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Corresponding Author: Prof. Antonio Marcomini,

Corresponding Author's Institution: University Ca' Foscari Venice

First Author: Silvia Torresan, PhD

Order of Authors: Silvia Torresan, PhD; Andrea Critto, PhD; Jonathan Rizzi, PhD; Alex Zabeo, PhD; Elisa Furlan; Antonio Marcomini

DESYCO: a decision support system for the regional risk assessment of climate change impacts in coastal zones.

Silvia Torresan [1], Andrea Critto[1,2], Jonathan Rizzi [1,2] , Alex Zabeo[1,2], E. Furlan[1,2], Antonio Marcomini [1,2]

(1) Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC), via Augusto Imperatore 16, 73100 Lecce, Italy.

(2) Department of Environmental Sciences, Informatics and Statistics, University Ca' Foscari Venice, Calle Larga S. Marta 2137, I-30123 Venice, Italy.

Corresponding author: prof. Antonio Marcomini

Telephone number: +39-041-2348548

Fax number: +39-041-2348584

Correspondence address: Department of Environmental Sciences, Informatics and Statistics, University Ca' Foscari Venice, Calle Larga S. Marta 2137, I-30123 Venice. Email address: marcom@unive.it

Abstract

Several decision support systems were developed in recent years to encourage climate adaptation planning in coastal areas, especially at a national to global scale. However, few prototypes are easy to use and accessible for decision-makers to evaluate and manage risks locally. DESYCO is a GIS based decision support system specifically designed to better understand the risks that climate change poses at the regional/subnational scale (e.g. the effect of sea level rise and coastal erosion on human assets and ecosystems) and set the context of strategic adaptation planning within Integrated Coastal Zone Management. It implements a Regional Risk Assessment (RRA) methodology allowing the spatial assessment of multiple climate change impacts in coastal areas and the ranking of key elements at risk (e.g. beaches, wetlands, protected areas, urban and agricultural areas). The core of the system is a Multi-Criteria Decision Analysis (MCDA) model used to operationalize the steps of the RRA (i.e. hazard, exposure, susceptibility, risk and damage assessment) by integrating a blend of information from climate scenarios (e.g. global/regional climate projections and hydrodynamic/hydrological simulations) and from non-climate vulnerability factors (e.g. physical, environmental and socio-economic features of the analysed system). User-friendly interfaces simplify the interaction with the system, providing guidance for risk mapping, results communication and understanding.

DESYCO was applied to low-lying coastal plains and islands (i.e. the North Adriatic Sea, the Gulf of Gabes and the Republic of Mauritius), river basins and groundwater systems (e.g. Upper Plain of Veneto and Friuli-Venezia Giulia, Marche Region). The paper presents the RRA methodology, the structure of DESYCO and its software architecture, showing the capabilities of the tool to support decision making and climate proofing in a wide range of situations (e.g. shoreline planning, land use and water resource management, flood risk reduction).

Keywords: Decision Support Systems (DSS), risk assessment, climate change adaptation, Multi-Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS).

1. INTRODUCTION.

Global climate change is likely to pose increasing threats in nearly all sectors and across all sub-regions worldwide. The impacts envisaged for coastal systems (e.g. sea level rise inundation, increased storm surges, saltwater intrusion and sea water quality deterioration) will have severe implications for population and economic activities and are rising the attention of decision-makers and coastal managers at different levels (IPCC-AR5, 2014; Voice et al., 2006; EEA, 2010).

Particularly, the need to develop national adaptation strategies and cross sectorial risk management plans, to better prevent and prepare for climate related disasters, has become a strategic goal for all the EU Member States (EC, 2007b; EC, 2013). Accordingly, decision makers are increasingly calling for information on what impacts are expected under projected climate change, their location and the groups or systems most affected (Carter et al., 2007, Santoro et al., 2013); and there is a growing importance of innovative integrated and multidisciplinary approaches to support the preservation, planning and sustainable management of coastal zones, considering the envisaged effects of global climate change (Hinkel et al., 2010b; Mokrech M., 2009).

Many Decision Support Systems (DSSs) were developed so far by the scientific community for the integrated coastal zone decision making environment (Westmacott, 2001) and for tackling unstructured problem solving in the field of environmental management (Agostini et al., 2009; Giupponi, 2009), decision making, and decision implementation (Le Blanc, 1991). Computer based information systems showed a great potential to support climate change impact and adaptation assessment in coastal zones, by integrating simulation models operating at different scales (e.g. climate, ecological and economic models) and by applying increasingly sophisticated methodological approaches and interfaces (Ramieri et al., 2011; Iyalomhe et al., 2012).

Existing tools and DSS for coastal zones management (e.g. BTELSS (Reyes et al., 2000; Martin et al., 2002), Delft 3D (Hsu et al., 2006 and 2008), RACE (Halcrow Group Ltd, 2007) include various applications, which offer limited functionalities and features (e.g. focusing on specific coastal processes or impacts) and do not support the implementation of ICZM principles. Moreover, even if climate change risks are more significant at the local and regional level, available DSSs often show low flexibility concerning the scale of analysis (e.g. the DIVA tool show low adaptability for increasing the spatial resolution of the assessment; Hinkel and Klein, 2007; 2009 and 2010a) and have significant constraints about data requirements and for their customization to new geographical regions (e.g. SimClim (Warrick, 2009), Wadbos (van Buuren et al., 2002), Delft 3D). In fact, DSSs addressing climate change issues in coastal zones are often developed for research purposes and are not directly accessible to the public (e.g. CORAL (Westmacott, 2001); Coastal Simulator (Nicholls et al., 2009); DITTY (Agnetis et al., 2006)), requiring medium-high levels of expertise (BTLESS, Delft3D, DIVA). Finally, they do not regularly integrate needs and questions from the policy debate by engaging stakeholders and decision-makers through participatory processes (ReGIS (Holman et al., 2008; Coastal Simulator and CVAT (Flax et al., 2002)).

As a consequence, the majority of available tools is not used in the real world to effectively integrate climate information in coastal zone management and support the formulation, application or evaluation of adaptation responses to climate change impacts.

The DEcision support SYstem for COastal climate change impact assessment (DESYCO), was designed to capture the regionally specific nature of climate change in coastal zones and to produce a spatially explicit assessment of risks, fostering decision-makers and long-term investors in the development of adaptation policies and measures.

The core of DESYCO is a spatially resolved Regional Risk Assessment methodology (RRA, Landis, 2005; Landis and Thomas, 2009) allowing to estimate the relative risks in the considered region, by comparing different hazards, stressors and vulnerable exposure units and then ranking targets and sub-areas at risk from climate change in the analysed region.

After a preliminary overview about the conceptual framework and the main steps of the RRA methodology, this paper presents the structure and software architecture of DESYCO, showing what the interfaces can offer to the end-user, and highlighting its capabilities for the diagnosis of climate change impacts across different case studies and the definition of adaptation options for coastal zone management and planning.

2. The Regional Risk Assessment Methodology.

Usually, RRA aims 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). It is a procedure allowing the evaluation of impacts produced by multiple sources of various stressors in multiple endpoints, considering the presence of multiple habitats (Landis, 2005; Landis and Thomas, 2009). The overall aim of the RRA methodology described in this paper is to help decision-makers in examining the possible consequences associated with uncertain future climate and identifying hot-spot areas and targets where adaptation measures could be required.

This Section presents the conceptual framework of the RRA, including an overview of coastal impacts that can be addressed, and the main steps of the methodology including hazard, exposure, susceptibility, risk and damage assessment.

2.1 Conceptual framework.

The RRA methodology was designed to address a variety of climate-related impacts in coastal zones (Figure 1), including the effect of hydrodynamic processes (e.g. storm surges flooding and inundation phenomena, coastal erosion), impacts on soil and groundwater (e.g. surface water drainage and saltwater intrusion), impacts on marine waters (e.g. seawater quality deterioration), and finally impacts affecting the biological component (e.g. impacts on vegetation and wetlands, on ecosystem productivity and on fishery and aquaculture). The overall focus of the methodology is on the complexity of physical-environmental impacts affecting the land-sea interface, which are tackled adopting the integrated (ecosystem-based, COM/2000/547) approach as guiding principle for the impact and risk assessment studies. Where relevant, the RRA framework is also applicable to address the cascading impacts on the socio-economic system, such as potential loss of economic and cultural values or impacts on population and human health.

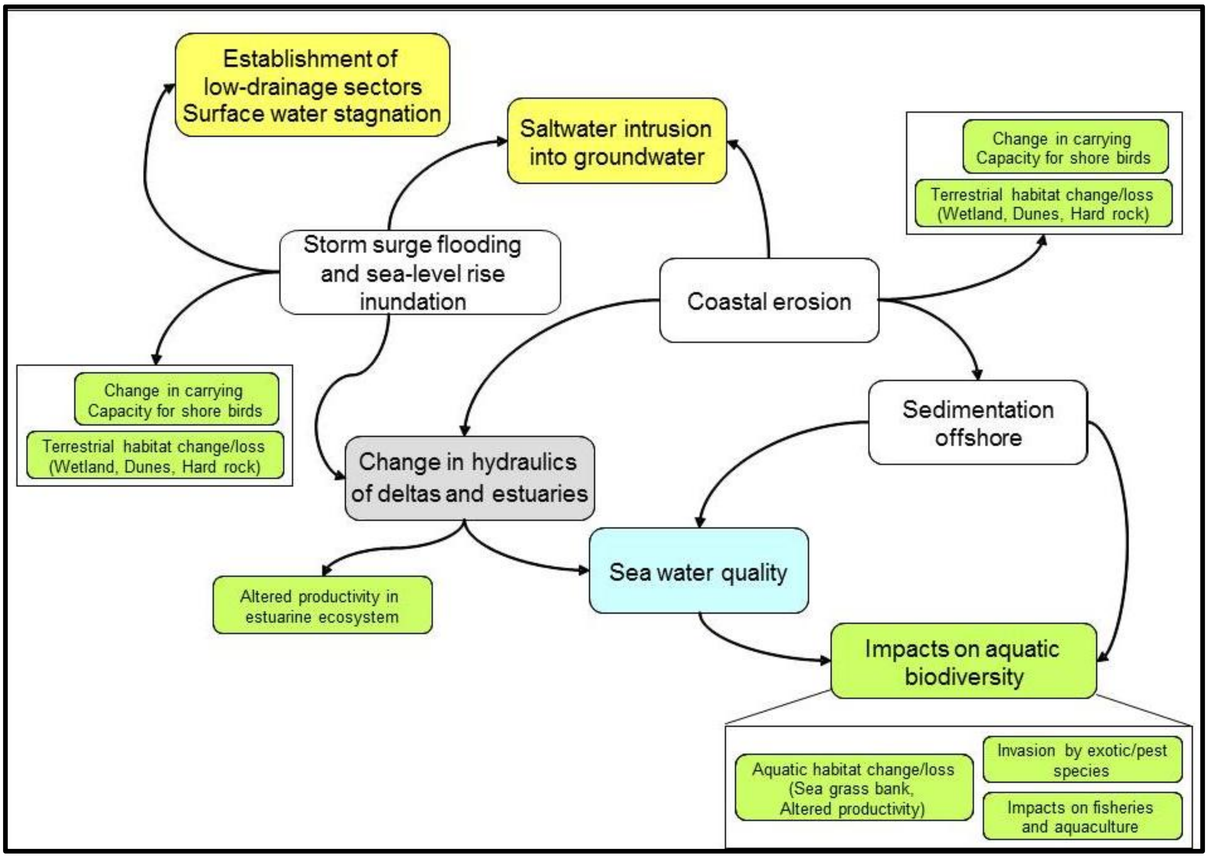


Figure 1. Interrelations among physical-environmental impacts of climate change in coastal areas: hydrodynamic impacts on coastline and sea bottom (white cells), hydrodynamic impacts in transitional environments (grey cells), impacts on sea water quality (blue cells), impacts on soil and groundwater (yellow cells), impacts on marine and terrestrial biodiversity (green cells).

The concept of risk, hazard and vulnerability are often interpreted in different ways, reflecting the evolution of a variety of scientific disciplines in the field of climate change and natural hazards communities (Romieu et al., 2010). A clear explanation of the adopted terminology is essential to support the proper use of risk assessment and decision support tools.

A key aspect of the RRA framework proposed in this paper is the distinction between two major determinants of risk: climate change hazard and vulnerability of a particular system (Figure 2).

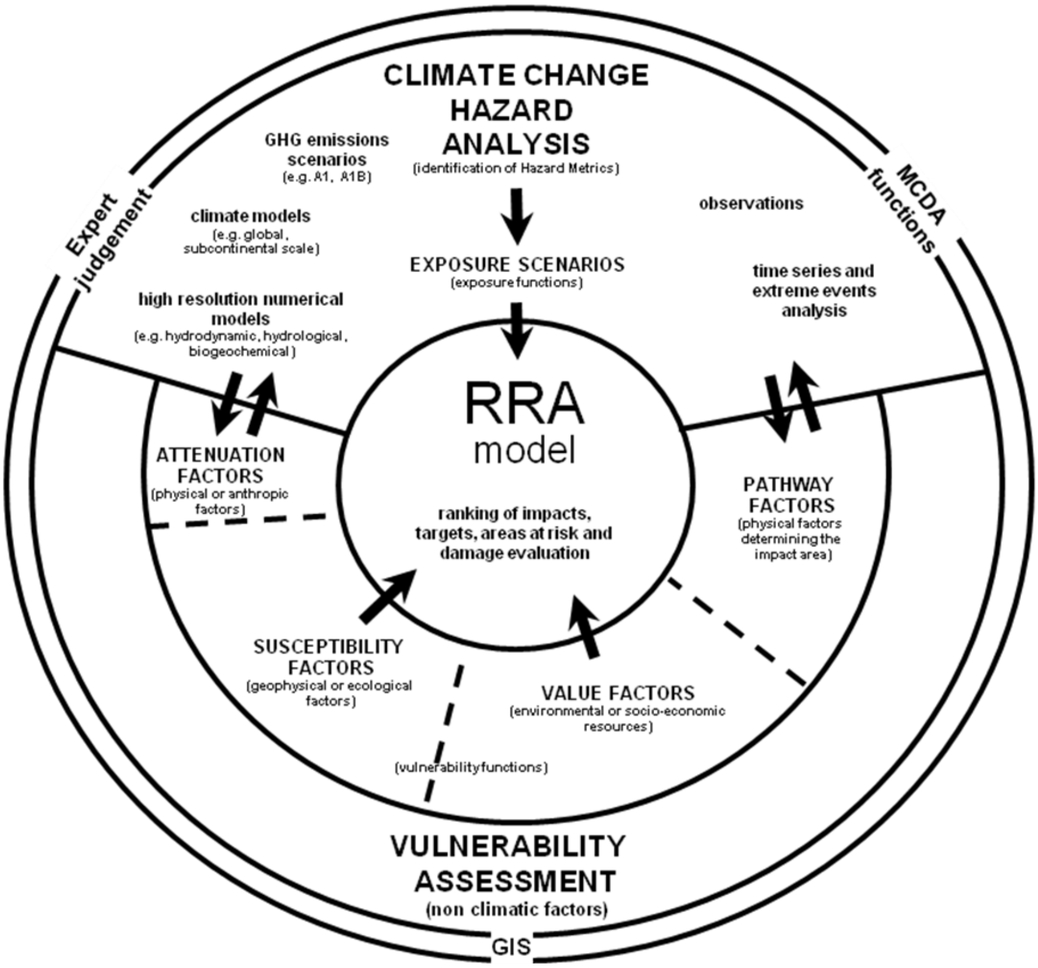


Figure 2. Regional Risk Assessment (RRA) conceptual framework.

According to the approach applied by the disaster risk community, hazard is considered as a physical event - related to climatic variability or change - that may cause the loss of life or social and economic disruption or environmental degradation (e.g. droughts, floods, storms, episodes of heavy rainfall, sea-level rise inundation) (UNISDR, 2009). Basic data supporting hazard analysis include climate simulations running at the global and the sub-continental scale and simulations of cascading physical processes performed by high resolution numerical models for the region of concern (e.g. hydrodynamic, biogeochemical and hydrological models). Simulations can be related to different scenarios of greenhouse gas emissions and aerosol (e.g. IPCC-AR4 emission scenarios) (Nakicenovic et al., 2000) or AR5 representative concentration pathways (Moss et al., 2010). Finally, useful information in constructing hazard scenarios include the analysis of observations and time series of climate parameters and extreme events. The output of numerical models (or time series analysis) produces the so called *hazard metrics* ($h_{k,s}$) used in the RRA to characterize the location, intensity, frequency or probability of the hazard.

The second main component of the RRA framework is vulnerability, that, according to UNISDR (2009), is considered as a multidisciplinary concept encompassing the site-specific characteristics of a community increasing its sensitivity to hazards' impacts (e.g. physical, social, economic, and environmental factors). In the specific RRA framework vulnerability assessment requires the analysis of four main categories of factors: *susceptibility factors (sf), value factors* (*vf*), *attenuation factors* (*af*) and *pathway factors* (*pf*). *sf* are used to determine the susceptibility of a receptor to climate change hazards. Susceptibility is mostly represented by geo-physical or ecological factors (e.g. geomorphology, sediment budget, vegetation cover) and corresponds to the degree to which a receptor could be affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2007). Accordingly, *sf* denote the dose-response relationship between the exposure of a receptor to climate stimuli and the resulting effects (Füssel and Klein, 2006). *vf* identify relevant environmental and socio-economic values of the receptors that need to be preserved for the interest of the community (e.g. land use, fishing areas, population density). *af* are elements that attenuate the intensity of the hazard associated with an impact: for instance, an artificial structure (e.g. a dike) able to reduce the hazard related to a storm surge flooding or to coastal erosion. Finally, *pf* stands for physical characteristics of the receptors (e.g. elevation, distance from coastline) which determine the possibility that climate change hazards would occur and therefore will support the identification of potential exposure areas.

Within the RRA methodology (paragraph 2.3), Multi Criteria Decision Analysis (MCDA) techniques are used to aggregate and normalize vulnerability and hazard parameters, in order to evaluate and rank targets, areas and risks from climate change at the regional scale. Geographic Information Systems (GISs) are used to manage, manipulate, process, map and spatially organize data to facilitate hazard, vulnerability and risk analysis. As described in the following paragraph, experts' opinions and judgments are integrated, directly or indirectly, at each step of the RRA process (i.e. from hazard characterization to risk assessment) and are particularly important for the assignment of weights and scores to vulnerability and hazard parameters.

2.2 Steps for the application of the regional risk assessment methodology.

As shown in Figure 3, the RRA methodology requires several steps for its application.

Hazard and the vulnerability matrixes are used to collect input data needed to apply the RRA and to identify all the components contributing to the computation of risk in the case study area (i.e. stressors, impacts and receptors) and their relationships.

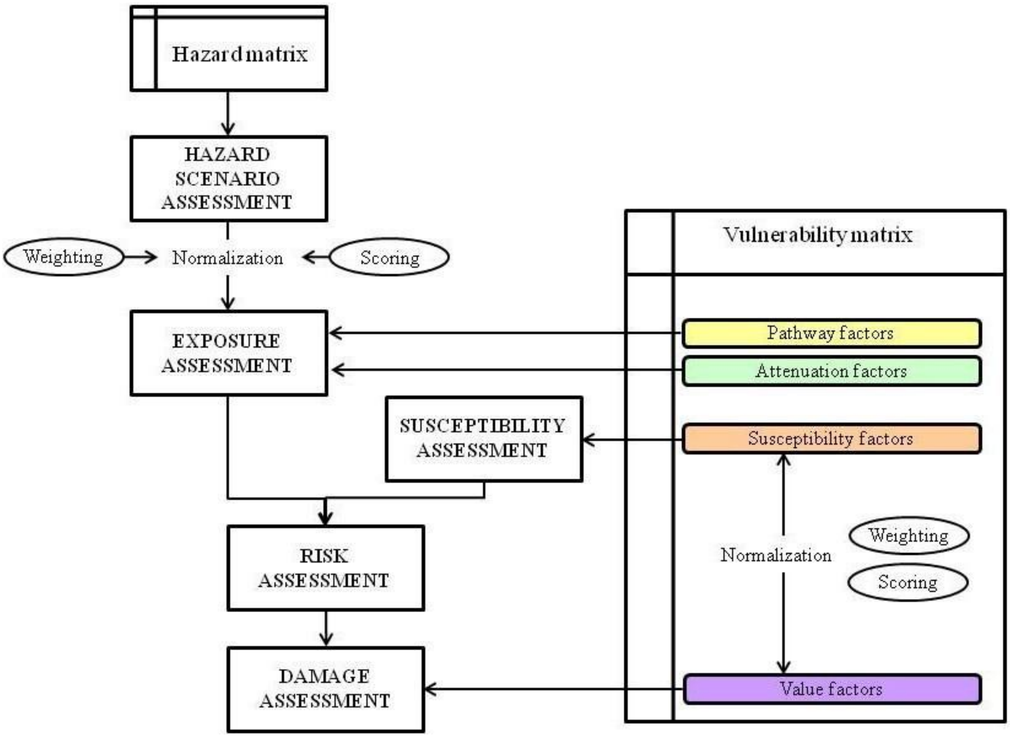


Figure 3. Steps for the application of the Regional Risk Assessment methodology.

The vulnerability matrix (Table SM1) identifies the elements at risk (or receptors) which are considered in the RRA procedure. Receptors represent natural or anthropogenic systems of interest due to ecological, economic or social reasons and are not equally affected by climate change hazards (UKCIP, 2003). A variety of vulnerability factors - employed in different stages of the RRA procedure - is included in the matrix: *pf* and *af* are defined according to each climate change impact; *sf* are defined based on the impact and receptor considered in the assessment; finally, *vf*, are defined based on each specific receptor.

The hazard matrix (Table SM2) identifies the stressors determining the investigated impacts and the hazard metrics which are then used in the Hazard scenario assessment phase. Each climate change impact can be caused by an ensemble of one or more stressors. A stressor can be defined as the cause of environmental hazard which impacts large geographic areas and can create a regional hazard to a population, species or ecosystems (Hunsaker et al., 1990). Each stressor can be characterized by one or more hazard metrics (*hm*) that are quantitative measures of climate variables, deriving from statistical analysis of past measurement of weather, or from numerical models projections (UKCIP, 2003). Overall, the vulnerability and hazard matrixes are flexible tools that needs to be adapted to the user purposes, to the specific case study context and according to the available dataset.

The first step for the implementation of the RRA is the **Hazard scenario assessment** that is aimed at the characterization of climate change hazards that impact on a system. Climate change hazard scenarios *s* aggregate *hm* values based on a specific timeframe (e.g. 2070-2100) and a given climate forcing (e.g. A1B) in order to determine the future conditions of hazard to climatic changes against which a system needs to adapt in order to keep its ecological or socio-economical functions. They can consider not only changes in the mean state of climate but also changes in climate variability and extremes, compared to a baseline reference scenario.

The second phase of RRA is the **Exposure assessment** that aims at identifying and classifying areas where the hazard can be in contact with the target (i.e. potential impacted areas). For impacts affecting the terrestrial coastal environment (e.g. sea level rise inundation, storm surge flooding) the exposure function is used to project the information provided by sea water models inland.

In the Exposure assessment phase the *hm* are first normalized through the assignation of scores and weights and then aggregated with *pf* and *af* using Exposure functions.

The following **Susceptibility assessment phase** is aimed at evaluating the degree to which the receptors could be affected by a given climate change impact, based on site-specific territorial information. Specifically, susceptibility assessment brings in the assessment of how much the receptors could potentially be harmed by a hazard, given their intrinsic characteristics (in physical-environmental and non-monetary terms). To this aim, the susceptibility assessment aggregates *sf* defined in the vulnerability matrix for each receptor *j* using a function based on MCDA methods. The application of the susceptibility function requires that each susceptibility factor (*sf*) is first classified, scored and weighted, taking into account the expert judgment.

The **Risk assessment phase** is aimed at integrating information about the exposure to a given hazard scenario and the receptors' susceptibility, allowing identification and prioritization of areas and targets at risk in the case study area by means of a relative risk score R_{jks}.

Finally, the **Damage assessment phase** aggregates the results of the Risk assessment with the assessment of the environmental and socio-economic value of a receptor, in order to provide a relative estimation of the potential social, economic and environmental losses associated with targets and areas at risk in the case study area (EC, 2007a). The estimate of the receptors' value (Va_j) is performed aggregating the *vf* included in the vulnerability matrix and normalized through the assignation of scores and weights, by means of MCDA functions. Then, the damage function allows the identification and prioritization of the potential losses associated with targets and areas at risk in the considered region, supporting the identification of areas which require prior adaptation actions to prevent socio-economic losses related to climate change. More details about the functions implemented by the RRA model can be found in the supplementary material available on-line (Table SM3).

Each step of the RRA can be easily performed using the DSS DESYCO in order to develop GIS-based exposure, susceptibility, risk and damage maps (Figure 4).

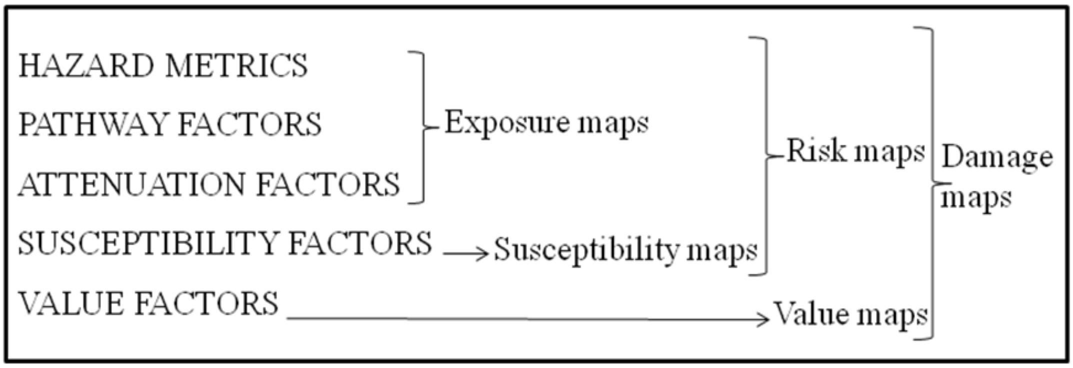


Figure 4. Output maps derived from the RRA methodology.

As described in more detail in Section 3, all these maps are in raster format (i.e. cell based maps) and allow to establish relative priorities for intervention, providing a basis for coastal zone management and land use planning in light of the potential consequences of climate change. Moreover, through the DESYCO tool several statistics can be calculated in order to synthesize relevant information coming from RRA maps (e.g. percentage of receptors associated with each risk/damage class, percentage and surface of receptors with higher risk/damage scores for each administrative unit) and support the decision making process.

3. THE DSS DESYCO

The DSS DESYCO is the computerized tool implementing the RRA approach described in Section 2. It was developed in 2010 (as a product of the CMCC-FISR Interministerial Italian Project) with a first software release for the integrated assessment and management of different climate change impacts in coastal areas and related ecosystems (e.g. beaches, river deltas, estuaries and lagoons, wetlands, forests, protected areas, urban and agricultural areas), and then upgraded with new modules for groundwater bodies and river basins (GEMINA Interministerial Italian Project). The actual version of the DSS enables the user to quickly evaluate information about future climate change scenarios as well as environmental and socio-economic vulnerabilities, in order to assist planners and decision makers in the formulation of adaptation and risk management strategies.

The following sections illustrate the software architecture and its technical features, highlighting the functionalities offered by the tool for planning and management purposes, across different typologies of case studies.

3.1 DESYCO structure, software architecture and technical features.

The structure of DESYCO is composed of 4 main components: a geodatabase for the storage of environmental and socio-economic data related to the study area; a multi-scale scenarios module to deal with data provided by numerical models simulations or time series analysis; a Relative Risk Model (RRM) that integrates Multi Criteria Decision Analysis (MCDA) techniques for the application of the RRA methodology; Graphical User Interfaces (GUI) facilitate the interaction of the final user with the system and simplify results analysis and understanding.

In order to make the software easily extendable with a high level of flexibility and interoperability, DESYCO was implemented on a multi-tier architecture composed of three levels: Data tier, Logic tier and Presentation tier (Figure 5). The software was developed by making use of two open source libraries for the management of geographic data, i.e. GDAL and OGR, and programmed using the Phyton and C# languages. The GDAL and the OGR libraries were selected taking into account their wide applicability and stability; they represent the *de facto* standards for open source GIS-based applications. GDAL (http://www.gdal.org) is a translator library for the management of raster geospatial data formats, while OGR (http://www.gdal.org/ogr/), which is a subproject of GDAL, is a C++ library providing access to a variety of vector file formats. The choice of using open source libraries and applications, which adoption is continuously increasing over the last years, allows DESYCO to be independent from commercial, and often expensive, software. Moreover the number of people voluntarily supporting the development and maintenance of these libraries is rapidly growing following the general growth of open source software (Martinez-Torres M. R. et al., 2014).

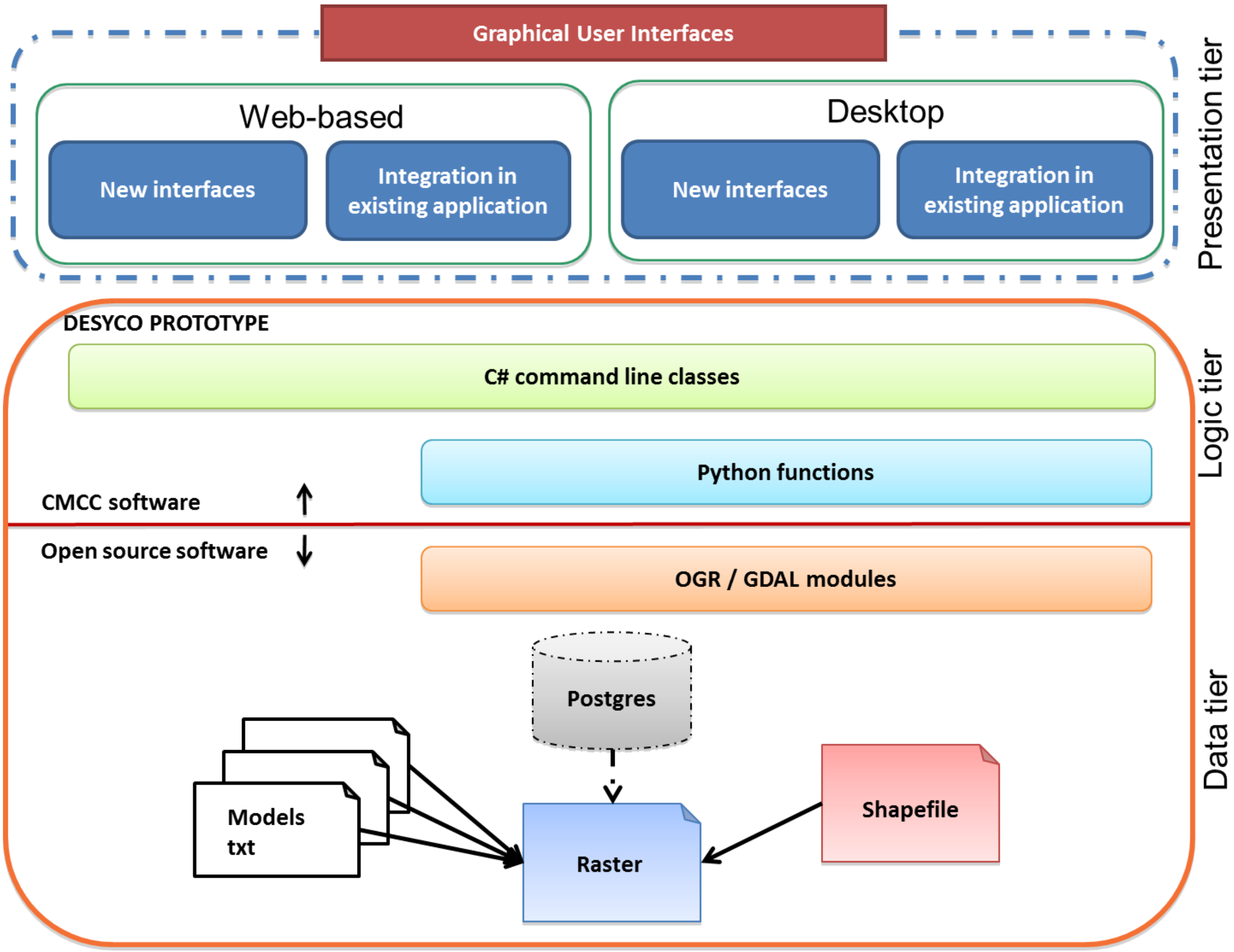


Figure 5. The multi-tier architecture of DESYCO.

The **first tier** of the software architecture, the Data Tier, is represented by a geodatabase and by system folders containing input and output data elaborated by the software. Input data are represented by environmental and socio-economic data related to the area of concern and useful to represent pathway, attenuation, susceptibility, and value factors (e.g. coastal topography, geomorphology, presence and distribution of vegetation cover, location of artificial protection etc.). Moreover, input data include parameters provided by numerical models or time series analysis, representing hazard metrics in the RRA (e.g. temperature, precipitation, sea level rise projections etc.). For each case study area all input data must be homogenized before being loaded through the software's GUI in order to have the same reference system, geographical extension and pixel dimension.

Output data are represented by exposure, susceptibility, risk and damage maps elaborated during the application of the RRA methodology, by statistics calculated at the end of the assessment and by a report showing the main results and all the configuration parameters (e.g. scores and weights used for *sf* and *vf*).

The **Logic Tier**, corresponding to the second level of the architecture, is a library composed of basic and advanced functions implementing the RRA’s equations (Table SM3). The basic functions represent building blocks allowing to perform simple, general, operations (i.e. weighted sum, probabilistic or, weighted average) required by the RRA model. Such functions are then integrated into advanced functions allowing to perform all the complex operations required by the RRA model (i.e. hazard, exposure, susceptibility, risk, value and damage functions). Basic functions were programmed in Python, and make use of the open source libraries GDAL and OGR, while advanced functions were programmed in C#.

Finally, the third level, the **Presentation Tier**, is represented by the Graphical User Interfaces (GUI). This tier manages all the interactions between the system and the user and allow to deal with the different steps of the application. Due to the layered architecture of DESYCO, its GUI can be implemented both in desktop or web environments. More specifically, the DSS can have desktop interfaces within stand-alone applications (e.g. as a Java application executable in different operating systems) or it can be integrated as a plug-in within third parties’ open source (e.g. QGIS) or commercial (e.g. ArcGIS) GIS software. The same also applies for web interfaces which can be stand-alone applications or integrations of new modules within existing web applications (e.g. p.mapper). The first version of DESYCO was implemented as a C# stand-alone application which can be launched directly as well as from the QGIS (Quantum GIS, http://www.qgis.org) open source software.

The specific technical features offered by the software for the potential DSS end-users are summarized in Table 1.

The flexible and modular approach of the DSS make it particularly useful to investigate the consequences of a variety of climate change impacts in different geographical contexts and at different spatio-temporal scales. Moreover, the tool allows an easy customization of input data (e.g. receptors, vulnerability factors and hazard scenarios), including the possibility to select scores and weights to be applied in the RRA, and is integrated with GIS functionalities, facilitating the spatial analysis and visualization of risk maps.

Technical features	Specification
Multi-scale spatial assessment	In principle the tool can be used at different spatial scales i.e., from a broader level (e.g. national, supranational and continental scale) to a more detailed one (e.g. regional and local scale). The spatial scale of analysis depend on the purposes of the assessment and on the availability of future scenarios from climate and physical impact models and datasets to characterize vulnerability.
Flexible temporal analysis	Possibility to tailor the assessment for different future timeframes depending on the availability of information about future scenarios, stakeholder needs and management purposes.
Geographic flexibility	The tool allows to manage different input data (e.g. climatic data, land cover and land use, geomorphological maps, protected areas maps, topography models) for different typologies of case studies and geographical areas.
Multi-impacts assessment	Possibility to perform the assessment for a variety of climate change impacts in coastal areas (e.g. sea level rise inundation, coastal erosion, storm surge flooding), groundwater bodies and river basins (e.g. groundwater table level variations, saltwater intrusion, river floods), facilitating the prioritization of elements at risk in the considered region.
Multi-target assessment	Possibility to consider different natural and human receptors (e.g. beaches, wetlands, forests, protected areas, groundwater, urban and agricultural areas) potentially affected by climate change impacts in the considered case study area.
Multi-Criteria Decision Analysis (MCDA) features	A tiered MCDA module to perform operatively each step of the RRA (i.e. exposure, susceptibility, risk and damage assessment), integrating step by step climate scenarios and environmental modeling outputs (e.g. global/regional climate projections, hydrodynamic/hydrological and biogeochemical simulations) with environmental/socio-economic vulnerability factors.
Customization according to end-user needs	Possibility to customize the assessment selecting receptors, vulnerability factors and hazard scenarios to be considered within the case study area. Scores and weights used for MCDA can be tailored according to stakeholders' preferences and experts' judgments.
GIS spatial analysis and bi-dimensional visualization of risk maps	Possibility to import data with different formats compatible with GIS (e.g. raster, vector or text files). The user can explore interactively two-dimensional exposure, susceptibility, risk and damage maps allowing the localization and prioritization of targets and areas vulnerable to or at risk from different climate change impacts. GIS spatial analysis tools can be used to calculate indicators and indexes (e.g. distance and surface calculation) and perform vector analysis (e.g. overlap, intersection, union, merge).

Table 1. Technical features offered by the DESYCO tool for the potential DSS end-users.

3.2 Functionalities for stakeholders across case studies

Typical applications of the DSS are performed by a team of experts and technicians (e.g. climate experts, physical impact modelers, risks experts, GIS analysts) and require a strong involvement of stakeholders and decision makers potentially interested in the output produced by the tool.

Different categories of stakeholders, with authority levels ranging from the macro to the micro scale in the field of coastal, marine and water management (e.g. regional agencies for the protection of the environment, municipalities, basin and port authorities, irrigation consortia) were therefore engaged at different stages of development of DESYCO and RRA in order to improve the functionalities offered by the DSS for potential end-users' and provide customized risk-based adaptation services useful to plan effective adaptation policies (Table 2).

Stakeholders were involved in a continuous dialogue with the developers of DESYCO by means of targeted workshops, questionnaires and thematic groups (Santoro et al., 2013; Giannini et al., 2012; Pasini et al., 2012; UNIVE team, 2013).

Macro

Level	Istitution
Supranational	Adriatic Euroregion
National	Institute for Environmental Protection and Research
	Civil Protection
Inter-regional	Water authorities
	River Basin authorities
Regional	Public works offices
	Soil conservation services
	City and infrastructures planning services
	Integrated hydric services
	Geologic services
	Regional meteorological services
	Regional agencies for the protection of the environment
Local	Provinces
	Municipalities
	Park, reserves and protected areas authorities
	Tidal forecasting centre
Independent authorities	Port authorities
	Energy authorities
	Industrial areas consortium
	Irrigation consortium

Micro

Table 2. Different categories of stakeholders involved in different stages of development of DESYCO (adapted from Giannini et al., 2012).

Results from the participatory processes were fully implemented to improve: the RRA methodological framework (e.g. in terms of terminology and input data such as receptors, vulnerability factors and thresholds); the output format and layout (e.g. methods of classification for risk maps and statistics, colours of legends); the software architecture (e.g. the graphical interfaces and functionalities provided by the tool).

The actual version of DESYCO offers a range of functionalities that were tested in a variety of case studies (Figure 6) to tackle a range of site-specific risk assessment and management problems in a changing climate perspective, for coastal, marine and water management authorities (Table 3).

In order to aid decision-making processes in coastal zones, DESYCO can be used to evaluate different climate-related impacts on both land and sea, thus providing coastal managers with effective information for the management of 'land-sea interface', as required by the recent European proposal establishing a framework for Maritime Spatial Planning (MSP) and integrated coastal management (COM/2013/0133). Integrating projections from climate and oceanic models, the tool offers the possibility to develop climate-proofed plans and policies for shoreline management, including the definition of SLR and CE measures (e.g. beach nourishment, sea barriers and gates, shores' plans regulating settlements, concessions and activities along the coast) (Torresan et al., 2014; Gallina et al., 2014).

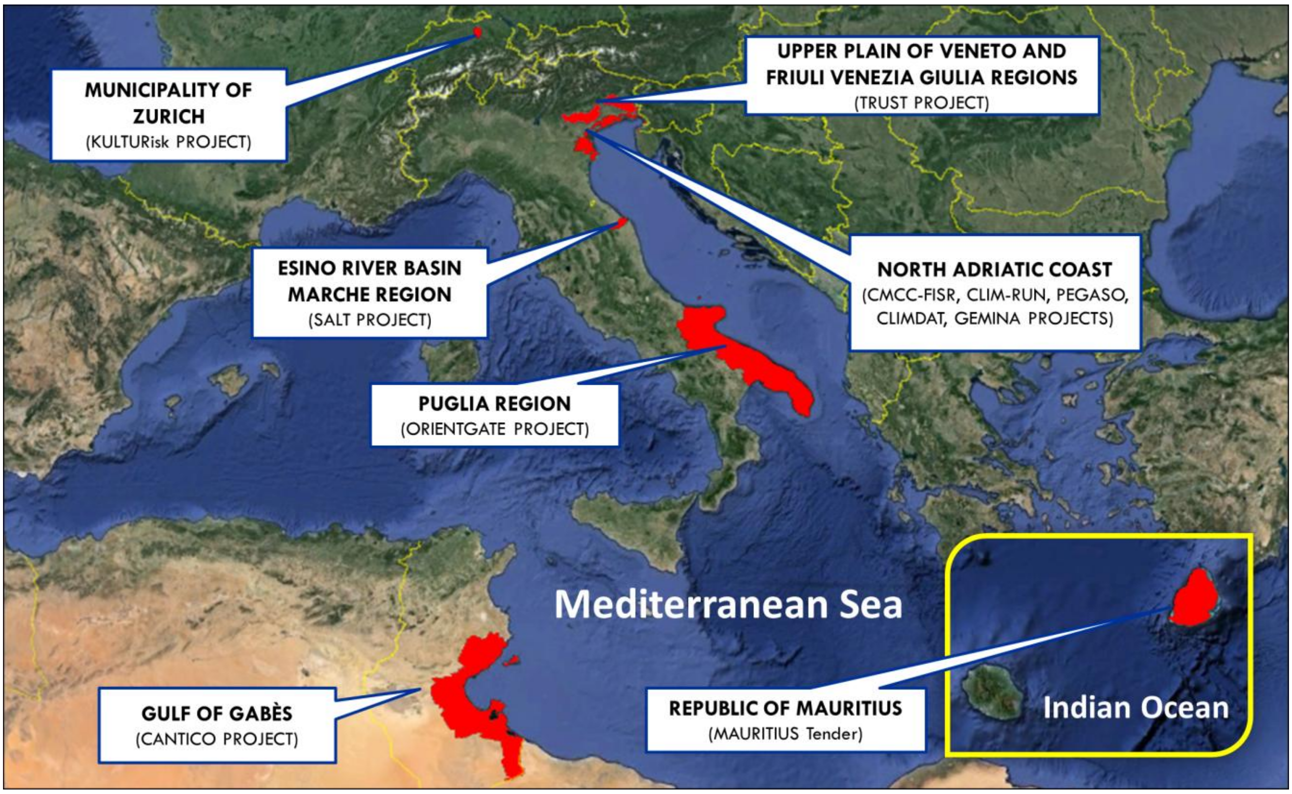


Figure 6. Case study areas and projects analyzed with the RRA approach and the DESYCO tool.

ACRONYMS (FUNDING PROGRAM): KULTURisk - **K**nowledge-based approach to develop a c**ULTU**re of **Risk** prevention (FP7); TRUST - Tool for regional scale assessment of groundwater storage improvement in adaptation to climate change (Life +); SALT - **S**ustainable m**A**nagement of the Esino river basin to prevent saline intrusion in the coasta**L** aquifer in consideration of clima**T**e change (Life +); CMCC-FISR – Italian Special Integrative Fund for Research and the development of the Euro-Mediterranean Centre for Climate change; CLIM-RUN – Local **Clim**ate Informations to **R**espond to **U**sers **N**eeds (FP7); PEGASO - **P**eople for **E**cosystem Based **G**overnance in **A**ssessing **S**ustainable Development of **O**cean and Coast (FP7); CLIMDAT – **Clim**ate **Dat**a and Scenarios for assessing the impacts coastal impacts induced by climatic changes in the North Adriatic (National project); GEMINA – Italian project consolidating the CMCC centre (Italian funds for Research); CANTICO - **C**limate and local **AN**thropogenic drivers and impacts for the **T**unis**I**an **CO**astal area (ERA-NET); MAURITIUS - Consultancy Services for the Development of an Inundation, Flooding and Landslide National Risk Profile, Maps, Strategy Framework and Action Plans for Disaster Risk Management for the Republic of Mauritius (UNDP -African Adaptation Program).

For the problems related to the marine environment, DESYCO can be used as screening tool to evaluate the potential variations of water quality (and the related impacts for marine ecosystems and economic activities) under future climate scenarios, by allowing the selection of different indicators of pressures and state related to the environmental descriptors included in the Marine Strategy Framework Directive 2008/56/EC. Accordingly, it can be used for assisting national and regional authorities in the evaluation of risks of not achieving the good environmental status of marine regions, as legally required by the MSFD (Rizzi et al., 2014).

A) Coastal and marine environment				
Location of case study area	**Scale (surface area)**	**Reference**	**Analyzed impacts**	**Decision/management problem**
North Adriatic (Italy)	Regional: Veneto and Friuli-Venezia Giulia (20.218 Km^2)	Torresan et al., 2014; Gallina et al., 2014; Rizzi et al., 2014; Rousset et al., 2014; Santoro et al., 2013; Torresan et al., 2012; Unive Team, 2013.	Sea level rise inundation; coastal erosion; storm surge flooding; seawater quality variations; pluvial floods.	Improve coastal zone management and planning considering the impacts on coasts coming from both land and marine physical hazards related to climate changes.
	Local: Venice Municipality (415 Km^2)	Rousset et al., 2014; Torresan et al., 2013; Giannini et al., 2012.		
Gulf of Gabes (Tunisia)	Regional/sub-national (74.373 Km^2)	Lamon et al., 2014.	Storm surge flooding; sea level rise inundation; seawater quality variations.	Define Integrated Coastal Zone Management (ICZM) options considering local effects of climate change scenarios.
Republic of Mauritius	Regional/sub-national (2.040 Km^2)	Republic of Mauritius, 2012.	Storm surge flooding and sea level rise inundation.	Design and implement a strategy framework and action plans for disaster risk management in coastal zones.

Key functionalities addressed for risk assessment:	**Key functionalities addressed for risk management:**
Which bio-physical and environmental factors (e.g. land use, permeability, slope) contribute to increase the vulnerability to climate change impacts?	Which conservation measures (e.g., restoration of vegetation communities or dunes, reshape of beaches) can be more effective for increasing the resilience of coast to climate-related impacts?
Which key natural receptors along the coast are more vulnerable to climate change impacts?	Where investments on coastal disaster mitigation and climate adaptation measures could be required in order to prevent and reduce the effect of storm surge/coastal erosion under changing climate?
Which coastal areas and receptors could be more submerged by sea level rise according to future climate change scenarios?	How to integrate the information concerning future climate change scenarios in the development of new building regulations and urban plans?
How different climate change scenarios will affect coastal ecosystems? And which will produce the higher impact?	How to manage uncertainty linked with climate models' projections to minimize potential harms and losses?
How much climate change will affect the occurrence of emergencies due to extreme events (e.g. heavy precipitations, storm surges)?	How to define coastal zoning and shoreline protection (e.g. dike building and beach nourishment) in climate risk areas?
How much climate change will affect water quality and therefore the risk of not achieving the Good Environmental Status in marine ecosystems?	Which measures and policies are required for maintaining marine ecosystems in a healthy, productive and resilient condition, in view of climate change?

B) Groundwater				
Location of case study area	**Scale (surface area)**	**Reference**	**Analyzed impacts**	**Decision/management problem**
Upper plain of Veneto and Friuli Venezia Giulia regions (Italy)	Regional/ sub-national (4.100 Km²)	Baruffi et al., 2012; Pasini et al., 2012.	Groundwater table level variation; changes in nitrate infiltration processes; changes in water availability for irrigation.	Identify measures to manage groundwater resources in adaptation to climate change.
Esino river basin - Marche region (Italy)	Local (1.203 Km²)	Iyalomhe et al., 2014.	Groundwater table level variation; Saltwater intrusion.	Define remediation actions to be incorporated to the river basin planning measures in order to prevent salt intrusion increasing in the coastal aquifer induced by climate change.

Key functionalities addressed for risk assessment:	**Key functionalities addressed for risk management:**
What will be the effect of future climate change scenarios on groundwater quantity and quality?	Which adaptation measures should be taken to maintain sustainable use of groundwater resource in the future (e.g. artificial aquifer recharge)?
What is the trend of nitrate infiltration in groundwater under future climate change scenarios?	How to adapt the spatial configuration of ecosystems to optimize the rate and quality of natural aquifer recharge?
How surface ecosystems (i.e. natural and semi-natural environments, agricultural areas and wetlands) will be affected by groundwater level lowering under changing climate?	How to avoid over-abstraction of groundwater and the related loss of highly valued ecosystems (e.g., wetlands, forests, spring waters)?
What is the trend of salt intrusion in the case study area under future climate change scenario?	Which adaptation actions are needed to maintain the quality of groundwater for domestic, industrial and irrigation use (e.g. process of nitrate reduction or desalination treatment)?

C) River basins				
Location of case study area	**Scale (surface area)**	**Reference**	**Analyzed impacts**	**Decision/management problem**
Puglia region (Italy)	Regional (19.345 Km²)	Orientgate WP5 report, 2014.	Hydrological droughts on water quantity/quality and consequences for human uses (i.e. irrigation, domestic, industrial)	Implement concerted and coordinated climate adaptation actions in order to improve water resources management and planning.
Zurigo (Switzerland)	Local (78 Km²)	Ronco et al., 2014a,b.	Floods/urban floods	Reducing and mitigating the impact of floods on sensible targets.

Key functionalities addressed for risk assessment:	**Key functionalities addressed for risk management:**
What will be the effect of future climate change scenarios on water supply for irrigation?	Where allocate resources and investments in order to increase resilience and implement risk reduction plans to avoid flood-related damages?
What type of crop will be more affected by meteorological and hydrological drought?	Where changes in urban infrastructures (i.e. network of roads, railways and drainage systems) are required to better cope with weather variability and future climate perturbations?
Which targets (e.g. people, infrastructures, human activities, cultural heritage and ecosystem services) will be at risk of flooding? And how to quantify damages and losses of these extreme events?	Which risk hotspots require the implementation of specific early warning systems and preparedness actions for disaster risk reduction?
How to produce flood hazard and risk maps comparing baseline and alternative scenarios, including climate change?	How to manage the agricultural sector in order to reduce economic losses in future climate change scenarios (e.g. implementation of diversified and drought-resistant crops)?

Table 3. Summary of DESYCO testing areas: location, scale and surface of case studies, impacts assessed, decision problems and functionalities addressed for risk assessment and management purposes in coastal and marine environment a); groundwater b) and river basins c).

Concerning surface and groundwater management, DESYCO can elaborate the output from hydrological and hydrogeological models to assist river basin authorities in planning adaptation measures aimed at avoiding future impacts of climate change on natural environments and agricultural systems potentially affected by water scarcity, and to evaluate different scenarios of availability (or lack) of water resources for human uses (e.g. irrigation, domestic, industrial) (Pasini et al., 2012). Moreover, the tool can be easily used to project the consequences of sea level rise on coastal aquifers, providing useful information for defining remediation actions against saltwater intrusion under different climate change scenarios (Iyalomhe F. et al., 2014).

Finally, by evaluating the potential consequences of drought (or changed climatic regime) on river run-off and/or groundwater infiltration, as well as the presence of punctual and diffuse sources of nutrients and pollutants, the tool can also be used to evaluate the negative effect of climate change on water quality, supporting the implementation of the Water Framework Directive 2000/60/EC and the Groundwater Directive 2006/118/EC (Pasini et al., 2012).

As far as extreme events are concerned, DESYCO and the RRA can be used to tackle the issues posed by river, coastal and pluvial flood hazards in different typologies of case studies (e.g. low-lying coastal plains, small and large catchments, urban areas), providing specific functionalities for the assessment and management of flood risks for different elements at risk (i.e. buildings, population, infrastructures, cultural heritage) and hazard scenarios (e.g. floods with low, medium and high probability of occurrence), as required by the Flood Directive 2007/60/EC (Ronco et al., 2014a,b, Torresan et al., 2013). Flood hazard mapping, integrated with climate projections, exposure and vulnerability assessment, is used by the DSS to create risk maps that can be used to plan disaster mitigation measures aimed at preventing or reducing the impact of natural hazards in the medium and long term.

Climate risk scenarios offered by the tool can also be operationally used for Strategic Environmental Assessments (SEAs) which requires to evaluate significant effects of climate change in the development of Plans, Programmes and Policies (PPPs) since the early stage of the planning process (Directive 2001/42/EC). In this context DESYCO can assist end-users in the complex process of development of climate-proofed PPPs, considering the interconnections between land-use planning, climate adaptation and disaster prevention.

3.3 DESYCO interfaces and output

The Graphical User Interfaces (GUI) of DESYCO have been designed in order to simplify the interaction of the end-user with the system and to facilitate results' visualization and understanding. Different interfaces and tabs allow the sequential navigation through the steps of the RRA methodology (Paragraph 2.3), supporting the upload of all the input data required to apply the DSS to a specific case study (e.g. hazard metrics, susceptibility, value, pathway and attenuation factors). All data loaded in the DSS are listed in the 'project interface' (Figure 7) which represents, within a case study, the link between the different elements involved in the RRA methodology (future hazard scenarios, impacts, receptors, susceptibility and value factors).

Project interface enables the user to perform one or more projects for the same case study, combining in different way the same input data to define and thus analyse several risk scenarios.

Once all the input data are loaded, the user can start the assessment phase by means of the assessment interface (Figure 8) designed to perform all the steps of the RRA methodology and produce a GIS map for each step (i.e. exposure, susceptibility, risk and damage maps) (Figures 9 to 13).

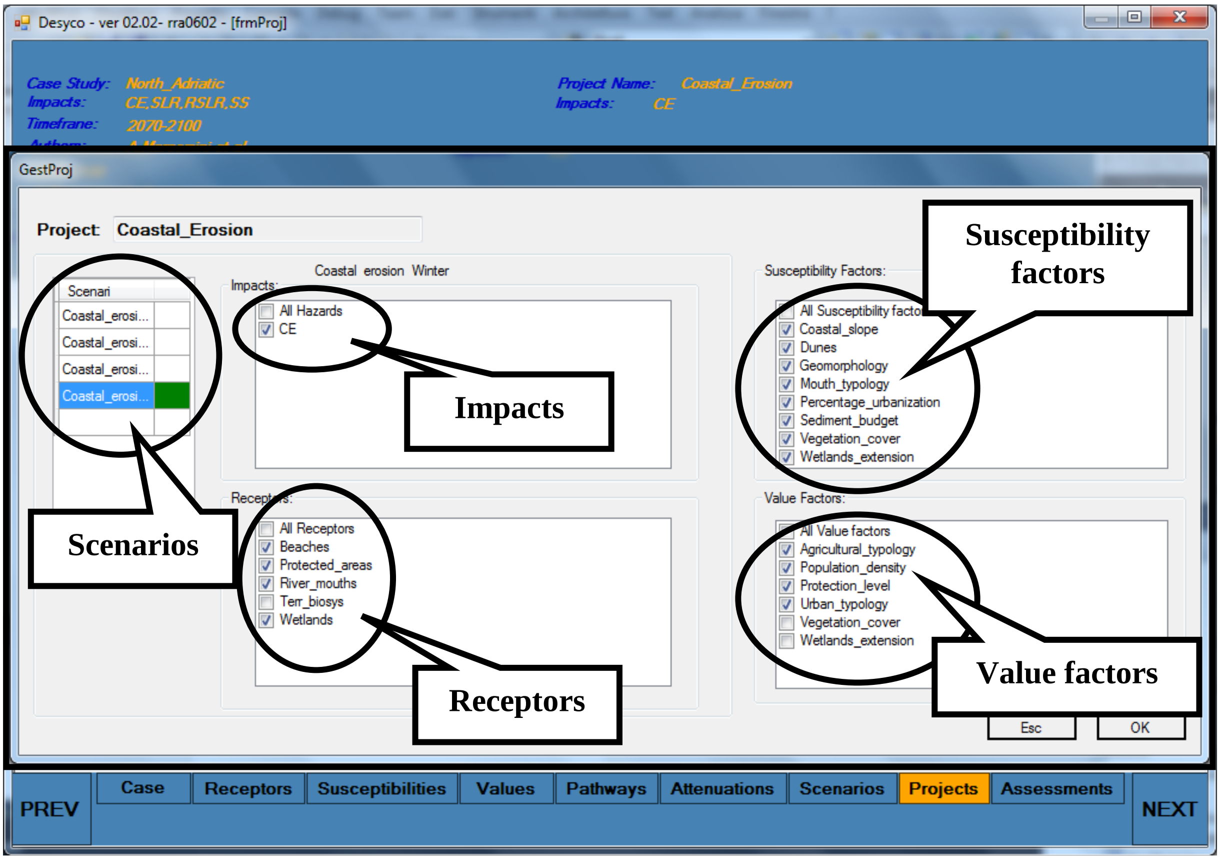


Figure 7. Project interface of DESYCO: panels for the selection of hazard scenarios, impacts receptors, susceptibility and value factors.

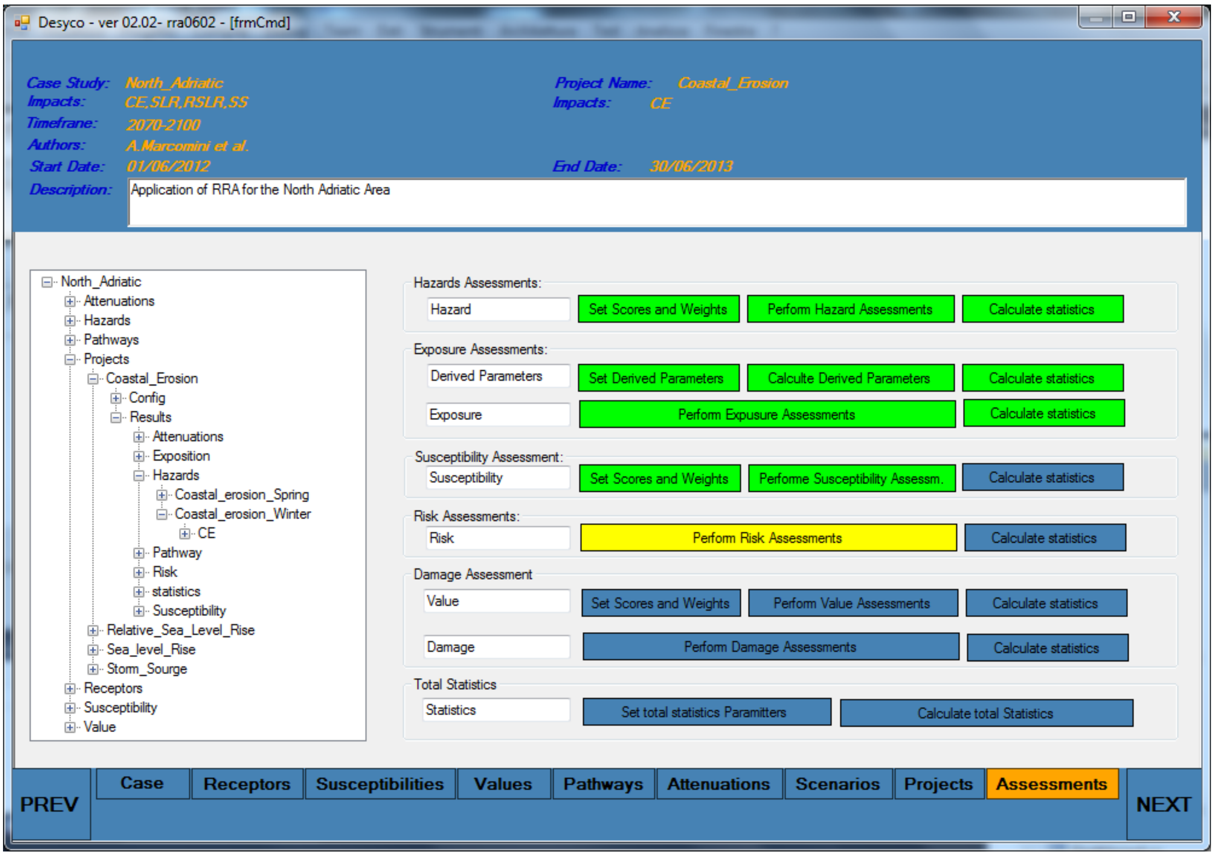
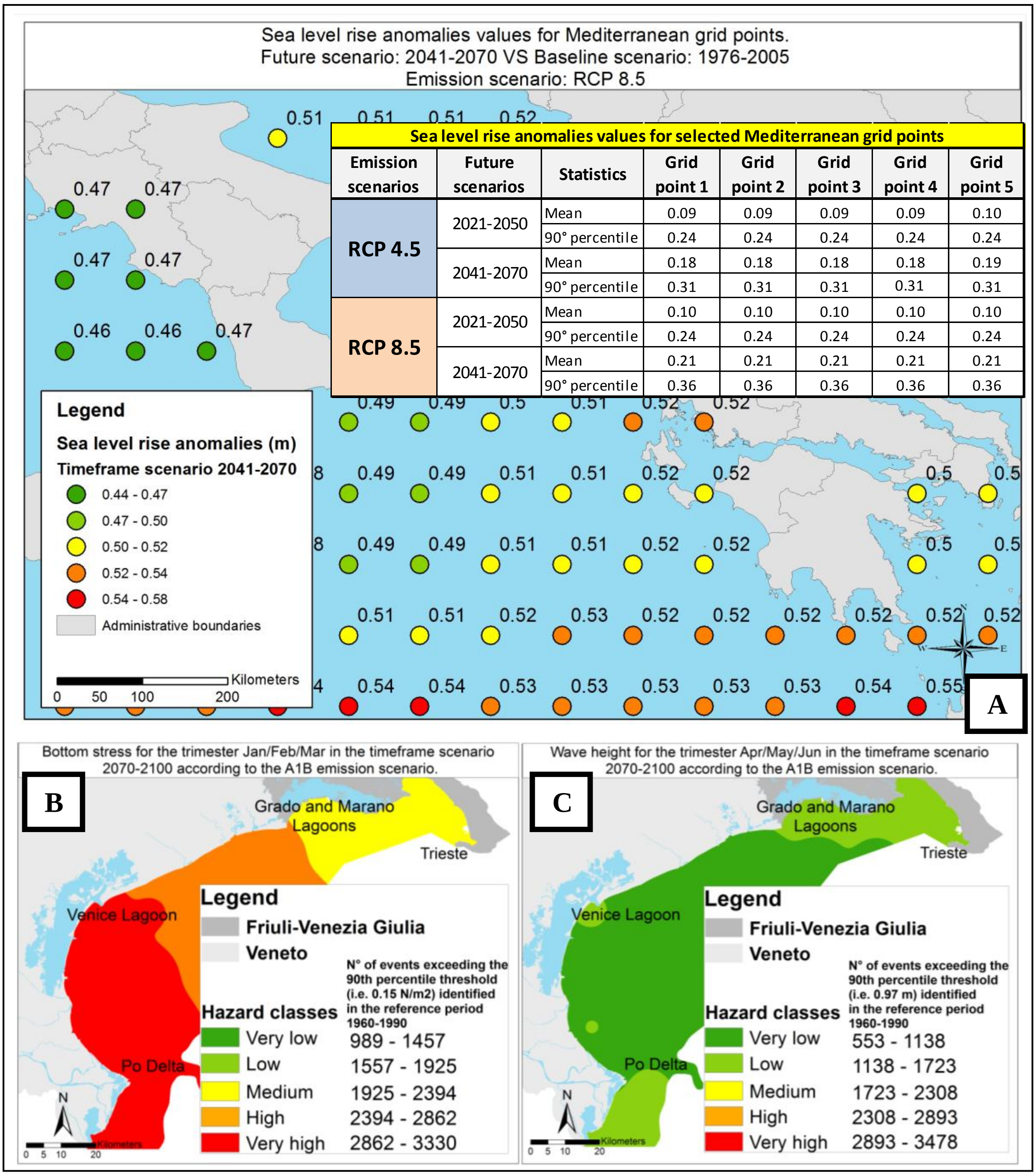


Figure 8. Assessments interface useful to perform all the steps of the RRA methodology. The tree diagram - in the box on the left - allows the exploration of the system folders of the project.

Within the assessment interface (Figure 8), the first step to be performed, coherently with the RRA methodology, is represented by the **hazard scenario assessment**. This step allows the inclusion into the DSS of the output from external numerical models (e.g. global and regional climate models or hydrodynamic, hydrological and hydrogeological models), representing the hazard metrics that will be used in the following exposure assessment step. Hazard scenario require the upload of one or more maps representing the hazard metrics' (e.g. bottom stress and wave height maps to analyse coastal erosion impact) for different climate scenarios (e.g. emission scenario A1B) (paragraph 2.3) (Torresan et al., 2014). Several timeframes can be considered, focusing the assessment on a specific temporal window (e.g. medium or long-term analysis) or resolution (e.g. annual or seasonal trend) according to the decision problem to which the application responds. Moreover, suitable statistics need to be calculated in order to characterize the hazard pattern in the investigated timeframe (e.g. number of events exceeding the threshold, percentile, minimum and maximum value in the considered period, etc.). In fact, hazard assessment can be based on the evaluation of the more conservative conditions (i.e. precautionary approach) depicting the more extreme circumstances for the investigated timeframe (e.g. Figure 9b and c); or on the assessment of a set of scenarios representing a wider span of variability ranging from the average (mean) conditions (e.g. difference between mean of sea-level anomalies in the future and baseline periods) to the evaluation of more extreme events (e.g. difference between the 90th percentile of sea-level anomalies in the future scenario vs the baseline) (Figure 9a).



Emission scenarios	Future scenarios	Statistics	Grid point 1	Grid point 2	Grid point 3	Grid point 4	Grid point 5
RCP 4.5	2021-2050	Mean	0.09	0.09	0.09	0.09	0.10
		90° percentile	0.24	0.24	0.24	0.24	0.24
	2041-2070	Mean	0.18	0.18	0.18	0.18	0.19
		90° percentile	0.31	0.31	0.31	0.31	0.31
RCP 8.5	2021-2050	Mean	0.10	0.10	0.10	0.10	0.10
		90° percentile	0.24	0.24	0.24	0.24	0.24
	2041-2070	Mean	0.21	0.21	0.21	0.21	0.21
		90° percentile	0.36	0.36	0.36	0.36	0.36

Figure 9. Example of hazard maps and statistics representing: sea level rise anomalies from a Mediterranean Regional Climate Model (GCM CMCC-CM model) and related statistics for each grid point (A), bottom stress and wave height hazard metrics from hydrodynamic models (B, C) useful to analyse coastal erosion impact (adapted from Orientgate WP5 report, 2014 and Torresan et al., 2014).

Hazard scenarios assessment, according to multi-models projections, allows a more robust comparison between different future climate projections, facilitating science-based decision-making in an environment of uncertainty.

The following **exposure assessment** step, whose main output is represented by the exposure map (Figure 10) of the case study area, is performed to integrate hazard metrics values with pathway and attenuation factors in order to identify potential impacted areas from different coastal hazards (e.g. sea level rise, storm surge, coastal erosion). Figure 10A shows an example of exposure map for the sea level rise impact where the colours, from green to red, indicate the exposure score which is proportional to the water level that can be reached in each geographical unit of the case study due to a coastal flooding event. Exposure maps can be easily classified according to different classification methods (i.e. equal interval, natural breaks) in order to better visualize results and simplify maps' understanding.

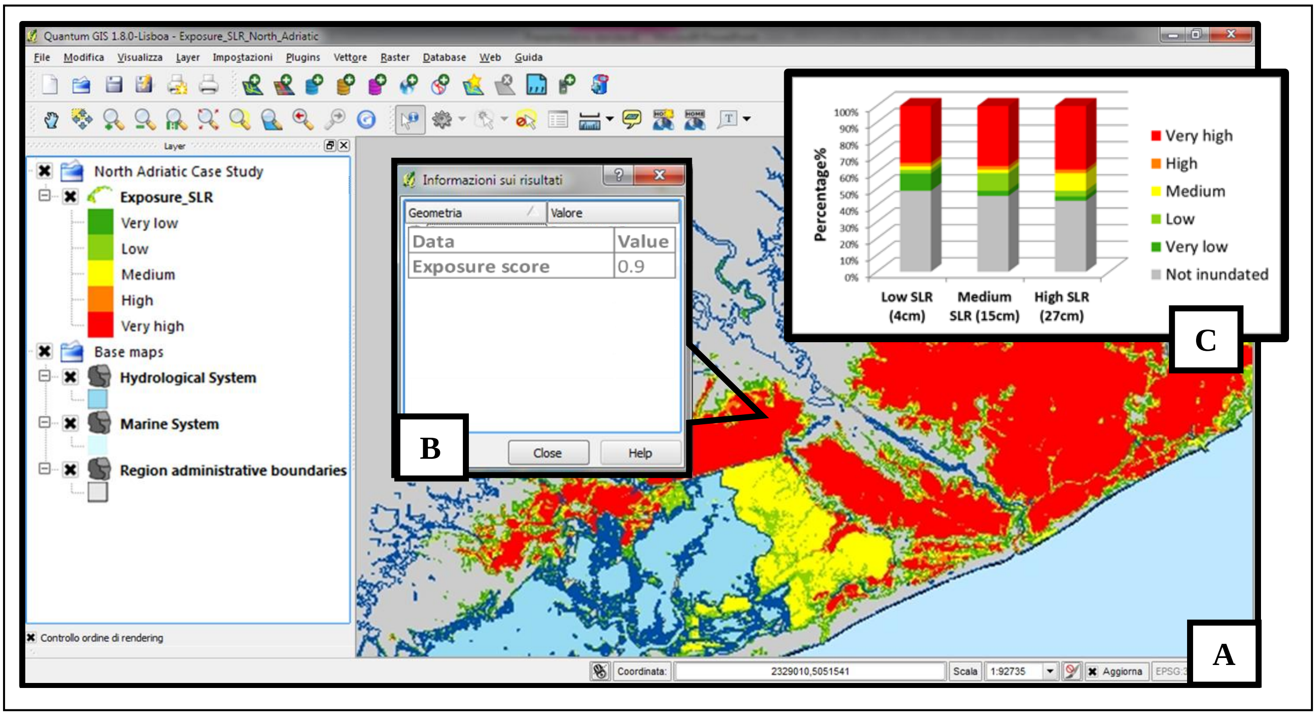


Figure 10. Exposure map produced by DESYCO - integrated with QGIS interface – to simulate sea level rise inundation in low-lying coastal areas (A), query about exposure results (B) and graph showing an exposure statistic for the whole case study area according to low, medium and high sea level rise hazard scenarios (C).

This map can be useful to support coastal planners in the development and implementation of regional and local land management plans, by considering the extension of potential inundated areas in order to design the zoning of the territory. More specifically, the exposure map allows to localize and rank potentially hazard-prone areas where the construction of new houses, infrastructures or economic activities should be allowed only under specific building regulations or the designing of adaptation measures (e.g. the construction of artificial protection such as sea barriers and gates) aimed at protecting territory from sea level rise or high storm surge events.

Figure 10c shows an example of statistic that can be calculated from the exposure maps: the percentage of surface of the case study area within each exposure class. DESYCO can easily calculate this statistic for different scenarios (e.g. low, medium and high sea level rise scenarios), allowing the comparison of results and the identification of the worst conditions for the investigated timeframe.

Afterwards, the user can move toward the **susceptibility assessment**, whose main output is represented by susceptibility maps showing, for each receptor, areas which are more sensitive to the considered impact according to their physical-environmental features (Figure 11). Each susceptibility map is generated by aggregating a predefined subset of susceptibility factors that are selected, scored and weighted by a team of experts (paragraph 2.3). Within this assessment phase, the DSS creates also a classified and weighted map for each susceptibility factor showing the results of the classification based on scores and weights previously defined by the user. Through all these output, for each cell of the resulting map the user can see the total susceptibility score and the score of all considered factors after being classified and weighted (Figure 10B). Accordingly, it is possible to identify which factors are mainly contributing to hot-spot susceptibility areas (e.g. coastal slope, agricultural typology, vegetation cover), tailoring the selection of more effective measures for decreasing the overall susceptibility score. Figure 11A shows an example of susceptibility map for the coastal erosion impact. Based on this map, the system allows also to calculate the percentage of receptors' surface in each susceptibility class (Figure 11C).

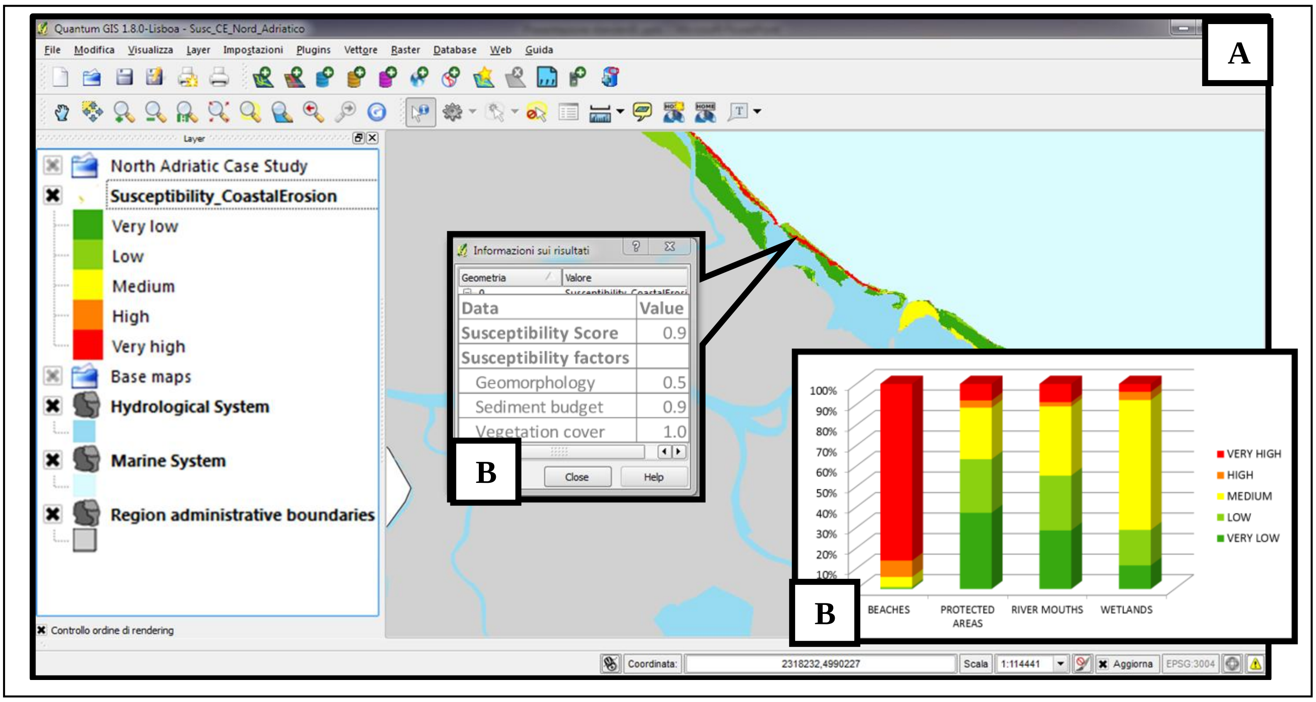


Figure 11. Coastal erosion susceptibility map produced by DESYCO - integrated with QGIS - for the coastal areas of the North Adriatic sea (A), query about susceptibility results (B) and graph showing a susceptibility statistic and ranking for different receptors (C).

Susceptibility maps are specifically designed to support the development of adaptation measures aimed at increasing the resilience of receptors to climate-related impacts. Particularly, they can be used to localize areas requiring preventive conservation measures (e.g., restoration of vegetation communities or dunes, reshape of beaches) to make the coast more resilient to coastal erosion or flooding. Such measures can also be part of (and in line with) plans for the conservation of biodiversity and ecological status, as required by National and European regulations such as the Habitats Directive (EC, 1992). For the human targets, susceptibility maps can also be used to define criticalities (e.g. flood-prone areas) where the network of roads, railways or drainage systems should be improved to better cope with weather variability and future climate perturbations.

The following **risk assessment** step leads to the production of relative risk maps and statistics (Figure 12) showing the relative risk score for each analysed receptor, based on qualitative classes, from very low to very high.

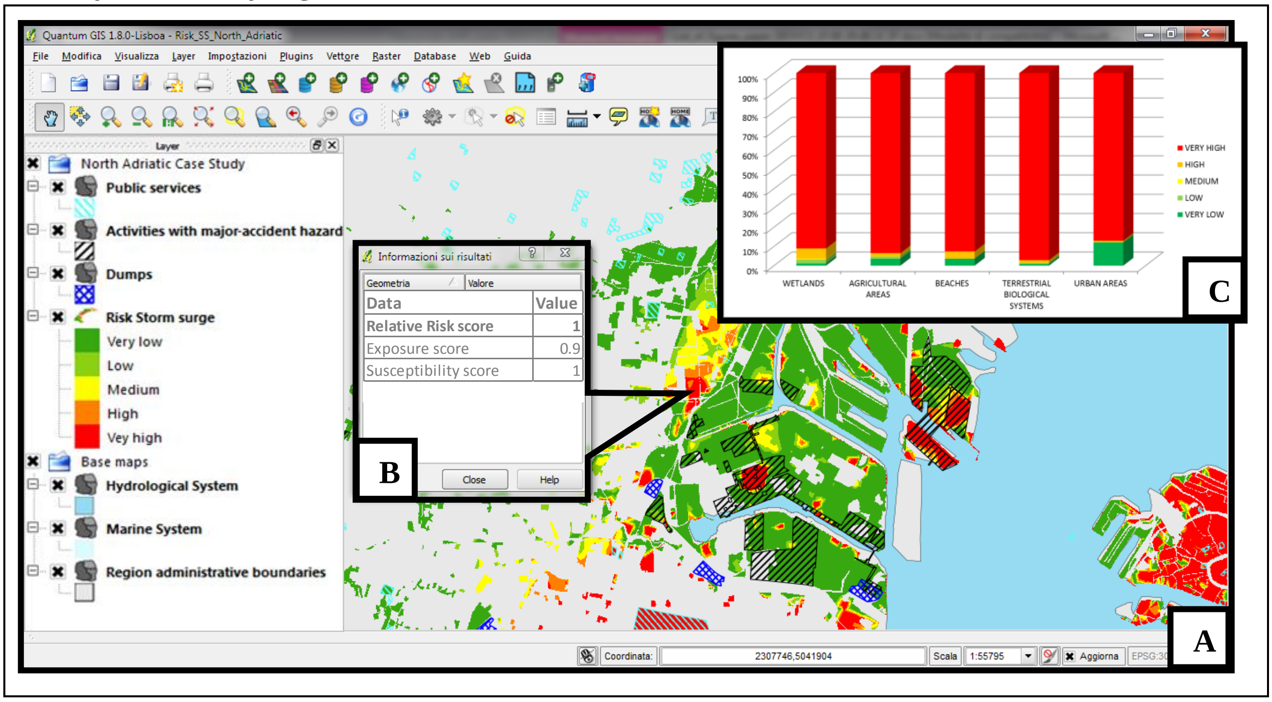
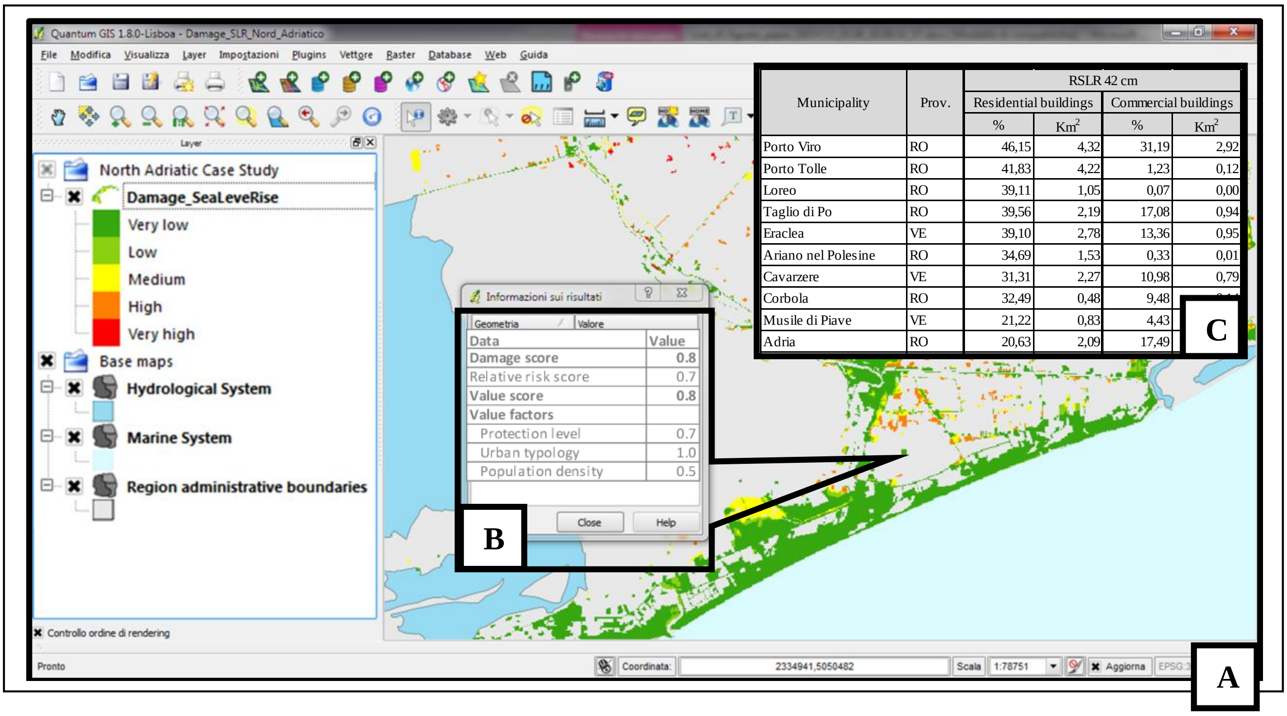


Figure 12. Storm surge risk map produced by DESYCO - integrated with QGIS interface (A) with overlap of territorial layers concerning dumps, activities with major accident hazard and public services, query about risk results (B) and graph showing the statistics and ranking of relative risk classes for different receptors (C).

Map reported in Figure 12A is an example of risk map for the storm surge flooding impact considering the receptor ‘urban areas’, whereas graph in Figure 12C compares the relative risk scores for different receptors, allowing to understand which ones are more at risk. Risk maps are specifically designed to assist decision-makers in the development of policies and measures aimed at reducing exposure and/or sensitivity to climate risks (e.g. dike building or beach nourishment) and at increasing the individual and community capacity to adapt to changes. The overlay of risk maps with other relevant layers (e.g. schools, hospitals, activities with major-accident hazard, dumps and landfills), allow a better contextualization of the assessment results and the identification of risk hotspots in the analysed area, producing relevant information (e.g. information about infrastructures, economic activities and other public services located in higher risk or damaged zones), useful for decision makers and planners in the definition of management and development strategies. Moreover, according to the recent European decision 1313/2013/EU on a Union Civil Protection Mechanism, climate risk scenarios represent a fundamental tool for the development of preventive disaster risk management strategies.

Finally, the last **damage assessment step** is useful to produce maps identifying areas and targets where higher socio-economic losses are expected (Figure 13). As described in paragraph 2.3, the damage assessment phase aggregates the value score associated to each receptor with the relative risk score calculated for a given impact, receptor and scenario. Likewise the risk, this is a relative assessment which provides an estimation of the damages in semi-quantitative terms, integrating stakeholders' judgement. In the same way of the susceptibility assessment, value assessment requires the assignation of scores and weights related to the value factors that can assume different weights, also considering perspectives from local stakeholders.



Municipality	Prov.	RSLR 42 cm			
		Residential buildings		Commercial buildings	
		%	Km²	%	Km²
Porto Viro	RO	46,15	4,32	31,19	2,92
Porto Tolle	RO	41,83	4,22	1,23	0,12
Loreo	RO	39,11	1,05	0,07	0,00
Taglio di Po	RO	39,56	2,19	17,08	0,94
Eraclea	VE	39,10	2,78	13,36	0,95
Ariano nel Polesine	RO	34,69	1,53	0,33	0,01
Cavarzere	VE	31,31	2,27	10,98	0,79
Corbola	RO	32,49	0,48	9,48	[illegible]
Musile di Piave	VE	21,22	0,83	4,43	[illegible]
Adria	RO	20,63	2,09	17,49	[illegible]

Figure 13. Sea-level rise damage map produced by DESYCO - integrated with QGIS interface - for the coastal areas of the North Adriatic sea (A), query about damage results (B) and table showing a damage statistic for the comparison of the surface of residential/commercial buildings with high/very high damage scores in different municipalities (C).

Figure 13A shows an example of damage map for the sea level rise impact focused on the receptor urban areas. Also in this case by clicking on the map it is possible to see the list of the considered value factors' scores and the final damage score (Figure 13B).

Damage maps can be useful to insurance companies in the identification of areas where insurance should have higher or lower prices according to the expected damage. Moreover, based on these maps some spatial analysis and statistics can be calculated (Figure 13C) analysing the percentage of different building typologies (e.g. commercial or residential) that are expected to suffer higher damages in different municipalities. This information can support decision makers at the regional level in defining how to allocate resources and investments in order to implement adaptation plans in areas where higher damages are expected. As further example, damage maps identifying potentially damaged crops (e.g. permanent culture, stable meadow, arable) can also be useful for a first screening evaluation of areas where the economic damage in terms of lost income for the agricultural sector can be higher. In order to prevent this loss, well-planned and interrelated adaptation measures should be taken, including the planting of crops with higher resistance to climate change (e.g. salt tolerant agricultural crops, plants with less water requirement) and farm risks insurances (Saleem Khan A. et al., 2012).

RRA maps can be directly visualized in QGIS (http://www.qgis.org) or can be opened by any other commercial or open-source GIS software allowing to further perform spatial analysis, overlaying the results with other territorial layers (e.g. land-use, geomorphological map, urban and environmental plans related to the case study area). Based on these maps the user can also perform some statistical and geostatistical analysis, calculating the territorial surface, and related percentage, included in each exposure, susceptibility, risk or damage class. By means of a specific interface implemented in DESYCO, statistics can be calculated for the entire case study area, for each considered receptor or for other homogenous areas (e.g. administrative units).

The overall maps and statistics produced by DESYCO can be used by end-users to implement the principles of SEA and ICZM where, key systems at risk from climate change, should be assessed and prioritized according to a range of future climate scenarios. Maps produced by DESYCO can also be helpful for the implementation of Environmental Impact Assessment (EIA), in order to evaluate more-sustainable futures, taking into account the possible effects of climate change (Duinker and Greig, 2007).

4. CONCLUSIONS

Existing tools and DSS for coastal zones management include various applications, which offer limited functionalities and features, do not support the implementation of spatial planning and ICZM and have different scope compared to the real needs of the end-users. Several tools address problems at a coarse national/sub-continental scale, not useful to respond and manage risks locally; others are rather complex, being focused on modelling site-specific coastal processes (e.g. wetland changes, coastal erosion), and cannot answer effectively to a variety of questions important for decision making (e.g. which are the main regions or sectors more vulnerable to global climate change? Which scenario is the least harmful for a target at risk?). The DSS DESYCO can be easily applied to aid risk mapping and adaptation processes in case studies with different geographical and decisional contexts. Its application in different European and Italian projects (Figure 6) has confirmed the flexibility of the tool to be applied for a range of climate-related problems across the land-sea interface of coastal zones (i.e. from water resources management to conservation of biodiversity and land use planning) and the potentiality of the tool to be in principle applied at broader spatial scales and resolutions (e.g. national, supranational and continental scales) according to the purposes of the analysis and the availability of climate and hazard models. Its open configuration allows the users in selecting different receptors, input data and scenarios, focusing the analysis on several targets and climate change impacts, according to specific end-user needs. Furthermore, the results of its application can be easily implemented within planning processes on a national and sectorial level (e.g. Integrated Coastal Zone Management, Plans for water protection, Pre-Disaster Mitigation Plans), reviewing and potentially adapting them in order to consider future climate change scenarios and risks. Being developed upon a bottom-up approach involving stakeholders early in the process, DESYCO can be considered as an adaptation service provider, effectively supporting end-users and policy-makers in the definition of adaptation strategies to cope with climate change (e.g. localization of areas where artificial protections can be required, relocation of urban, industrial and tourism infrastructures). Future developments of the tool will include the development of a Web-based version of the software; an upgrade of the relative risk model to an advanced multi-risk version; and finally, the development of new risk modules for the social and economic assessment, suitable to consider adaptive and coping capacity indicators (e.g. income level, education, safety network) as well as a more quantitative assessments of the adverse consequences of climate change in terms of direct and indirect costs.

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Highlights

- A Decision Support System for coastal climate change risk assessment is presented
- It implements Multi-Criteria Decision Analysis and Geographic Information Systems
- We present architecture, interfaces and functionalities for end-users
- The software is configurable and adaptable to different case studies
- Results show how the tool can be applied to aid coastal adaptation decision-making