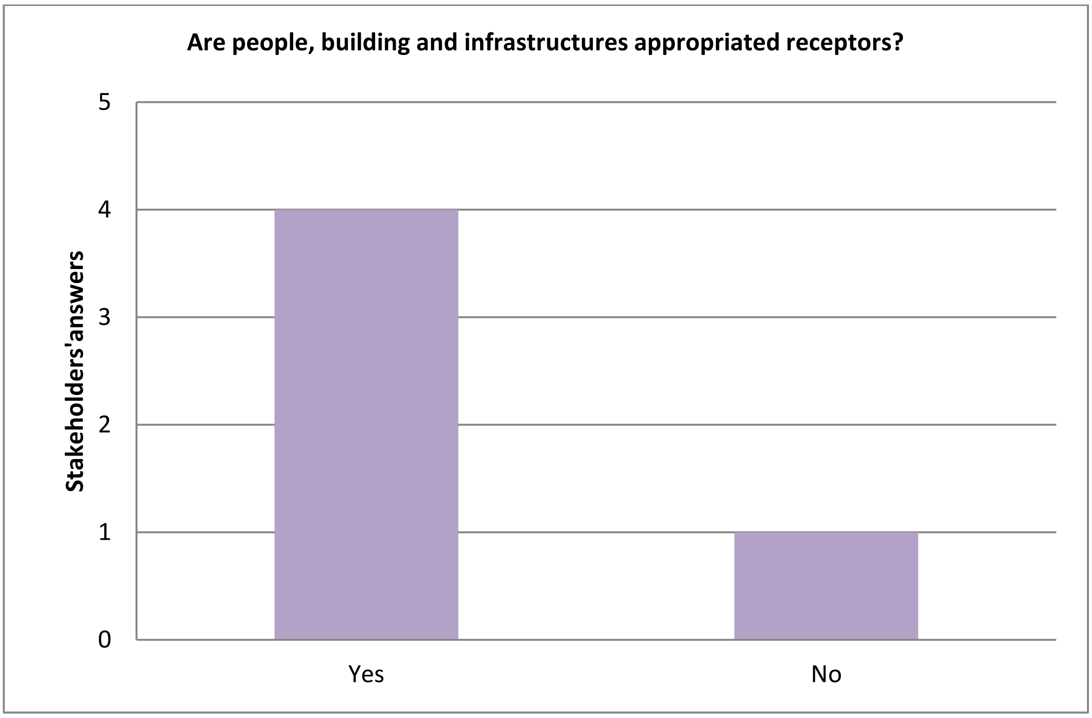

Figure C3. Receptors that should be considered for the pluvial flood risk assessment.

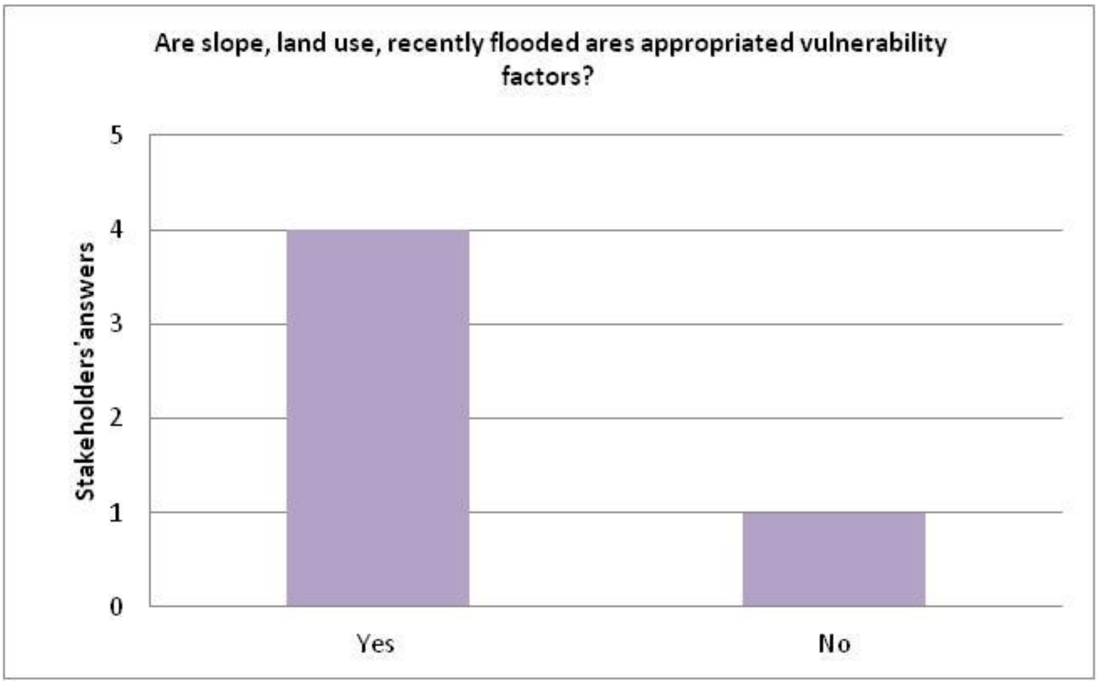

Figure C4. Vulnerability factors that should be considered for the pluvial flood risk assessment.

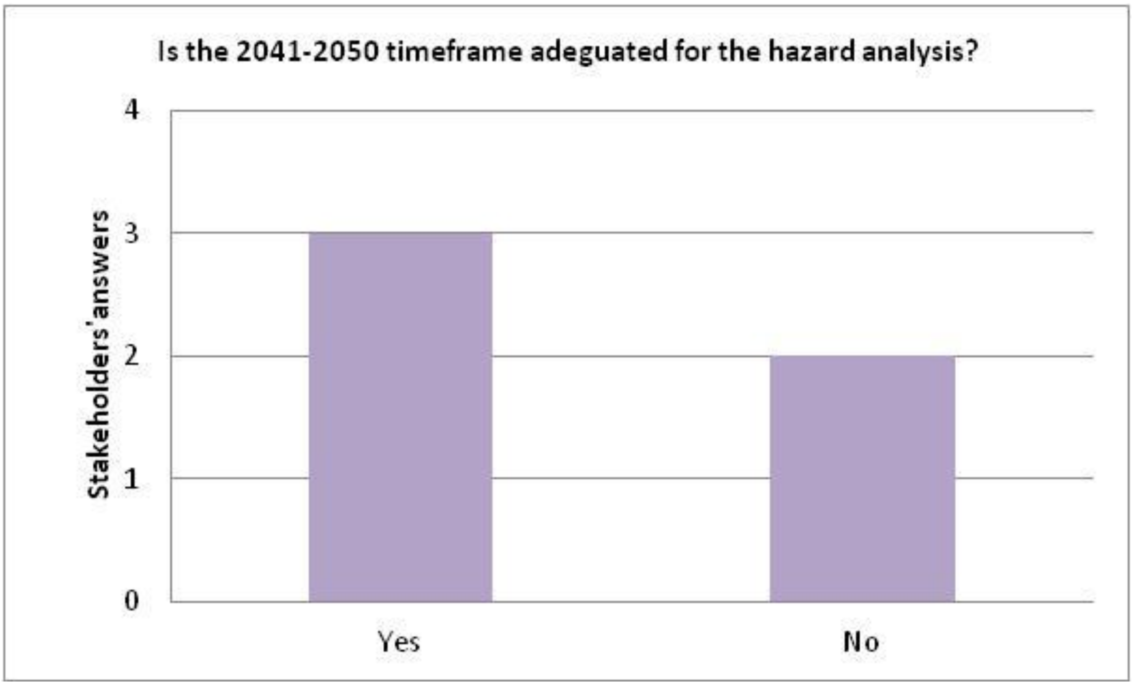

Figure C5. Timeframe that should be considered for the pluvial flood risk assessment.

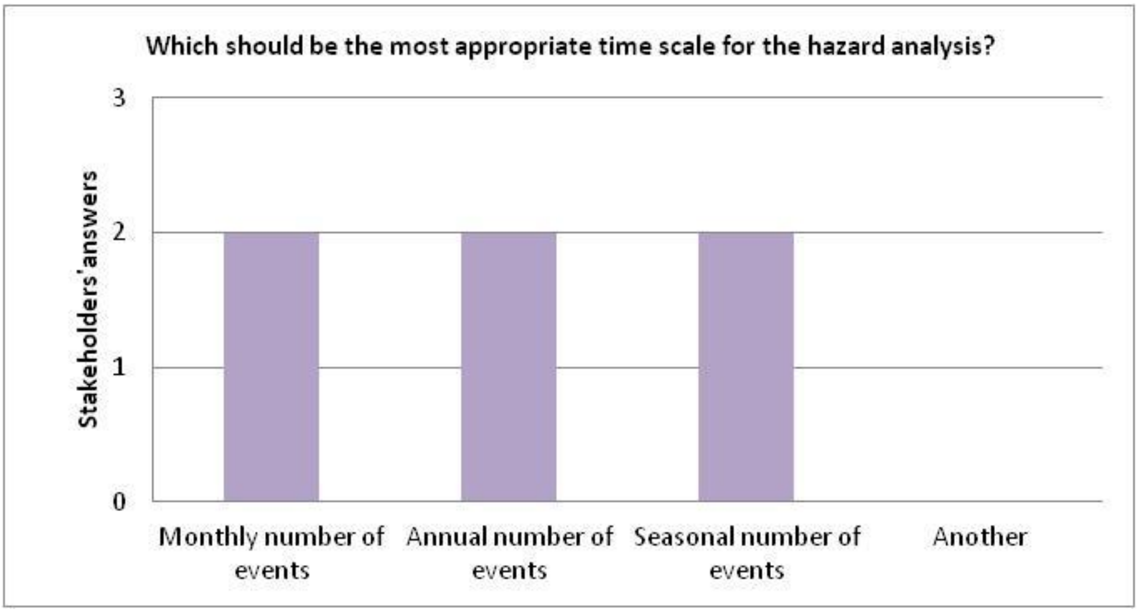

Figure C6. Time scale that should be considered for the pluvial flood risk assessment.