Risk and Root Cause Assessment (RRCA) Methodology and Applicability

Final report describing the full RRCA methodology and its applicability

Work Package 1

Deliverable Report 1.3

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Preparing for Extreme And Rare events in coastaL regions

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Abstract (for dissemination, 100 words)	This paper describes the novel approaches adopted in PEARL to understand the formation of risk and vulnerability in the case of small-scale but high local impact disasters, namely a qualitative root cause analysis coupled with both a survey-based and spatially-based vulnerability assessment. The paper reflects on the application of these approaches in research sites across Europe and the Caribbean and their integration in a holistic risk assessment model through respective agent-based models. The evolution of both approaches in PEARL is charted, and lessons for other holistic risk assessment frameworks discussed.
Keywords	Risk and Root Cause Assessment, Root Cause Analysis, Vulnerability Assessment, Holistic Risk Assessment

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Content

1 The PEARL RRCA Framework and Associated Methodologies

1.1 Summary of the Risk Root Cause Analysis Framework as developed in Deliverable 1.1.

The following figure (Figure 1, below) sets out the Risk and Root Cause Assessment Framework (RRCA) for PEARL. It is divided into three parts: (A) Overall concept, (B) Process, (C) Methodological Approach. Discussed extensively in Deliverables 1.1 and 1.2, this Deliverable provides a full report into (C), the methodologies used to derive the final RRCA and its findings, and the contribution of the RRCA to the PEARL Holistic Risk Assessment Framework.

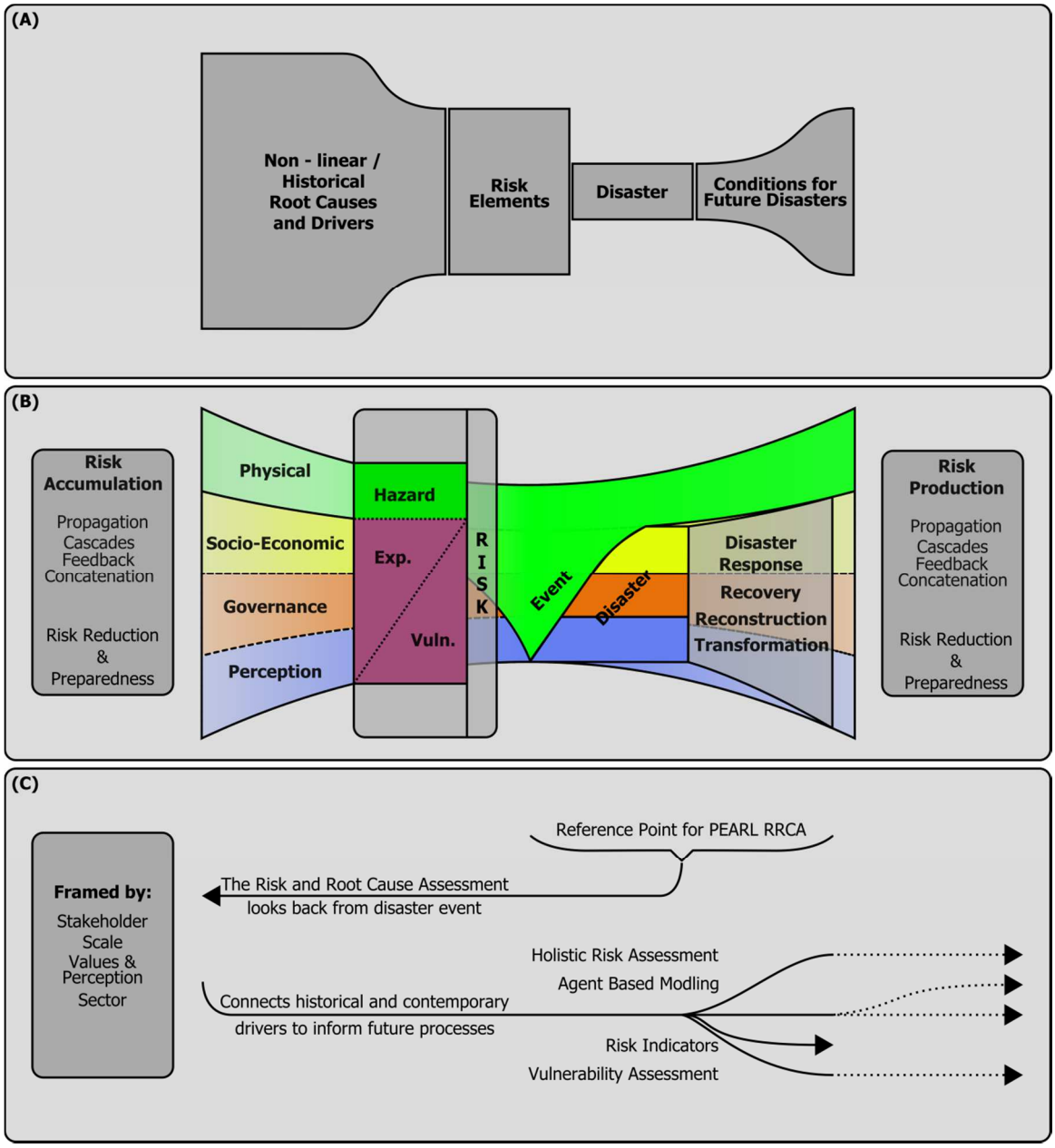


Figure 1 RRCA Framework for PEARL

To recap from the methodological proposal made in Deliverable 1.1, the reference point for the PEARL RRCA is the study of disaster impacts and losses and post-disaster development trajectories. This focal point in time is bracketed in the RRCA Figure. It provides a critical 'window' through which the historical drivers of risk can be assessed, and their manifestations in the contemporary context analysed. This perspective is then used to inform future risk scenarios. The interpretation of the event, disaster and post-disaster processes is framed by the perspectives and values of different stakeholders, sectors and the scale of the analysis. Risk and Root Cause Assessment, with its focus on bringing a historical perspective into the present, was proposed to feed into other methodologies in PEARL which will be used to benchmark and project future risks. These are a) a vulnerability assessment b) an agent-based model and c) risk and root cause indicators which can be used to assess efforts to address disaster root causes over time.

2 PEARL Root Cause Analysis Methods

2.1 Review of PEARL Root Cause Analysis Methods

The methods used in PEARL to undertake Root Cause Analysis were reviewed extensively in Deliverable 1.2, which provided a sourcebook for researchers and policy-makers interested in adopting the approach. The key elements of Deliverable 1.2 as they report the method used in PEARL are reproduced here.

Case study selection for the Root Cause Analysis was undertaken using the systematic criteria set out in Deliverable 1.1, which combined selection on the basis of the features of the case with the organisational viability of the research (e.g. local partners willing to support the research). This resulted in the selection of Genoa, Italy, Rethymno, Crete and St Maarten, Dutch Caribbean as primary research sites, with Hamburg and the Elbe Estuary being developed on the basis of secondary literature, given issues of stakeholder fatigue and the wealth of existing literature. As the primary researcher at KCL did not speak the languages required to undertake the Genoa and Rethymno case studies and local partners did not have in-house capacity for translation, however, KCL contracted Italian and Greek researchers for a 3 month period, working intensively with the KCL researcher (who undertook the field work in St Maarten) to develop Risk and Root Cause Analysis reports for the three cases. The Hamburg study was undertaken by PEARL partners at the Technical University of Hamburg (TUHH).

A key principle of the PEARL Root Cause Analysis is the inclusion of multiple stakeholders from different disciplinary perspectives. The table below shows the types of stakeholder interviewed for each PEARL Root Cause Analysis case study:

Table 1 Example of stakeholders interviewed for PEARL Risk and Root Cause Analysis Reports

PEARL case study	Stakeholders interviewed
Rethymno, Crete	Water resources and civil protection agencies, former mayor and prefect, NGO representatives, port authority, hotel and restaurant owners, local households
Genoa, Italy	National civil protection and environment agency; Regional civil protection centre, environment agency and coastal ecosystem and water cycle management team; Municipal civil protection, urban planning and communications office; River basin authority; Sustainable education and citizens' participation office; Flood protection voluntary organisation and other NGO representatives; Specialist academics and lawyers; International centre on environmental monitoring.
St Maarten, Dutch Caribbean	Independent expert consultants; Ministry of Public Housing, Spatial Planning, Environment and Infrastructure; Ministry of Public Health, Social Development and Labour; Fire Department; Meteorological Office; Ministry of Economic Affairs; Department of Communications; NGOs; Business sector bodies; Insurance companies; Port, Harbour and Marina companies

A range of methods can be used for Root Cause Analysis, and the exact choice of methods will depend on the context for and aims of the analysis. Qualitative methods capture depth, context and meaning but, as discussed further below, can also be used in conjunction with quantitative methods, for example to understand the strength of different causal factors, or model actor relationships globally. The method for Root Cause Analysis in PEARL centred on qualitative methods but varied according to the context of each case study:

- In Genoa, Italy, the analysis drew on 17 semi-structured telephone interviews with key stakeholders to supplement a review of the vast existing literature in Italian on the floods and flood history in Genoa, including technical reports, planning documents, legal documents and scientific reports and articles as well as analysis of relevant media reports, which covered more than 150 articles published online between 2010 and 2015.
- By contrast, in St Maarten, Dutch Caribbean, in-depth primary material was not readily available and the analysis focussed on face-to-face interviews.
- In Rethymno, Crete, findings from face-to-face interviews with individual experts and stakeholders were corroborated with findings from a stakeholder workshop.
- In Hamburg, Germany, stakeholder fatigue meant that the study was based on a desk-based review of existing literature rather than new interviews with experts.

Face-to-face interviews typically lasted between 1-2 hours. The main aim was to undertake a threshold number of interviews that captures the different representative viewpoints on the problem. For the PEARL case studies that involved face-to-face interviews, the number of interviews ranged between 17 and 22.

The interview questions and Root Cause Analysis reports were structured around the Root Cause Analysis framework discussed above, and focussed as far as possible on understanding the causes of specific disaster events. The following method points discuss these aspects of the interview process.

Method point 1: Using the PEARL Root Cause Analysis framework to structure interviews

PEARL Root Cause Analysis used the following, simple thematic table based on the PEARL Root Cause Analysis Framework to structure questions in face-to-face interviews as well as the findings in the final Root Cause Analysis reports. Under the governance category, questions were asked about the role of disaster preparedness and response policies and actions in influencing risk.

Table 2 Framework for Root Cause Analysis interviews

Category of root causes	*Pathway*	*Temporal expression*
Root causes and Drivers of hazard	Physical	Historic
		Contemporary
		Future
	Socio-economic	Historic
		Contemporary
		Future
	Governance	Historic
		Contemporary
		Future
Root causes and Drivers of exposure	Physical	Historic
		Contemporary
		Future
	Socio-economic	Historic
		Contemporary
		Future

	Governance	Historic
		Contemporary
		Future
Root causes and Drivers of vulnerability	Physical	Historic
		Contemporary
		Future
	Socio-economic	Historic
		Contemporary
		Future
	Governance	Historic
		Contemporary
		Future

As the method focussed on interviews with relevant experts rather than affected households and individuals, root causes and drivers related to perceptions, values and beliefs were not systematically explored and not included in the table. However, the analysis highlighted that often conflicts of perception formed part of the governance root cause category, while socio-economic and related demographic change influenced perceptions, values and beliefs. Root Cause Analysis was also conducted in conjunction with a household-level vulnerability assessment - for a discussion of the use of the two methods together see below.

The general PEARL template was adapted for the local context through the design of more detailed interview questions. Box 1 illustrates the types of questions developed for the Genoa case study after an in-depth review of the secondary literature, including existing academic literature and media reports, which revealed a gap in understanding governance drivers, in particular related to the role of particular aspects of risk management policy and practice. In each case study, interview questions were then applied according to the type of stakeholder being interviewed, and their anticipated areas of knowledge and expertise. The sections on event and causal analysis were common to all interviewees. Questions on risk mapping, management, warning systems and risk awareness/preparedness were tailored by stakeholder type. For example, the head of the Regional Civil Protection Functional Centre was mainly asked about warning systems. However, when interviewees had knowledge about multiple sectors, the opportunity was taken to ask them about different issues. For example, the officer for Regional Coastal Ecosystem & Water Cycle Management had previously worked for civil protection so she had a lot of relevant knowledge about emergency management.

Box 1: Example of interview questions developed for the Genoa, Italy, Risk and Root Cause Analysis

Event

- What were understood to be the immediate, proximate causes of the disaster of the initiating events?
- Was the event forecast or predicted?
- Was the existing knowledge available and accessible? Were there any decision-makers who were unaware of the information (or less aware than they might have been)?
- How was the risk of this event perceived and understood by all the categories of stakeholders?
- What strategies, laws, policies or measures had been considered to prevent the impact of the event or reduce its consequences? Were any options rejected? To what extent had strategies, policies or measures actually been implemented and put in place? Were they effective? How and to what extent?
- What was the economic/social status of the community immediately before the event and how did it change subsequently? Was there any sense of unfairness or discrimination in the community before, during or after the event? Are there contrasting or conflicting views?

Causal analysis

- What were the critical transitions in recent history (preconditions) that increased and changed the distribution of impact?
- How did economic and political status influence the disaster risk? How did culture and societal norms influence the disaster risk?
- What were the drivers of disaster prevention/resilience by broad categories: social characteristics, economic activity and livelihoods, levels of investments that reduced risk, institutional and governance structures, environment, infrastructure (critical infrastructure and residential environments), community competence (including prior experience with events, social cohesion, and social networks).
- Were there barriers to disaster risk reduction? If yes, what were they?

Risk management

- How are you/is your organisation dealing with the risks of floods in Genova and/or Liguria region (depending on the organisation and its mandate)? What kinds of prevention and mitigation measures are at place? What kinds of precautions have been taken to ensure people and buildings? What has been the number one concern and priority in risk management? What will be number one concern and priority in the future?
- Does the local administration have the capacity to deal with flood risk? How could this capacity be improved? What do you think are the current constraints in managing flood risk?
- Are there regional guidelines for flood risk management? Do you have access to them? Do you apply them? What are your views on the support received from regional and national levels for risk identification, communication and management? Is it adequate? If not then what more needs to be done?
- Do you think that the funding for risk management is enough? Is there a fair distribution of funding for structural and non-structural measures/ among towns in the Liguria region/ among Italian regions?
- Do you think there are any legal conflicts related to flood risk management? Did recent legislation enacted after the 2011 and 2014 events contribute in changing the situation? If yes, how?

Risk mapping

- How are the basin plans and the watershed plans implemented in practice?
- What, in your opinion, is the main purpose of mapping flood risk? How will the maps translate into policy? What scale is appropriate for what kinds of uses?
- Who will make most use of the maps, and what problems might arise?
- What do you think about the availability of this data/services? How easy are they to use/understand? What challenges/problems do you encounter in the use of the maps?

Warning systems and emergency management

- Does the local administration have the capacity to deal with emergencies? How could this capacity be improved? What do you think are the current constraints in managing emergencies?
- Are there regional guidelines and municipal plans for emergency management? What are your views on the support received from regional and national levels for risk identification, communication and management? Is it adequate? If not then what more needs to be done?
- Do you think that the funding for emergency management is enough? What have been the priorities in the past and what will be the priorities for the future? Why?
- How do you/your organisation deal with the scientific (but also legal and social) uncertainty related to the warning system and emergency management?
- Do you think that citizens are well prepared? How could they be better prepared? What is the role played by new technologies and social media in emergency management? How is it changing? Should responsibility for emergency management be reallocated? How? Should better communication protocols be prepared? How?

Risk awareness, citizens' involvement and participation in risk and emergency management

- How do you think the locals respond to the risk – has it changed over the years? In what way has it changed your practice and sense of risk? Do you think that you have a good information and training on how to deal with the danger of floods?
- In your opinion, is the public aware of flood risk? Do you think they trust the public authorities to protect them against this risk? Are there environmental groups or citizen groups that advocate for more protection? What is the role of the political parties? What kinds of conflicts among the stakeholders have arisen?

A limitation of the method was that interviewees found it difficult to separate out some of the Framework's elements in practice, which are indeed inter-related. This applied to identifying drivers of exposure as distinct from vulnerability. Governance, economic and social drivers are also difficult to separate – the legal controversies which have stopped the disbursement of funds to build risk mitigation measures in the Genoa case, for example, are both economic and governance-related. Physical drivers, too, interact with socio-economic pathways, with flood risks in the case studies affected by poor drainage or stream clearance, or the deepening of ports for economic activities. It was also difficult for some stakeholders to identify future scenarios as different to contemporary conditions. While the intention was to capture local-level drivers as well as broader structural drivers (with interviewing at the regional and national scales for the Rethymno case, and questions asked about the role of the EU and global economic downturn in the St Maarten case study) there were limitations as to how well stakeholders themselves could articulate the complex interlinkages between global changes and local conditions, and how far the researchers could gain local-specific insights from broadening the reach of the interviews (e.g. to EU officials, the Netherlands government, regional and global economic institutions).

The St Maarten Risk and Root Cause Analysis report also identified further challenges in using the Framework, which were addressed in the analysis table used in the report:

1. The Framework table does not explicitly capture manifestations of resilience as well as risk and related causes (therefore noted in the table).
2. The Framework table does not distinguish between root causes and drivers (therefore noted in the table).
3. It is important to reiterate that risks can be highly localised, spatially, sectorally and socially, even on a small island like St Maarten. Spatially, the highest risk areas were identified by UNESCO-IHE studies in 2006 as being the densely populated areas which have developed rapidly up the hillsides (and particularly those closest to the highest terrain), such as the Cul-de-Sac neighbourhood, which is in an enclosed basin and suffers the effects of erosion and flash flooding. The areas liable to coastal flooding are low-lying areas between the sea and the inland lagoons, including the densely populated areas of Philipsburg, the capital, and Simpson's Bay and the sites of most major critical infrastructure for the island, such as the electricity generator and the airport. While the quality of building construction and socio-economic status of neighbourhoods such as Cul-de-Sac was described by interviewees as of reasonable standard, the areas of the highest social vulnerability are settlements of illegal immigrants who stand to be affected more by hurricane winds than pluvial or coastal flooding. Different sectors of the economy too exhibit different forms of resilience – the marine sector, for example, is able to get up and running after storms more quickly than the hotel sector, for instance, as it does not rely on fixed infrastructure. Finally, the risks are both primary and secondary in impact: a major concern for St Maarten is the secondary public health risk from flooding due to the inadequacy of the sewage infrastructure and threats to drinking water supply when pipes get broken or electric pumps fail. Perceptions too, matter: as one respondent reported "when the pond goes into town you know what to do, so you don't consider it a flood" (Interview SHTA). As far as possible, therefore, the Table aimed to draw out generic root causes and drivers whilst noting the influence on these different manifestations of flood risk.

The presentation of the Framework as a Table also impedes understanding some of the interconnections between root cause domains (e.g. governance, socio-economic) as well as the past, present and future. An alternative way of presenting such results might be as a problem tree, or a relational diagram (e.g. some form of causal or actor mapping). This was partially undertaken for some of the case studies and is discussed further below.

Table 3 illustrates how the Framework was then used to present the findings in the case of Rethymno, Crete.

Table 3 Illustration of the RRCA findings according to RRCA Framework elements for Rethymno, Crete

Category of root causes	Pathway	Temporal expression	Manifestation for Rethymno
Drivers of hazard	Physical	Historic	Long-term dynamics of physical processes. Geographic location of town: extremely vulnerable to winds and storm surges from the sea, and in a drainage basin (and therefore vulnerable to three streams overflowing during winter and carry large quantities of sediment)
		Contemporary	Combination of physical processes with more pressure from extreme rainfall patterns due to climate-change
		future	Climate-change and sea-level rise
	Socioeconomic	historic	Rapid urbanization in the last three decades in a disorganized fashion. Lack of drainage capacity and poor maintenance.

		Contemporary	
		future	
	Governance	Historic	Rapid urbanization in the last three decades in a disorganized fashion. Lack of drainage capacity and poor maintenance.
		Contemporary	n/a
		future	n/a
Drivers of exposure	Physical	Historic	Absence of infrastructure to prevent floods Since the 1960s decentralization of responsibility to local authorities in Greece did not mean more funding. However things changed with EU funding in mid-1990s.
		Contemporary	Maintenance of existing infrastructure
		future	Austerity measures might stall new infrastructure plans
	Socioeconomic	Historic	Rapid urbanization, local economic interest groups influence siting of port in vulnerable area.
		Contemporary	Lack of efficient maintenance of the infrastructure
		future	Austerity measures might stall new infrastructure plans
	Governance	Historic	Planning and land-use decisions not suitable for preventing loss and damage from natural hazards. The construction of infrastructure usually followed the rapid urbanization in Rethymno. Most of policy decisions focus on economic growth, tourist development and certainly not civil protection, non-structural measures for disaster preparedness and vulnerability reduction. Transfer of power to Fire Dept inhibits preventative measures
		Contemporary	Lack of human resources due to the austerity measures, institutional fragmentation and bureaucracy EU finance does not filter down to local level Weakness of national-level frameworks where no monitoring or enforcement for implementation, lack of emphasis on preparedness and vulnerability and lack of multi-stakeholder engagement
		future	Challenges posed from the emergence of civil society organizations and their role in changing the party politics that has governed flood-related decisions
Drivers of vulnerability	Physical	Historic	Inadequate urban planning, location of harbor
		Contemporary	Poor maintenance of infrastructure due to austerity measures and lack of human resources
		future	
	Socioeconomic	Historic	Lack of awareness as new population moved into Rethymno. Most of them were originated from mountainous areas and carried local knowledge for preventing from other types of disasters mainly forest fires and landslides, not urban flooding or storm surges. In addition to that floods in Rethymno did not occur very often and locals in many cases developed the feeling that were safe. As a consequence their economy was not resilient to this kind of shocks leading to loss and damage of assets.
		Contemporary	As above. Lack of awareness also includes restaurant owners/residents in the old town that do not maintain properly the infrastructure and do proper waste disposal etc.
		future	
	Governance	Historic	Since the 1960s decentralization of responsibility to local authorities in Greece did not mean more funding. However things changed with EU funding in mid-1990s. Transfer of power to Fire Dept inhibits preventative measures

		Contemporary	The construction of infrastructure usually followed the rapid urbanization in Rethymno. Most of policy decisions focus on economic growth, tourist development and certainly not civil protection, non-structural measures for disaster preparedness and vulnerability reduction. EU finance does not filter down to local level Weakness of national-level frameworks where no monitoring or enforcement for implementation, lack of emphasis on preparedness and vulnerability and lack of multi-stakeholder engagement Clientelism and party politics inhibit state-civil society engagements at the local level
		future	Different levels of local governance disorientate from the accomplishment of integrated disaster risk management. The institutional fragmentation will probably persist with the economic crisis and lack of political will to reform the existing policy context.

Method point 2: Focussing on the causes of specific disaster events

Interviews for PEARL's root causes analysis work focussed where possible on eliciting personal and organisational opinions about the causal factors behind specific disaster events. For example, interviews in Genoa focussed on the 2014 and 2011 flooding episodes, and interviews in St Maarten on the effects of 2014 Hurricane Gonzalo and flash flooding in November of the same year. This interview technique was designed to draw out specific causal attribution and the relationship between causes and impacts, moving beyond the broad-brush opinions of respondents and pre-existing conceptions by researchers and stakeholders about possible causes. The thinking behind it was that disaster events act as a 'window' through which hidden causes of risk are often revealed. However, despite the focus on historical disaster events it was important to also link historic causes with contemporary risks and vulnerabilities, especially where the physical, governance and socio-economic dynamics of risk were changing, and this was emphasised in interview questions. Other challenges included recognising that different disaster events may have different causes and differential impacts even in the same place. In St Maarten, for example, 2014 Hurricane Gonzalo had major consequences for the local marine sector, but produced a very different kind of flooding event to flash floods in 2005 that affected hillside districts due to torrential run-off. In the selection of relevant events to study, on the one hand it was more difficult to see the effects of the response to more recent events, but on the other, not all stakeholders were able to reflect on more historic events. In St Maarten, for example, interviews were therefore conducted with current government officials who managed current and recent responses to risk but also past officials and individuals who could recall the impact and influence of hurricane events in the 1990s, which had shaped the disaster risk management system into the present.

Who should be interviewed?

In all the PEARL Root Cause Analysis case studies researchers identified key institutions and individuals from the secondary literature and 'snowballed' out from initial interviews, asking respondents for further recommendations of who to interview. The over-riding guiding feature was to capture as representative a selection as possible of the diverse viewpoints held by different stakeholders, recognising that different groups may have different values, beliefs and interests that influence how they view the causes of particular events. Through multiple interviews, initial research findings can also be triangulated and verified and viewpoints shared. The box below discusses some of the challenges to accessing stakeholder groups using examples from the PEARL Root Cause Analysis case studies.

Box 2: Challenges to accessing stakeholders

In attempting to reach multiple stakeholders, PEARL case study research highlighted common challenges of language barriers, timing interviews to suit busy interviewees, manging the impacts of staff turnover and unexpected events, and stakeholder fatigue with being interviewed. These issues must all be borne in mind when deciding who will undertake the research, deciding on appropriate methods and scheduling interviews. In addition, vulnerable groups and their representatives are often the most hard to reach. Governance issues may also be particularly sensitive topics to draw out and discuss, especially with local stakeholders.

PEARL researchers then used the PEARL framework to analyse the case study material, drawing out common themes as well as identifying divergences of opinion. Transcripts and notes from Root Cause Analysis interviews and documents were coded and synthesised either by hand or using computer software programmes such as atlas.ti. Case study reports and briefs draw together the analysis, structured around the Root Cause Analysis Framework and the interaction between its components. PEARL researchers followed the ethical guidelines for research set by King's College London, with ethics approval for the proposed procedures for the project granted by KCL. In particular, interviewees were given the option to remain anonymous in name and position, especially if the discussions concerned socially or politically sensitive issues, but their organisation and the date of the interview was used to reference relevant interview quotations.

A key plank of Root Cause Analysis is also comparative research that can draw common conclusions about the pathways to disaster events. The FORIN (or the FORensic INvestigations of disasters) project promoted by the Integrated Research on Disaster Risk programme identifies two types of analysis that aim to draw out common conclusions from multiple sets of case studies: meta-analysis (literature review across multiple cases to establish common causal pathways) as well as longitudinal analysis (observations of comparable events or events in comparable places). The methods used in PEARL allow for both types of analysis: commonalities can be detected across the multiple case studies and conclusions drawn about historically comparable local-level but high-impact urban coastal flooding events. An analytic journal article that does this in order to examine the interaction between local-level and global causal pathways to disaster is being prepared using the case study material developed in PEARL.Although the question of scale and level was not explicit in the RRCA Framework, and was predominantly concerned with revising the temporal framework of FORIN, interviews took place across spatial and jurisdictional scales and quickly began to reveal connections between changes in governance systems (e.g. decentralisation processes) and economic systems (e.g. down turn and austerity) and local conditions. The questions and method were refined through the process to put additional emphasis on these components – for example they formed a key part of the interview template used in St Maarten. This has enabled new insights for science – albeit partial ones - to emerge about the linkages between structural change and small, recurrent disasters which will be written up in the journal article.

A possible way to integrate, monitor and track the underlying root causes of risk in disaster management policies is through the development of root cause indicators, and this was proposed under the methodologies of the PEARL RRCA framework, with the aim of deriving these from the case study contexts studied. However, this methodology has not been fully developed in PEARL, with time constraints limiting time available to compare suggested indicators to locally-available data sets.

2.2 Developing New Methods for Root Cause Analysis

A number of methods for Root Cause Analysis were not fully applied in the PEARL project, but a record of their partial application is nevertheless included here:

- **Focus group exercises:** Although PEARL Root Cause Analysis focussed on individual expert interviews, exercises with focus groups can also provide important insights, and group exercises such as actor or causal mapping may provide a useful starting point for the research.
  A map of actor relationships produced by stakeholders in the Learning and Action Alliance in Rethymno, Crete, illustrated and confirmed the findings of the interviews (see Figure 2). For example, institutional fragmentation at the national level shown in the map has impeded effective implementation of flood risk governance, including the roll-out of the EU Flood Directive, while the municipal government has the main coordinating role. Qualitative analysis from individual expert interviews, however, was able to explain how these governance issues connected with physical and socio-economic dynamics, how they linked directly to the problematic of flood risk in Rethymno, and how such relationships were changing over time.
- **Actor and causal loop mapping:** PEARL reports and briefs included actor maps and tables of primary and secondary actors, as well as the findings from the research displayed in the format of the PEARL Framework table. Causal loop mapping may also be used to illustrate the inter-relationship between root causes. The Hamburg study included a causal loop map to illustrate the role of different stakeholders in the policy measures adopted over time (shown in Annex I). As well as producing actor maps like the one shown below for Rethymno, relevant actors and their relationships may also be visualised using mind maps, matrices showing the involvement, power, interest or other characteristics of different types of stakeholders, and timelines of policy measures (see Blaj 2014 for an illustration of these techniques for the Hamburg case and Annex II for an illustration of an actor map according to actor influence developed by PEARL partners for the Ayutthaya case). Such techniques provide useful ways of illustrating the role of different actors, characterising their relationships and showing a sequence of events, but need to be supplemented with full explanatory analysis of the meaning and motivation behind relevant decision-making processes and the deeper structural causes of such decisions.

Finally, in reflecting on the overall evolution of the PEARL RRCA Framework through its application in PEARL, it is worth noting that certain processes of Risk Accumulation, such as the role of Risk Reduction and Preparedness activities, emerged strongly from the research. However, more complex and less visible processes of Propagation, Cascading, Feedback and Concatenation were not necessarily strongly revealed by the research method in a systematic way – although aspects of these phenomena undoubtedly emerged across the case studies.

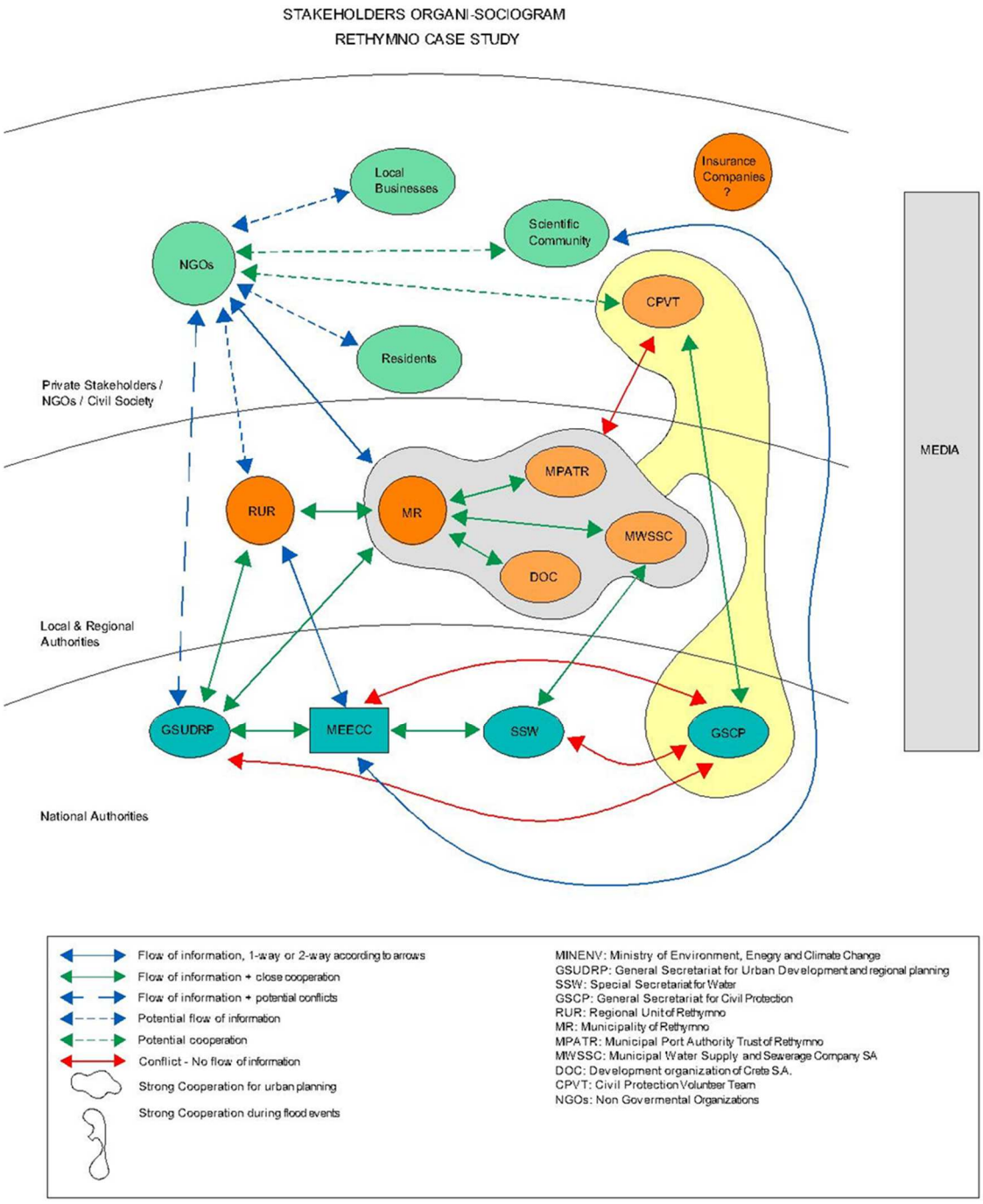


Figure 2 Stakeholder organi-sociogram Rethymno, Crete Source: NTUA

3 PEARL Vulnerability Assessment Methods

Chapter 3 summarizes the field research methods that were applied in the context of the PEARL Vulnerability Assessment in WP1. Its aim is to evaluate the vulnerability of societies exposed to coastal flooding. For WP1, two case studies were identified (Rethymno, Greece and Genoa, Italy) for the field research in the EU. The vulnerability assessment in here comprises a survey on household level, as well as an approach for spatial vulnerability assessment, including the calculation of a compound index. The spatial vulnerability assessment should be conducted on the smallest scale possible (Birkmann 2011) – determined by the availability of geospatial and statistical data in the respective case study area.

The present deliverable focusesses on the UNU-methodology of vulnerability assessment developed for PEARL by IREUS, with input from UNESCO-IHE. It is noteworthy, however, that a holistic apporach to flood risk assessment was developed by Vojinovic et al. (2015) for the PEARL case study Ayutthaya (Thailand). Here, risk is calculated as the comination of hazard (using a coupled 1D-2D flood model) and different dimensions of vulnerability (physical, social, economic and environmental dimension). For more details please refer to Annex II of this report.

3.1 Household survey

The focus of the PEARL project is on extreme hydro-meteorological events with a high local impact and great likelihood of recurrence. The examined case study areas have been recently and recurrently affected by coastal flooding. PEARL expands the definition of the term vulnerability as “the propensity or predisposition to be adversely affected” (IPCC 2012: 5) by further refining the terminology: The propensity of being affected depends on the underlying concept of susceptibility, as well as on coping capacity and ability to recover from disastrous events. Furthermore, vulnerability is an inherent characteristic “of a given context and not just the outcome of a particular disaster event” (Fraser et al. 2015: 7), which varies in space and time.

The aim of a household survey, in this specific case, is to deduce vulnerability patterns of local households and to gather information on how the households respond before, during and after a hazard, in order to get an understanding on local risk management strategies. Furthermore, experiences of previous events and the perception of locals regarding the assignment of responsibilities to improve the situation were assessed.

In two PEARL case study locations, namely Genoa (Italy) and Rethymno (Crete, Greece), a household survey was carried out. Within this task frame, information concerning susceptibility and capacities of a randomly selected sample of population was gathered. This included conclusions about the current state of the social system, which can be drawn by the collection and analysis of data like household structure, housing conditions or income. On the basis of the questions covered, the aim was to furthermore collect data with regard to local coping and adaptive capacities. This not only indicates knowledge on local natural hazards and resources, but also includes a specific learning ability and response. The survey also covers questions on the availability of information (e.g. early warning, evacuation routes), social networks and support from local authorities, as well as individual preparedness.

The underlying questionnaire was developed by the University of Stuttgart, Institute of Spatial and Environmental Planning (IREUS) with feedback and input from partners of WP1, WP3 and WP5. The work was closely coordinated with other project partners to make sure that all synergies can be exploited.

The survey was extended, compared to the initial description in the PEARL DoW (European Commission Directorate-General for Research and Innovation 2013). As described in Task 1.5, a sample size of about 100 participants for each case study were originally envisaged. This number was increased to ensure statistical validity and the survey now comprises approximately 500 questionnaires per case study, which were anonymously conducted and no names were used during the survey.

The local case study teams supported IREUS with the implementation of the household survey. Local interviewers were trained by IREUS for the collaboration. It was important to provide in-depth introduction to the topic and techniques needed for the survey to ensure methodological consistency across the case study methods. Hard copies of the questionnaires, in the respective national language, were provided by IREUS. From this point all necessary survey work was carried out by the local interviewers. After finishing the field work, the hard copies were returned to IREUS for evaluation. The questionnaire includes several open questions, whose answers had to be translated by the interviewers beforehand.
In respect of data quality and information yield, the oral questioning of households has significant advantages. However, it was up to the interviewers to decide, based on the given local circumstances, whether the survey was conducted orally or written. Box 3 discusses the main findings and hypotheses derived from the PEARL household survey.

Box 3: Summary of findings (PEARL Household Suvey)

Local origin as a factor which strengthens disaster response skills

The vast majority of interviewees in both case study areas have the respective national citizenship (Genoa 92 %; Rethymno 95.4 %). Furthermore, 77.8 % of Italian respondents indicate to originate from Genoa, as 74.5 % of Greek respondents come from Rethymno. This information is highly valuable, since it means that the interviewees should be able to refer to local knowledge and previous experience dealing with extreme events. Aldunce et al. (2014) state that those who have not experienced disasters due to their age, migrant or touristic background, have less knowledge on behavior during disasters. The lack of knowledge and experience means consistently an increase of vulnerability resulting from reduced flood-response skills (Newel and Wasson 2002) "In addition, having a large portion of the local population that has lived there for more than a few years increases the likelihood of having a community that is engaged and invested in its own well-being, in both short- and long-term contexts" (Cutter et al. 2014, p. 68). The majority of respondents of both cities owns the accommodation they live in, however this condition is not automatically linked to the willingness to invest in flood protection measures. More than half of the Italian respondents feels better prepared for future events, the same applies for at least a quarter of Greek respondents. If researcher ask what respondents have undertaken to implement concrete measures, it generally appears that they have a lack of understanding of how to independently achieve a higher level of preparedness to deal with extreme events in coastal regions. The most common precautionary measure in both case study sides is the avoidance of having property stored prone to flooding. Only 7.8 % of interviewees from Genoa and 8.8 % of respondents from Rethymno autonomously installed better protection measures.

Information deficit

The household survey reveals a severe knowledge and information deficit. In Genoa three quarters of respondents did not gather any information on flooding, while this number is presumably higher for Rethymno (92 %). Furthermore, about 64 % of interviewees from Genoa and 81 % of those living in Rethymno do not have knowledge on whether flood information is used or displayed in urban planning documents. One of the main findings of the survey is that the number of respondents who received early warnings is alarming low. In Genoa only a third of those interviewed were forewarned. In Rethymno only a small share of 2.3 % of respondents indicated that they were provided with early warning. The situation is further aggravated by the circumstance that 85 % of interviewees in Genoa and 76.6 % of those in Rethymno have no information on evacuation routes. The RRCA report for Rethymno underpins this statement – for Rethymno, there are solely evacuation maps for earthquakes available.
The general assessment of early warnings reveals that they are classified as either not perceived, or not appropriate, which in this case means that they do not offer a sufficient time frame for reaction. The respondents of Rethymno predominantly state that if they received early warning they followed the given instructions, while the Italian respondents predominantly answered the respective question in the negative. From the point of view of risk assessment, the lack of early warning is alarming and substantially increases vulnerability. However, the insufficient dissemination of early warning is not perceived as a main driver of risks, neither as a prior adaptation method by respondents of both case study locations.

The main source of information regarding natural hazards is television in both areas (Genoa 58.7 %, Rethymno 48 %). Presumably, there are more reliable and precise sources of information. As presented in detail in the Genoa RRCA report, a variety of official and unofficial communication tools are available. Alduce et al. (2014, p. 7) argue that information cannot be transformed into knowledge if it is not meaningful to the community. Available information might not meet the affected persons' needs, therefore it has to be assessed what kind of information is needed and why.
The lack of self-reliance is not only displayed by insufficient adaptation (private investment in protection measures, change in behaviour, better level of information, etc.), but also in inadequate insurance cover. Along with the information deficit, the majority of respondents had no insurance cover when the last flood hit, neither do the most of them have now. However, the proportion of insured respondents feels more prepared. Again, the RRCA provides important insights, it states that there is not a culture of private insurance schemes for natural disaster damages in Italy.

Private commitment in contrast to reliance on officials / Protection measures

The assessments of socioeconomic aspects regarding the susceptibility of respondents is important but, as Cutter et al. (2014, p. 68) state, a "community that would seem, demographically, to be resilient to disasters may not be particularly conscientious and helpful to one another". Thus, in the course of the survey the level of private engagement was also evaluated in contrast to the reliance of respondents on authorities. Even though respondents declare to primarily depend on family and friends in case of emergency rather than to trust in authorities, it becomes apparent by the preferences of chosen answers that the interviewees actually heavy rely on official bodies.
In both cases the level of accounted liability ranges from local to national government (in order of frequency of response). The respondents of the core groups named self-responsibility of citizens with less than 10 %. Based upon the responses to the questionnaire, people in Genoa think that bad urban planning (30.09 %) is the main driver of losses, followed by increased amount of precipitation (21.9 %), inefficient decision making (17.9 %) and steep slopes (14.9 %). Only 6 % of responses consider the lack of early warning, as well as the attitude of citizens as the most important reason for losses. The outcome for the city of Rethymno presents a similar picture. Bad urban planning (31.2 %) was named on the first place, followed by old infrastructures (25.03 %) and increased amount of rain (17.3 %). Since only a small fraction of interviewees received early warning at all, it is surprising that only 10.7 % of responses indicate the lack of early warning as a main driver of losses. The attitude of citizens (6.9 %) was classified as the weakest driver. On the other hand, the interviewees were asked to name the most important actions to be taken from their individual perspective. The Italian respondents predominately named radical restructuring of certain areas (58.8 %) and better protection measures (29.6 %), while only 5.4 % of them requested better financial support for citizens taking action. Respondents from Rethymno mainly demanded better protection measures (50.7 %) and radical restructuring of certain areas (35.6 %). Just as for the Italian case study side, a small share of 6.9 % names better support of self-reliant citizens. It is generally recognized that the participation of citizens is a fundamental element for the resilience of communities (Norris et al. 2008). In the course of the Learning and Action Alliances for Rethymno this problem was addressed during stakeholder discussions (see Chapter 5.2 of this report).
The general census in both core groups is a focus on constructional implantation of protection measures. Technical protection methods obviously demonstrate that "action has been taken", which explains their popularity to a certain extent. Newell and Wasson (2002) conclude that building levees affects the risk perception and therefore leads to an increase of vulnerability. Additionally technical measures can prevent smaller to medium events, and thereby can have adverse effects on the "community´s opportunities to learn from a range of manageable experiences" (ibid, p.9). The RRCA, as well as the stakeholder workshops in the course of the establishment of Learning and Action Alliances provide further insight into this topic. Both methodologies support the thesis that non-structural education and awareness raising, particularly in Rethymno, should gain in significance.

3.2 Statistical and geo-spatial assessment

In order to broaden the information on local vulnerability and to provide information at a wider scale that could also be quantified for the holistic risk assessment carried out in WP3, a geo-referenced vulnerability assessment approach was developed. Its aim is to enhance the understanding of vulnerabilities and formation of risks to extreme events in coastal regions. For this purpose, vulnerability is defined on the basis of three components: *susceptibility*, *coping capacity* and *adaptive capacity*, which are further defined for the PEARL context (see Box 4). By combining these aspects, vulnerability can be assessed. The purpose of the spatial vulnerability analysis is to display the results either on maps, as a compound index or parts (susceptibility, coping and adaptive capacities), or as ranked lists. The advantage of this method is that all sub-indices can be represented separately or as a combination. In this way, a better understanding of the vulnerability structure can be achieved.

The starting point of the spatial display is the selection of suitable statistical information. In the course of data collection a strong collaboration with local partners and representatives is needed. For the calculation of indicators information is required, starting with (1) geo spatial data and (2) spatially explicit statistical data on the respective scale. The results of the vulnerability assessment aim to be tractable to policy-makers and can be integrated in ongoing or future spatial planning or management processes. The PEARL vulnerability index is based on a modular structure with three elements (susceptibility, coping capacity and adaptive capacity) according to the scheme presented in Figure 3. These three elements in turn consist of several sub-indices (displayed in Table 4). The structure is following the approach of the *WorldRiskIndex* (see e.g. Bündnis Entwicklung Hilft 2011), which was developed by colleagues from UNU/IREUS. While the *WorldRiskIndex* covers *risk* by taking the natural hazard sphere into consideration, the focus of the proposed concept is solely on aspects of vulnerability.
Due to the individual characteristics of data availability, the assessment of vulnerability in the respective case study locations are not directly comparable. There is an internal report available explaining the PEARL Vulnerability Assessment approach in detail (Sorg et al. 2017). The report attempts to provide a general overview on how to carry out spatial vulnerability assessments and introduces the procedure based on the Genoa case study example.

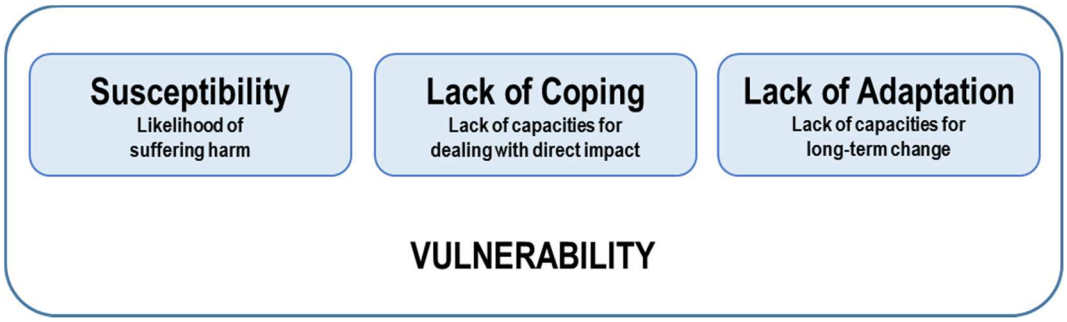


Figure 3 Components of the PEARL vulnerability assessment (Source: own draft 2016)

Box 4: Definitions for the PEARL Vulnerability Assessment

Susceptibility
In this context, susceptibility is defined as the current status of a society and their likelihood to suffer harm. It refers to the condition of exposed citizens and infrastructure. To achieve a general picture about the current situation, we propose to divide susceptibility into four parts (as summarized in Table 4):

- *Demography*
- *Health*
- *Poverty and Income*
- *Housing and Neighborhood Conditions*

Coping capacities
Coping capacity is evaluated by strengths and resources for direct actions that reduce the level of vulnerability. This not only implies knowledge about local natural hazards and resources, but the ability to react immediately when a disaster strikes to minimize harming impacts. For the coping capacity we propose the following indicators:

- *Government and Authorities*
- *Social Network*
- *Economic Coverage*
- *Medical Service*
- *Immediate Actions*
- *Information*
- *Awareness/Preparedness*

Adaptive capacity
Adaptation in contrast to coping, which is linked to the impacts, is closer related to change (Birkmann 2011). In order to deal with negative impacts of future disasters, adaptive capacities enable societies to transform. Therefore, they include a specific learning ability and response. For the PEARL vulnerability assessment four sub-categories are suggested:

- *Education and research*
- *Gender equity*
- *Environmental status / Ecosystem protection*
- *Investments*

Due to data limitations, uncertainties and other aspects, it is not possible to capture the totality of vulnerability, as a multifaceted coupled system (Turner et al. 2003). "The goal is not to *reveal the truth*, but rather to provide information and analyses that can improve decisions" (European Commission Directorate-General for Environment 2010: 18). Depending on variability in terms of data availability, indicator calculation and other decisions which influence the analysis, the vulnerability assessment can have various outcomes.

The aggregation of numerous components into a single index allows to draw conclusions at one glance, because every spatial entity is assigned to one value. There are, however, also limitations. With the calculation of an index, only certain aspects of vulnerability can be taken into consideration, depending on the previously selected factors. Although attempts were made to assess a wide range of features, the result of the spatial vulnerability assessment is only one possible depiction of a complex societal system. The limits of its validity might also be explained by the fact that economical and technical factors can be measured easily, while the inclusion of societal factors like e.g. neighbourhood support is much more multifaceted. Still, only factors can be considered for which quantifiable data are available (Mucke 2014). All components of vulnerability and therefore the vulnerability itself, are not static but highly dynamic. Consequently, the display of vulnerability in a static map can only provide an overview. It has to be noted that the vulnerability index solely displays a current status of a system (based on specific assumptions) and does not have the objective, neither the ability, to forecast any disasters. Furthermore, the target is to also include a certain long-term view of vulnerability, especially by the integration of the adaptation component. With regard to these challenges, the spatial vulnerability map should be discussed with local partners, e.g. in the PEARL Learning and Action Alliance context or in supplement with other vulnerability studies in the respective case study areas.

In the PEARL context, the focus is on European coastal regions and the vulnerability assessment tries to cover as many aspects as possible. The respective case study teams have to decide, based on their local knowledge, which components are crucial and which components, in turn, can be neglected. The data sets have to be individually determined for each case study location, with regard to local conditions. Since the availability of data is individual for each case study area, the definition of indicators might be also unique. None the less, the development of the compound index should be as transparent as possible. Therefore, after checking the data availability (and thus, the choice of suitable sub-indicators), the data has to be prepared with care. The data collection includes existing statistical data (e.g. census data, disaster loss data) at local and provincial levels. The scale of the assessment is highly dependent on the availability of data - while data availability on household level would be the optimum, data on ward level would be minimum required (Birkmann 2013).

Vulnerability includes, on the one hand, aspects which make people susceptible to the negative impacts of a natural hazard, and, on the other hand, factors which increase their ability to cope and adapt to them. For the calculation, the lack of coping and adaptive capacity is taken into consideration, in order to assess negative impacts on vulnerability. Since it is not feasible to include every single aspect of societal vulnerability, the aim is to rather provide an overview on its important key components. Hereby, a more general picture of a current snapshot of vulnerability will be attained.

One has to bear in mind that different preconditions may require modified definitions of sub-indicators. The suggested content of Table 4 is based on a literature research and discussions with colleagues at IREUS and UNESCO-IHE. Annex III of this deliverable includes the description of the respective parameters in detail. The approach was applied for the Genoa case study and a report was prepared, explaining the general approach and the implementation on the basis of the concrete case study example. By providing a guideline, other case study partners are encouraged to carry out a vulnerability assessment.

Table 4 Own draft 2016 with input based on discussions with colleagues at IREUS&UNESCO-IHE and literature input from Birkmann 2013; Birkmann et al. 2010; Birkmann et al. 2011; Bündnis Entwicklung Hilft 2011&2015; Depietri et al. 2013; United Nations 2007; Vojinovic et al. 2015

SUSCEPTIBILITY	COPING CAPACITY	ADAPTIVE CAPACITY
1. DEMOGRAPHY 1.1. Vulnerable Age Groups 1.2. Elderly living alone 1.3. Population density 1.4. Language Ability / Origin 2. HEALTH 2.1. Number of disabled or chronically ill persons 3. POVERTY AND INCOME 3.1. Dependency Ratio 3.2. Share of population living under national poverty line 3.3. Unemployment rate 4. HOUSING AND NEIGHBORHOOD CONDITIONS 4.1. Building conditions 4.2. Type of building	5. GOVERNMENT AND AUTHORITIES 5.1. Crime rates per X population 5.2. Turnout at local elections (%) 6. SOCIAL NETWORK 6.1. Household size, average number of members 7. ECONOMIC COVERAGE 7.1. Household income 7.2. Insurance coverage (life insurances excluded) 8. MEDICAL SERVICE 8.1. Number of physicians / hospital beds 8.2. Access to medical service 8.3. Vaccination coverage 9. ACTION 9.1. Immediate Action: Multi-storey buildings 10. INFORMATION 10.1. Access to early warning and evacuation information 10.2. Internet access per X habitants 10.3. Smartphone user per X habitants 11. AWARENESS / PREPAREDNESS	12. EDUCATION AND RESEARCH 12.1. Proportion of people holding higher qualification / education level 12.2. NEETs 12.3. Literacy rate 13. GENDER EQUITY 13.1. Gender parity in education (primary, secondary and tertiary education) 13.2. Gender parity in annual gross pay (female-male) 14. ENVIRONMENTAL STATUS / ECOSYSTEM PROTECTION 14.1. Air quality data 14.2. Green infrastructure 15. INVESTMENTS 15.1. Life expectancy 15.2. Flood protection measures 15.3. Risk awareness.

Case Study Example Genoa

The vulnerability assessment for Genoa was conducted on the smallest scale possible. In this case, the analysis was set up on the basis of SEZ (Sezioni di censimento). SEZ is a code that uniquely identifies the census tract 2011 as part of each municipality (ISTAT 2016). The city of Genoa is divided into more than 3000 census sections. Moreover, the Italian census area is 40 rough categories – the census areas (ACE: Aree di censimento), which were chosen as the most suitable spatial polygons. The census areas are groupings of census sections, adjacent to each other. For Genoa city there are 40 areas, labelled from 0 to 39. A value of 0 refers to the residual parts of the township not further subdivided into areas (ISTAT 2016) and will not be taken into consideration for the calculation of the indices. These still leaves 3412 SEZ areas for the calculation of the indices. Area 0 is highlighted in light grey and labelled with "not specified" in the respective maps. Figure 4 shows an overview of the ACE and SEZ areas.

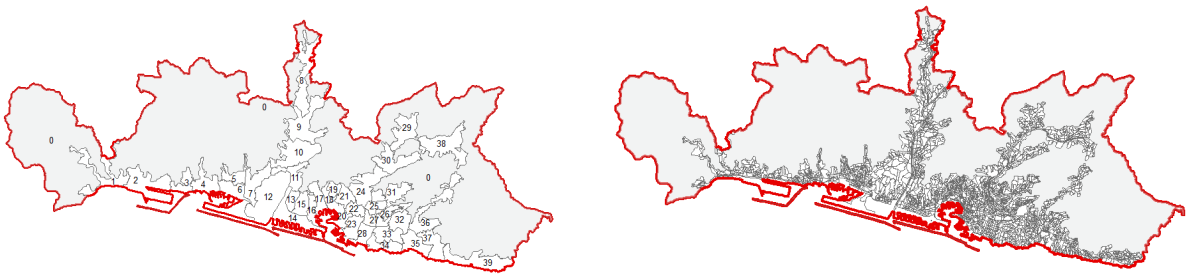


Figure 4 Overview ACE (right side) and SEZ (left side) areas (Source: Own draft, 2016)

Based on this data in combination with several other sources (see legend of the respective maps) the vulnerability assessment was conducted. All calculations were performed in MS Excel and then linked to an ArcGIS shapefile.

Concerning the MS Excel calculations for the respective SEZ areas, it should be mentioned again that the indicators were calculated either as ratios. In cases, where the fields were divided by "0", the respective field was reclassified with the value "9999", which indicates "No Data". For the further calculation the "No Data" fields were filtered and excluded from further calculation. By applying this methodology, a vulnerability value could be calculated for 3083 areas (from initially 3412 SEZ areas).

Following the discussions during IREUS/UNESCO-IHE workshops, the researcher agreed that the results for the SEZs is too small scaled for meaningful statements in a map (e.g. for further decision making processes). Therefore, after the calculation with the purpose of minimizing the information loss, the SEZ areas were aggregated (based on their mean) into the 39 valid ACE areas.

The result of the vulnerability assessment can be seen in Figure 5, where the extent of the flooding event 2014 is also highlighted. In general, spatial disparities concerning the vulnerability of the entities can be determined, which should be further discussed with experts and stakeholder involvement. However, it becomes obvious that the upper areas of the flooding extent 2014 have rather high vulnerability values, while the SEZ areas in the lower east parts show low values. The figure below shows the relative vulnerability value for the case study side, using the quantile method, which represents each class equally in the map and each class contains the same number of cases. For further details and a larger image, please refer to Annex IV.

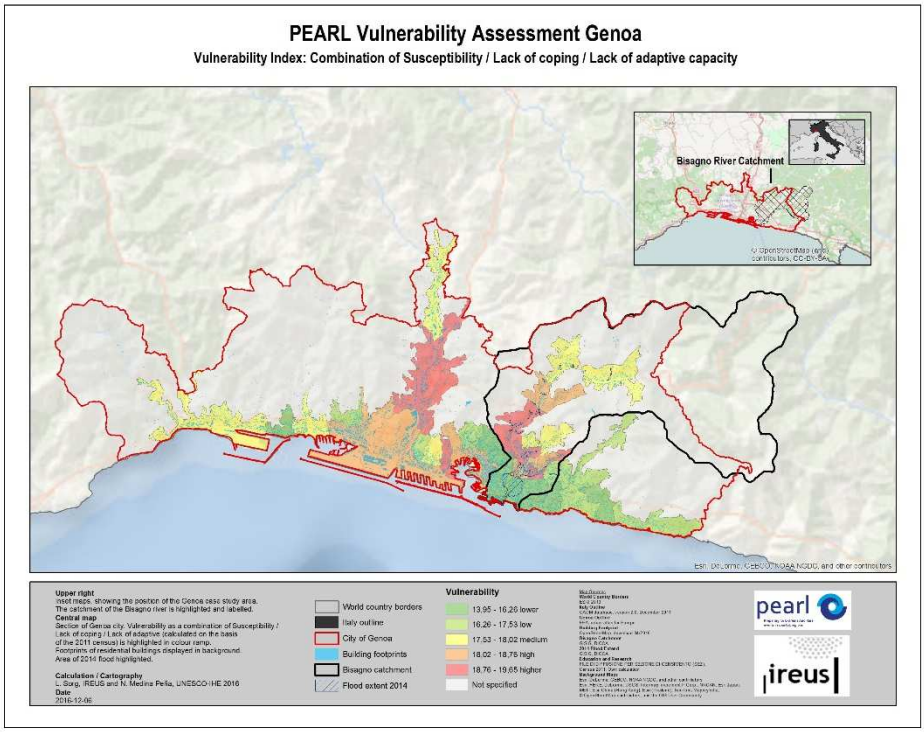


Figure 5 Result of the Vulnerability Assessment in Genoa (Source: Own draft, 2016)

3.3 Linking household survey and spatial assessments

In addition to the general vulnerability assessment for the Genoa case study site, a household survey was conducted for the purpose of gaining insights into the vulnerability patterns of exposed households. To ensure optimal use of information, IREUS and UNESCO-IHE developed an extended approach to incorporate findings from the related household survey in Genoa into the general vulnerability assessment scheme. It therefore comprises the combination of statistical data, deriving from the Census data (ISTAT 2016), geo-statistical data[1] and information on household level. The idea was to explore e.g. how factors of vulnerability that can be measured with statistical data (summed up into sub-indices) actually influence vulnerability in specific households.

The household survey was already introduces above, but in order to provide a better understanding it is important to compare the spatial extent of the two approaches (Figure 6). While the examination of the Italian household survey is oriented to the 2014 flood extent, the vulnerability assessment for Genoa (as summarized in Box 5) was conceptualized for the overall city area (see red shape in –A-). The survey was conducted by a group of 10 local students, who were assigned to an individual spatial entity, which covers a part of the 2014 flood extent. The questionnaire includes, beside the city area, also the spatial localization of the respondents. By using this information, it is possible to connect the two vulnerability methodologies.

[1] Data taken from ISTAT 2016, from the case study partner GISIG, as well as from open sources like open street maps – all sources are mentioned on the individual maps

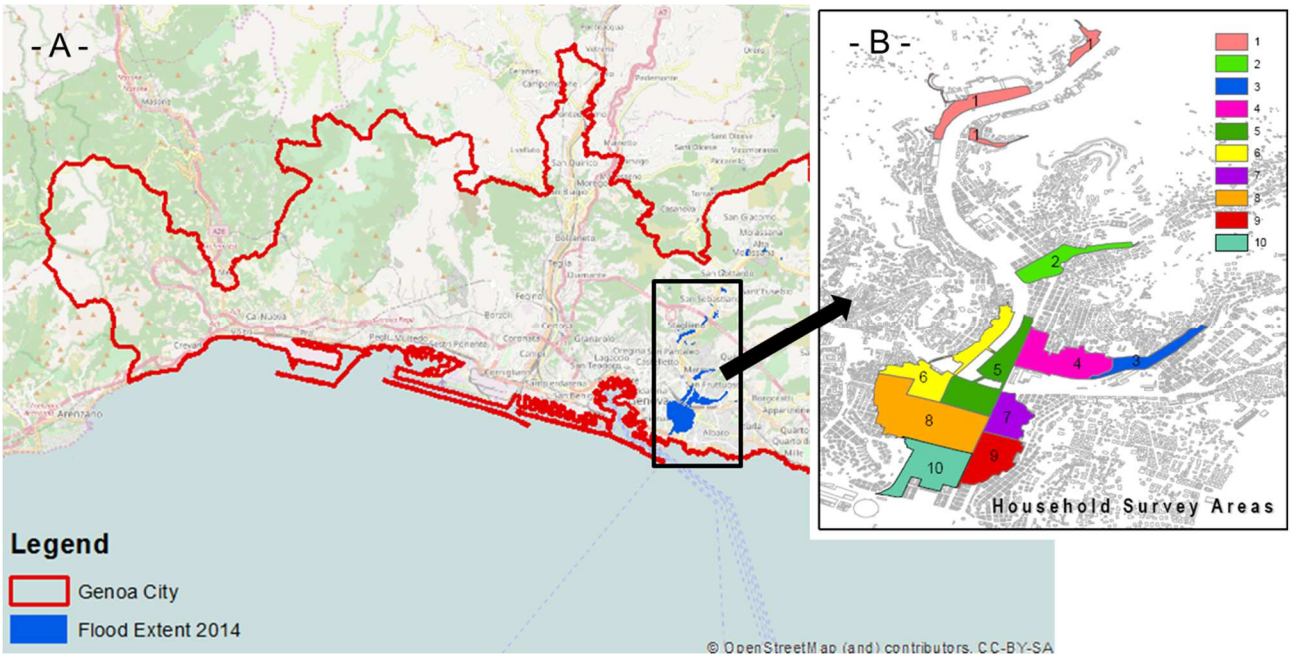


Figure 6 Overview on - A – city extent (Own draft, 2016) and - B - Household survey research area (Source: GISIG 2015)

The household survey consists, to large parts, of questions which include qualitative information. This information cannot be transferred into numbers. However, several questions of the survey can be considered for the calculation of a vulnerability value. The overall calculation is based on the structure proposed in Table 4, but the evaluation of suitable survey questions will be taken into account. Consequently, the basic table was extended and enriched by household survey input (see Table 5). The sub-indices deriving from household survey input are highlighted with the name affix "HH" and the respective number of question from the survey (Q). As it can be seen in Table 5, the household data provides a valuable contribution to the indices, especially to the coping capacity index. With the assignment of these "HH"-indicators, the vulnerability and the respective sub-indices can be calculated for each respondent of the household survey. The result of the general vulnerability assessment, can now be calculated on a smaller scale.

As previously mentioned, the selection of suitable survey questions for the vulnerability calculation heavily depends on the structure of the answers. There are three types of questions, which can be transferred into numbers:

- **Type (1):**Questions, which were answered with level of agreement to a certain statement (ranging from strongly agree to strongly disagree)
- **Type (2):** Rating questions (ranging from 0 to 10)
- **Type (3):** Questions, which can be answered with yes or no

Table 5 Incorporation of household survey results into the index calculation scheme (Own draft 2016, HH indicators highlighted in blue, display of applied indicators)

SUSCEPTIBILITY	COPING CAPACITY	ADAPTIVE CAPACITY
1. DEMOGRAPHY 1.1. Vulnerable Age Groups 1.4. Language Ability / Origin 3. POVERTY AND INCOME *3.1.* Dependency Ratio *3.3.* Unemployment rate 4. HOUSING AND NEIGHBORHOOD CONDITIONS *4.1.* Building conditions	5. GOVERNMENT AND AUTHORITIES *5.3.* Trust in institutions (HH, Q1.5) *5.4.* Performance Perception (HH, Q6.6) 6. SOCIAL NETWORK *6.1.* Household size, average number of members 7. ECONOMIC COVERAGE *7.2.* Insurance coverage (life insurances excluded) → *Insurance (HH, Q4.12)* *7.3. Financial Backup (HH, Q6.5)* 8. MEDICAL SERVICE *8.4. Medical Services Perception (HH, Q1.4)* 9. ACTION *9.1.* Immediate Action: Multi-storey buildings 10. INFORMATION *10.1. Access to early warning and evacuation information* *10.1.1. Dissemination of early warning (HH, Q4.3a)* *10.1.2. Knowledge of evacuation (HH, Q4.6)* *10.1.3. EW Lead time perception (HH, Q6.7)* 11. AWARENESS / PREPAREDNESS *11.1. Flood Risk Knowledge (HH, Q3.7)* *11.2. Increased Preparedness (HH, Q4.15)* *11.3. Perception of Preparedness (HH, Q6.2)*	12. EDUCATION AND RESEARCH *12.1.* Proportion of people holding higher qualification / education level *12.3.* Literacy rate 13. GENDER EQUITY *13.1.* Gender parity in education (primary, secondary and tertiary education) 14. ENVIRONMENTAL STATUS / ECOSYSTEM PROTECTION *14.3. Climate Change Perception (HH, Q1.3)* 15. INVESTMENTS *15.4. Enhancement of early warning (HH, Q5.3)*

As part of a workshop, researchers from IREUS and UNESC-IHE agreed on three different schemes (see Table 6 to Table 8) for the transfer of answers to numbers.

- For **Type (1)** it is assumed that a level of strong agreement to a statement (e.g. Q1.3 To which extent do you agree with the statement: *"The climate change is adversely affecting the Liguria region*") can be captured with a value of "0", while the level of strong disagreement is transferred into a maximum value of 100. All intermediary steps are assumed to be evenly spread over the minimum and maximum value (see Scheme (1) in Table 6).

- For the questions of **Type (2)** the conversion into indices is following scheme (2) in Table 7. An example for a Type (2) question is Q6: "Do you feel prepared in case a major flood will hit your household? On a scale between 0 (not prepared, expect major damages) and 10 (very good prepared / expect no major damages)". Since the question is assigned to coping capacity and the lack of coping has to be calculated, in order to assess factors which increase vulnerability a rating value of 0 (not prepared, expect major damages) is related to the maximum value "100",and the minimum value of "0" will be achieved with a rating of 10.

- For the **Type (3)** questions scheme (3), displayed in Table 8, applies. Answers in affirmance will be transferred into a value of "20", while negations are assigned the value "80". The values were chosen based on discussions during the IREUS/UNESCO-IHE workshop. An example for a Type (3) question is the information, whether a respondent thinks he/she is better prepared for future events (Q4.15).

Table 6 Scheme (1)

Answer	value
Strongly Agree	0
Agree	20
More Agree	40
More Disagree	60
Disagree	80
Strongly Disagree	100
No Answer	9999

Table 7 Scheme (2)

Answer	Value
10	0
9	10
8	20
7	30
6	40
5	50
4	60
3	70
2	80
1	90
0	100
No Answer	9999

Table 8 Scheme (3)

Answer	Value
YES	20
NO	80
No Answer	9999

Since the calculation of the vulnerability also requires input from the other indicators proposed in Table 4, the individual households were assigned the values of the spatial entities (in the Genoa case: SEZ) in which they are located.

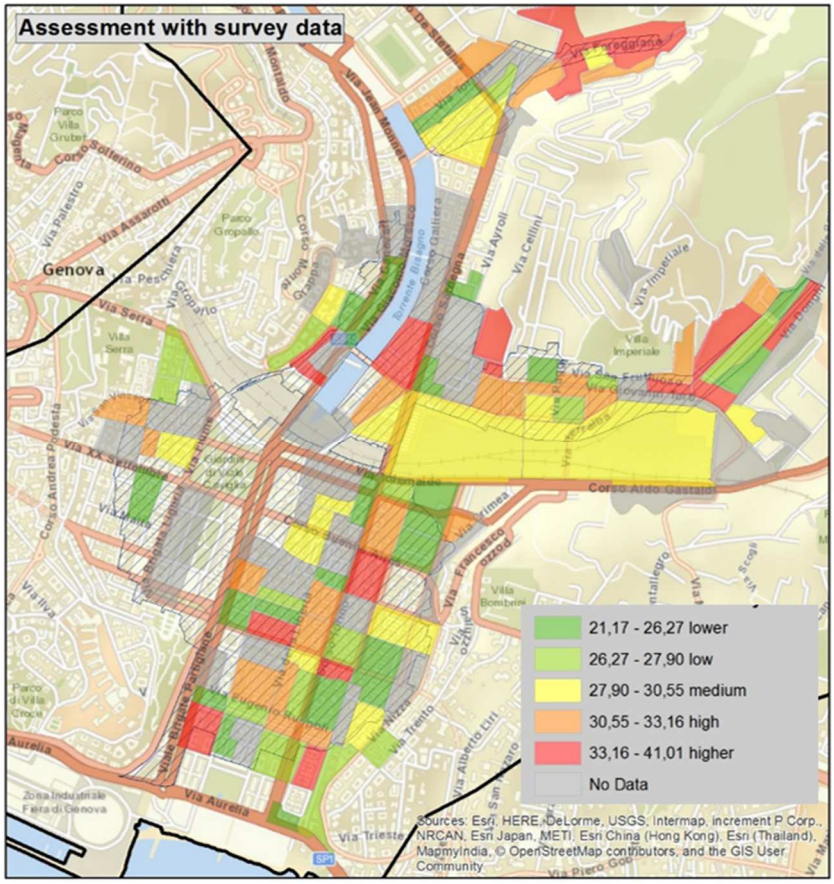


Figure 7 Result HH Vulnerability Genoa

Figure 7 shows the result of the vulnerability assessment on household level zooming into the study area of the household survey. In a first step the vulnerability values were calculated on household level and then, due to data privacy, aggregated into the SEZ areas.

The map above offers additional information for people-centred risk management, since it includes the perception of citizens to a certain extent.

The internal report related to the PEARL vulnerability assessment (Sorg et al. 2017) includes also the results for the underlying other indices (susceptibility, lack of coping capacity and lack of adaptive capacity), as well as the results for the focus area using solely Census data.

4 Linking RRCA - Methods for Holistic Risk Assessment

4.1 Linking Root Cause Analysis and Vulnerability Assessments in Work Package 1

Qualitative Root Cause Analysis in PEARL also informs and complements other risk assessment methods. The Vulnerability Assessment focusses on susceptibility, coping and adaptive capacities at a given time, which are the result of physical, socio-economic, governance and perception processes as drivers and root causes. Whilst the Root Cause Analysis aims to identify the unique characteristics of underlying root causes by focusing strongly on institutional aspects, the Vulnerability Assessment methods provide insights into contemporary vulnerability outcomes, and through the household survey the perception of exposed citizens. Root Cause Analysis also covers the drivers of hazard, exposure as well as vulnerability with regard to historic, contemporary and future temporal expression. The results of the household survey can be seen as a current snapshot of local vulnerability patterns, which includes related perceptions and values. The statistical and geo-spatial analysis, however, includes a certain long-term view of vulnerability, through the integration of the adaptation component, which also focusses on transformation processes. For further risk assessment, carried out in PEARL WP3, the compound vulnerability index (as introduced in the concept note of Sorg et al. 2017) can be combined with hazard and exposure information (following the procedure of the World Risk Index, see e.g. Bündnis Entwicklung Hilft (2011); for further information). Thus, the spatial distribution of risk in the respective case study areas can be calculated. The different methods are therefore mutually supportive.

While the questions and indices selected for the Vulnerability Assessment drew on established assessment methods (through the application of the World Risk Index) rather than being derived directly from the Root Cause Analysis in PEARL, the gathered information does help to verify the linkage between root causes and observed impacts of the disaster. The findings from the household survey confirmed major elements of the Root Cause Analysis for the case study sites:

- **Lack of household insurance in Genoa**
  The household survey in Genoa revealed that the respondents are showing only limited willingness to assume greater responsibility and more initiative for their situation. The unwillingness is not only displayed by insufficient adaptation (private investment in protection measures, change in behaviour, better level of information, etc.), but also in inadequate insurance cover. The majority of respondents had no insurance cover when the last flood hit, neither do the most of them have now. The lack of household insurance was confirmed in the RCA study findings, which draws conclusions from the history of Italian disaster risk management. The Italian RRCA report reveals that private insurance schemes for natural disaster damages are lacking in Italy and the main source of post-disaster finance is state emergency aid.
- **Different conceptions of responsibilities in Rethymno**
  According to the expert interviews of the RCA, the focus of disaster risk management in Greece is still on post-disaster management and structural solutions and less on prevention, preparedness and awareness raising. The general consensus among officials in Rethymno was that there was a need to focus on awareness-raising and private activities that contribute to flood risk, including private violations of planning regulations. The results of the household survey show that the local population relies on engineering methods, but also at the same time violates the implemented measures by ignoring planning regulations. Moreover, respondents prefer external, structural measures instead of e.g. financial support for citizens taking action.

- **Lack of evacuation routes in Rethymno**
  In Rethymno the vast majority of respondents (over three quarters) stated not having any information in case of a flooding event. This conclusion is supported by the related Root Cause Analysis, which states that there is a serious lack of communication of evacuation routes, which are solely available for earthquakes.
- **Information deficit Genoa**
  The household survey in Genoa reveals a severe information deficit. Solely on the basis of the questionnaire it is not possible to assess the underlying causes. With the aid of the RRCA report it is possible to clarify this circumstance to a certain extent. According to the RRCA, several communication tools have been developed for Genoa, in order to increase the risk awareness, preparedness level and emergency planning. Multiple information regarding emergency plans, hazard maps and other similar material is available online on the municipality website. However, it appears that there is a severe problem with knowledge sharing and communication. A possible conclusion is that the available information might not meet the affected persons' needs. This points to the need to assess what kind of information is needed and how to distribute it. The household survey detected that most of the respondents in Genoa use television as the main source of information concerning the latest updates on floods.

4.2 Linking Root Cause Analysis and Agent-Based Models

As conceptualized in the PEARL Holistic Risk Assessment Framework, information from the Root Cause Analysis method informs the development of agent-based models (ABM). There are two ABMs in PEARL developed at UNESCO-IHE. The first one focuses on the interaction of floods, humans and their built environment as drivers of hazard, vulnerability and exposure. The drivers are the institutions which in model terms are expressed in terms of institutional statements. For example, land use planning can be a driver of exposure and institutional statement derived from this driver could be "Land owners must not construct new buildings (or houses) if their land is located 25m from the waterfront." The ABM in this study addresses long-term institutions related to prevention and mitigation and recovery phases of the disaster management cycle. The second ABM focuses on the short-term, operational institutions related to preparation and response phases of the disaster risk management cycle. These include flood early warning and evacuation processes. Stronger links developed synergetically between the long-term institutional ABM and RCA, and between the short-term operational ABM and vulnerability assessment.

With regards to the Root Cause Analysis case studies, the St Maarten case was undertaken with a clear focus on inputs needed for the institutional ABM, both because of the continuity of the St Maarten case study researcher in PEARL (so she could then work closely with the ABM teams following the case study analysis) as well as the familiarity among some of the ABM modellers with the case. The interview protocol for the St Maarten Root Cause Analysis study was therefore most explicit out of all the Root Cause Analysis case studies in focussing on agent attributes, and the interactions between agents. The interviews centred on agent behaviour and motivation pre-, during and post- particular flooding events as well as eliciting stakeholder opinions about the broader causes of specific disaster events on the island. The findings from the St Maarten research were therefore first summarised in the MAIA structure which underlies the ABM model and submitted to PEARL as Milestone 4 in January 2016. However, the distinct social and political dynamics of risk management on the island need to be acknowledged and any derived models tested against comparable cases.

The main complementarity of the agent-based modelling work to the RRCA approach is that it provides a futures-oriented perspective and simulation of multiple scenarios, where the Root Cause Analysis and Vulnerability Assessments are mostly oriented to a historic and contemporary perspective for a particular case. In turn, the work of WP1 has been used to identify key stakeholders as well as key behaviours (rules and norms) for the ABMs and contributed to a stronger understanding of institutions and institutional dynamics in the MAIA model which underpins the institutional ABM work, beyond reference to social systems.
The following box illustrates how the Root Cause Analysis was used in the Institutional agent-based model:

Box 5: The RCA and the Institutional agent-based model

Theoretical background

Institutional ABM is part of a coupled agent-based-flood modelling method developed within PEARL to understand and simulate the complex interaction of human-flood systems. In the coupled model, ABM focuses on the human system (comprised of humans, their means of interaction and their built environment) whereas the flood model focuses on the flood system (comprised of hydrological processes and hydraulic elements/structures such as rainfall, runoff, urban floodplains, drainage channels, weirs and pumps).

ABMs have three components: set of agents, set of agent relationships and methods of interaction, and agents' environment (Macal and North, 2010). In the institutional ABM, agents (may also be referred to as actors or stakeholders) are representations of individuals or collection of individual agents such as a household, government, NGO and are capable of autonomous actions. These agents have internal states that define and give information about the current status of the agent. Agents also have behaviour that guides them to act, interact and make decisions. Agents' interaction can be between each other or with their environment, which in this case is an urban environment that can be described using GIS data. Agents' behaviour can be influenced by their internal state or by set of 'rules' known as institutions (such as laws, policies and guidelines). Institutions are shared perceptions and expectations or common understandings among a group of individuals that influence behaviour leading to outcome (Crawford and Ostrom, 1995). Therefore, the institutions help to understand the complex interaction of agents with each other, their built environment and floods as drivers of hazard, vulnerability and exposure. Institutions are classified as *rules*, *norms* and *shared strategies*, and can be expressed using institutional statements. Institutional statement refers to "the shared linguistic constraint or opportunity that prescribes, permits, or advises actions or outcomes for actors. Institutional statements are spoken, written, or tacitly understood in a form intelligible to actors in an empirical setting." Institutional statements can be described using the "ADICO" grammatical syntax in which "A" refers to attributes (or agents), "D" refers to deontic (modal operator which can be permitted, obliged or forbidden), "I" refers to aim (the actions or outcomes), "C" refers to condition (when, where and if (or if not) the aim is permitted, obliged or forbidden) and "O" refers to or else (the sanction for failing to comply with the rule) (Crawford and Ostrom, 1995). If an institutional statement consists of "AIC", it is regarded as *shared strategy*; if the statement consists of "ADIC", it is *norm*; and if the statement contains all the five components, it is called *rule*.

Building ABMs is not an easy task and needs to follow certain guidelines including problem formulation, system identification, concept and model formalization, software implementation, model verification, experimentation, data analysis, model validation and model use (van Dam et al., 2013). The crucial step of concept formalization can be performed using meta-models such as MAIA (Modelling Agent systems using Institutional Analysis) by Ghorbani et al. (2013). The MAIA meta-model is organised into five structures: *social structure* defines agents and their attributes such as properties, behaviour and decision making criteria; *institutional structure* defines the social context such as role of agents and institutions that govern agents' behaviour; *physical structure* defines the physical aspects of the system such as infrastructure; *operational structure* defines the dynamics of the system; and finally, the *evaluative structure* defines the concepts that are used to validate and measure the outcomes of the system.

Case study: Sint Maarten flood risk management (FRM)

The Caribbean island state of Sint Maarten is one of the study areas in PEARL. The Sint Maarten FRM is presented here as a case study of the complex human-flood system. As mentioned in Section 2.1, the RRCA in Sint Maarten is based mainly on face-to-face interviews with stakeholders such as independent experts, Ministries, Fire Department, NGOs, business sectors and insurance companies. However, the analysis also used publicly available documents such as Hillside Policy, Beach Policy and telephone interviews with residents. RRCA helped to identify the problems, system components, agents, root-causes and drivers of flood hazard vulnerability and exposure and flood reduction measures. The findings of the RRCA were used to formalise the concepts based on the MAIA framework. Institutional statements are extracted and coded from RRCA outputs based on the methods described in (Basurto et al., 2009; Watkins and Westphal, 2015).Concept formalization is an iterative process which continues until the problems formulated and systems identified are well captured in MAIA structures. The following tables show examples of the different structures of MAIA and the formalization.

Table A. Social structure

Name	Property	Personal value	Information	Possible role
Households	- Wealth - Level of risk to take - Risk awareness - Insurance - Building plan	- Safety	- Zoning policy - Beach policy - Hillside policy - Building ordinance - Insurance policy	- Land owners
Businesses	- Asset - Profit - Level of risk to take - Risk awareness - Insurance - Building plan	- Profit maximization - Safety	- Zoning policy - Beach policy - Hillside policy - Building ordinance - Insurance policy	
VROMI	- Budget - Enforcement - Fine	- Safety		- Permit - Inspection - New Project

Table B. Institutional structure

Name	Attributes (roles)	Deontic type	aIm	Condition	Or else	Type
Building code	Land owners	must	elevate new house/building by 0.2 m	any location and any time	fined	Rule
Beach policy	Land owners	must not	build houses/building	within 25 m from the coast line	fined	Rule
Flood risk management	New Project department	may	Construct or maintain FRM measures	If flood leads to casualty		Norm
Flood risk management	Businesses		fund FRM measures	if measures protect asset		Shared strategy

Table C. *Physical structure*

Name	Property	Type	Behaviour	Affordance
Building (residential or business or public)	- Location - Elevation - Building function - Floor height - Flooded - Damage	- Private	- Flooded - Damaged	- Constructed - Maintained
Drainage channels (pipes)	- Location - Cross-section - Physical condition - Design discharge	- Public	- Damaged	- Constructed - Maintained
Hazard triggering factors (precipitation, storm surge)	- Return period	- Public		- modelled
Flood map	- Depth - Extent	- Public		
FRM measure	- Type	- Private/Public	- Damaged	- Constructed - Maintained

Table D. Operational structure

Role	Entity Action	Pre-condition	Post-condition
- **Households** - **Businesses**	- Construct building	- if *wealth/asset* > threshold, AND - if new house/building *location* is not within 25 m from coast line, OR - if new house/building *location* is within 25 m from coast line and do not follow Beach policy	- increase number of houses/buildings by one - set new *location* - set *elevation* - set *building function*
- **Households** - **Businesses**	- Construct building	- if new house/building *location* is in flood zone	- set floor height according to the policy
- **Environment**	- Flood modelling	- if rainfall *return period* >= 5	- run flood model - produce and overlay flood map - set *flooded* (TRUE/FALSE)
- **Households** - **Businesses**	- Compute damage	- if *flooded* equals TRUE	- compute and set *damage*
- **New project department**	- FRM measure	- if *budget* >= threshold	- decide where to implement - decide *type* of measure - implement measure by updating files in flood model

Institutional ABM

The development of ABM for the Sint Maarten FRM case study started before the RRCA. The initial model was developed using the NetLogo simulation environment (Wilensky 1999). Model inputs are obtained from desk studies and previous UNESCO-IHE studies on the island. In this model setup, there were two types of agents: businesses and ordinary residents. Businesses construct commercial buildings (e.g., hotels) and residents build residential houses. The institutions incorporated in that preliminary model were based solely on the Hillside policy. Businesses build in mild slopes and low lying areas, especially along the coast (to attract more tourists) whereas residents have more flexibility to build their houses on the island. However, since the land use zoning in the island defined higher elevations for nature, it is not allowed to build in elevations higher than 200m. In the model, the buildings, whether commercial or residential, represent the owners. Early simulation result presented in Figure 8 shows that commercial buildings (yellow coloured) aggregate more along the coast. On the other hand, residential housings (brown ones) concentrate on the hilly areas. The modelling exercise shows the potential of ABMs in showing emergent phenomenon, which in this case is location of different types of buildings, from simple institutions.

After the RRCA, more agents and institutions were identified and hence the ABM is expanded. To simulate the co-evolution of the human-flood systems and the FRM dynamics better, the modellers identified the need to couple the ABM with a flood model. In addition to a more realistic representation of the flood system, coupling a flood model with the ABM provides a platform to test the different FRM policy implementations (e.g., enlarging channel cross-sections and constructing new detention basins). However, NetLogo was found to be limited in the coupling process, especially running the flood model executables and manipulating input-output files. Therefore, the modellers changed the modelling platform to Repast Simphony (North et al., 2013), a Java based ABM environment.

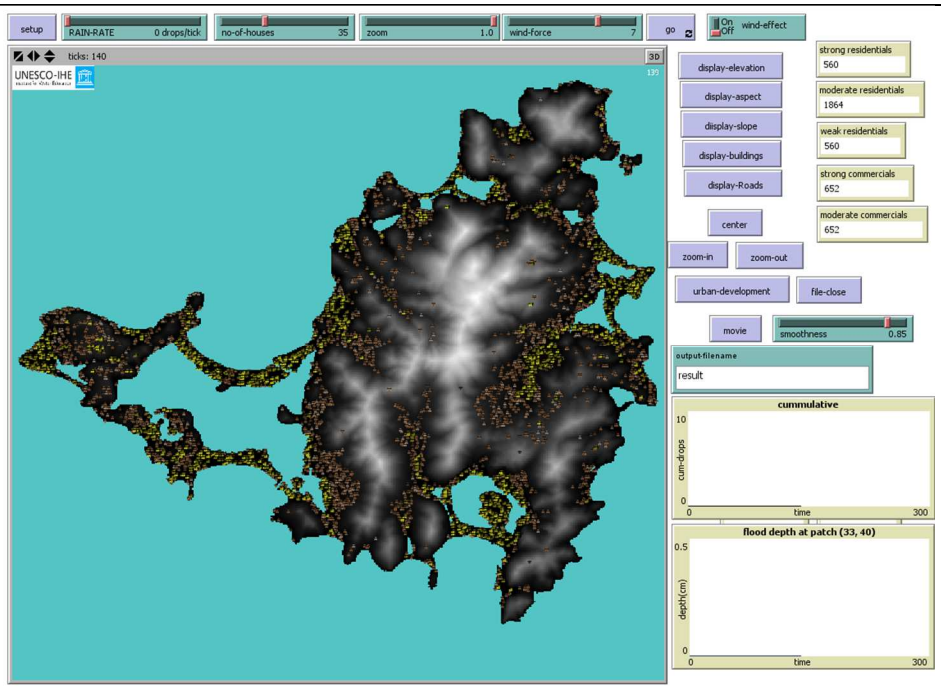


Figure 8 Building Pattern Result in the NetLogo visualization environment

The coupled institutional ABM – flood model being developed in PEARL focuses on long-term institutions related to prevention and mitigation and recovery phases of the disaster management cycle. The following preliminary result (Figure 9) shows an increase in the number of flooded houses (i.e., ticks 2, 7, 10, 13 and 17) for the same return period of rainfall (i.e., 5 year). The reasons for this can be increase in flood extent and new buildings constructed in flood plains. In the first case, increase in percentage of impervious surfaces because of construction of new buildings resulted in more runoff being generated from the same rainfall intensity. That, in turn, would create much flood covering larger extent. In the second case, most of the new buildings might not obey zoning regulations and not elevate their house.

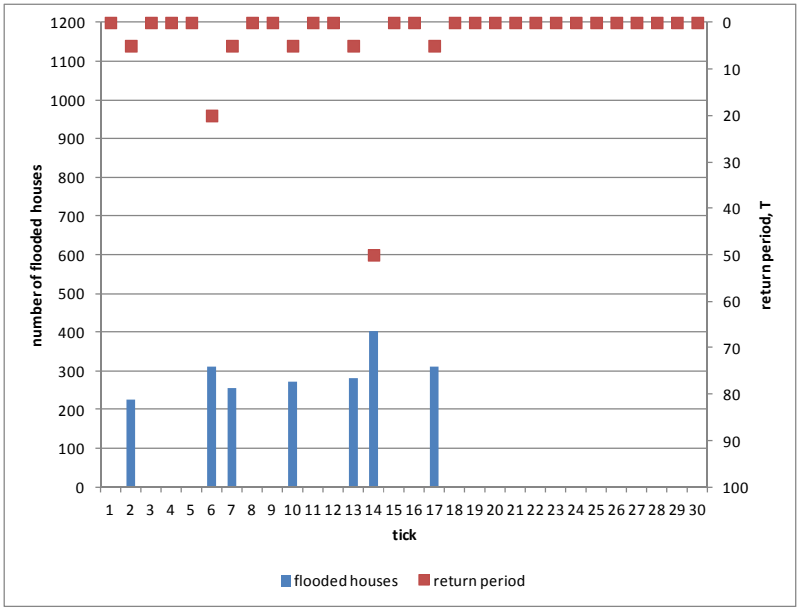


Figure 9.

In addition to the modelling described above, Institutional Network Analysis (INA) was conducted in the St Maarten case to support the MAIA framework. Most importantly, INA (especially the institutional network diagram) enhances the MAIA framework by providing a 'flow chart' like functionality to the operational structure. However, INA also provides detailed inputs to the collective (also called social) and constitutional (also called institutional) structures. Conceiving of institutional dynamics as a network within a complex adaptive system, the analysis first identified the agents and then the institutional statements (or rules, norms and shared strategies; see more about institutional statements in Crawford and Ostrom 2005) that guide responses to flood risk. Material from the Root Cause Analysis (both raw data and the relevant bibliographic library as well as the final Root Cause Analysis report for St Maarten) was shared with the ABM researcher at TU-Delft, who processed the data according to particular attributes identified from Social Network Theory, an Influence Diagram and the syntax of the MAIA Framework. Then, a series of institutional statements that could inform the model development was drawn up. For example, VROMI (the agent), must (the deontic condition), organise the clean-up (the aim), if necessary after a storm event (the condition) - followed by any applicable sanction. Networks also illustrate the main institutions involved in different areas of the flood response system, e.g. short-term response and clean-up. The use of qualitative material based on the Root Cause Analysis highlighted the importance of informal institutions as, if not more, important than formal institutions in determining responses to flood risk.

This blending of methodologies has generated also unique learning about the methodological challenges to the Holistic Risk Assessment:

- The difficulty in quantifying social and political phenomena highlighted by the qualitative methods used in Root Cause Analysis, such as clientelistic relationships. Social segregation could not be incorporated in the model used at UNESCO-IHE, for example. There was also no gradation of policy measures which might have been only partially implemented, or implemented and then not maintained, as opposed to implemented or not. The assumption of conscious and rational decision-making in the ABMs is not reflected in qualitative analysis for the Root Cause Assessments. This demonstrates the importance of retaining the two methods as independent parts of the whole, alongside their integration through model formulation.
- Root Cause Analysis, as based on purely qualitative methods cannot specify quantitative thresholds for decision-making, such as the magnitude or extent of a flood that might trigger policy measures. In conjunction, however, the methods can join the drivers and impacts of flood risk.
- The difficulty in generalizing the results of Root Cause Analysis to build a large population of agents for the model.
- The broad frame for Root Cause Analysis leads to the question of where ABMs should bound the system and what agents or institutions exert the most influence on a given system. Again, the Root Cause Analysis did not weight actors or causes. What this form of RCA can do is clarify and support the assumptions made in this respect.
- Reflecting in the ABM the values and relative judgements about risks held by different stakeholders, which is revealed by the Root Cause Analysis. The ‘system’ is therefore both objective and subjective – however, the objective aspects are easier to model.

Indeed, as mentioned, both WP1 and WP3 researchers reported that the findings of the Root Cause Analysis case studies spoke better to the model of long-run institutions and institutional causation than a shorter-run decision-making model where the focus would be on the detailed decision-making motivations and procedures of agents (e.g. who follows evacuation procedures, who self-evacuates etc.).

The fact that the Root Cause Analysis used an approach of testing causation through interrogating the drivers of a select number of disaster events also precluded being able to analyse a full decision-making sequence over time (e.g. the researcher probed the causes of 2005 and 2014 flooding events, rather than seeking to understand a continuous decision-making cycle throughout the time period).

4.3 Linking Vulnerability Assessments and Agent-Based Models

ABMs can use the data of vulnerability assessments, as introduced in chapter 3, and analyse it with a different methodology. The comparison of these methodologies would provide the basis for the integration of institutional and spatial factors for a more in-depth understanding.

The aim of the household survey in vulnerability assessment is to deduce vulnerability patterns and to gather information on how households respond before, during and after a hazard, in order to get an understanding on local risk management strategies. The survey gives an insight into local people´s view, perception of the rules, norms and strategies and some of the profound challenges. Therefore, the survey data might be valuable to identify key concerns and problems and define the states and behaviours of household agents. However, since the survey focuses only on households, it may not be as valuable in defining states and behaviours of composite agents such as government agent or an insurance company. In addition, it may not also provide enough information about physical structures (e.g. FRM measures implemented).

One of the commonalities, also a challenge for both, the household survey and ABM is an issue of generalization of findings. The information deriving from the household survey is strongly related to the respective case study. It is difficult to draw conclusions for other case study areas, even if they have similar boundary conditions. The same applies for ABM: It is difficult to build general ABMs since the approach is bottom-up, which implies that local conditions play a major role in the dynamics.

The vulnerability assessment in PEARL includes a methodology which is flexible in terms of the data and as such it can be applied for every case study area with regard to the availability of data. The statistical and geo-spatial vulnerability assessment, could also incorporate institutional aspects. The proposed sub-indicators in Table 4 are not rigidly fixed, therefore institutional factors which influence vulnerability can be integrated if data is available at the respective scale. As previously stated, an immense challenge is the quantification of qualitative aspects, which is inevitable when calculating indices. In turn, the individual sub-indices of the spatial vulnerability assessment might provide useful information to ABM work, since the result is a compound index, which can be unravelled. As an ABM is conceptualised depending on the problem(s) identified in the case studies, these data may be used in the ABM model set up.

For ABM, the modellers use institutions (i.e., rules, norms and shared strategies) to model the behaviour of agents and their interaction with other agents, their built environment and the flood system. The ABM evaluates effects of institutions and their implementation based on flood impact (e.g., number of flooded houses or physical damage). The ABM predominantly helps to understand the human system; however it also comprises a geographic component, and coupled with a flood model, it provides a method to study the co-evolution of the human-flood systems and FRM dynamics. Hence the coupled ABM-flood model can be seen as a risk model which maps how patterns change and includes a feedback loop that might affect the factors hazard, exposure, or vulnerability. The ABM is based on the risk concept proposed by IPCC (2014).

Ideally, it is conceivable to develop an approach for future scenario analysis of the spatial assessment with the help of ABM and possibility test multiple scenarios considering the social factors that influence spatial outcomes and vice versa. The combination of methodologies and development of scenarios is especially interesting in terms of the adaptation part of the vulnerability assessment, which can include long-term changes and transformation processes. If the ABM assumes certain developments it is possible to incorporated them into the calculation of the respective sub-indices of the spatial vulnerability assessment. A possible example might be the increase of investments as part of the adaptation index.

5 Practical Application of the RRCA

5.1 Using Root Cause Analysis in stakeholder learning platforms

A challenge for integrating Root Cause Analysis into policy is that Root Cause Analysis shows how the causes of risk arise across multiple sectors and multiple levels of governance, often well beyond the conventional remit of disaster risk management officials. PEARL case study analysis shows up how:

- Even when structural and non-structural risk mitigation measures are in place, urbanisation and economic development trends drive up risks. Across all PEARL case studies, tourism-related and other infrastructures are often developed without regard for land-use plans or building codes related to risk. This is a global trend.
- Demographic shifts with urbanisation also change the requirements of non-structural measures such as awareness-raising drives. In St Maarten, for example, a recognised challenge is how to provide early warning and preparedness campaigns in multiple languages, as the island has attracted increasing numbers of migrants to support its tourism development. A less well recognised challenge is how to improve trust in government communications by such groups, who are often politically unrecognised and economically and socially marginalised, and how to improve settlement conditions which lead to greater exposure and vulnerability.
- Identification of key actors which can be used in setting up ABM models
- A more general information concerning risk perception

PEARL Root Cause Analysis also highlighted how large-scale economic and institutional shifts occurring at global, national and regional levels influence the nature of risks as experienced in local contexts. Austerity measures and decentralisation, for example, have had positive and negative impacts in all PEARL case study contexts – exacerbating resource constraints for disaster management, but in some cases also leading to the development of more appropriate risk knowledge or creating new opportunities for social involvement in risk reduction. The precise effects are context-specific. Nevertheless, they point to the need to:

- **Find innovative local solutions.**
    - In the Genoa case study, the research has led to practical recommendations about how data about funding flows for flood protection from different sources can be improved in order to maximise the use of funds and better monitor and track spending.
    - In Rethymno, Crete, the analysis emphasises the need to take advantage of a new moment of political opening in Greece's history to involve civil society actors in the development of more holistic flood management policies.
- **Foster cross-country learning about innovation in flood protection in the context of resource constraints.** The PEARL project has enabled stakeholders to share experiences through an online learning platform, such as a presentation by the Head of Disaster Management for St Maarten about the organisational structure for disaster response on the island.
- **Engage stakeholders across all levels**, including national level and supra-national level bodies such as the EU, and improve capacity at the local-level to access funding and knowledge often available at other levels of government. This can be challenging: in Rethymno, Crete, attempts to include national-level stakeholders in a participatory action-learning alliance fostered by the PEARL project were abandoned as due to political changes and financial crisis in Greece personnel in national-level ministries of importance were either absent or unwilling to participate (Sorg et al. 2016).

In practice, difficulties in communicating the findings of the Root Cause Analysis in local-level forums were also exacerbated by the bias in Learning and Action Alliances towards the inclusion of technical perspectives and institutional representatives, as well as the difficulty in confronting the issues around local political cultures raised across the Root Cause Analysis case study reports as central to the contemporary weakness of flood risk management. Root causes are also dynamic, and while historic factors shape the causes of risk into the present, there are discontinuities and shifts in governance and socio-economic pathways which mean that pathways are not determined into the future. This points to the need for Root Cause Analysis – and related roadmaps - to be continuously reviewed.

5.2 Using Vulnerability Assessment in stakeholder learning platforms

The most important stakeholder platform for the incorporation and critical review of obtained vulnerability information are the PEARL Learning and Action Alliances (LAA). The LAAs can be used as distribution and discussion platform for the results. LAAs are a way to help different kind of stakeholder, with diverse perspectives on risk, to break their traditional approach and to be part of a social learning procedure (Ashley et al 2011). In the course of the project the LAAs take over various functions including to facilitate the research process by keeping contact with the stakeholders, to discuss results, to implement output, and to disseminate the final conclusions of PEARL.
Consequently, the outcome of the spatial vulnerability assessment, just as the outcome of the household survey, can be used for stakeholder involvement as information base and basis for discussions. Ideally, the vulnerability assessment will influence future managing and planning procedures by being integrated into decision-making processes, since the LAAs identify long term visions of stakeholders for the risk evaluation in the individual case study areas. The steps on how to achieve this vision are part of the road map development, performed in WP5.

The results of WP1 were already partially presented in the respective case study areas to feed them back into the local and regional planning and management processes. The Greek stakeholder workshop took place on 7th and 8th of July. At that time, a report (Sorg 2016), describing the extent, procedure and outcome of the household surveys, was already available and distributed to interested partners. Due to the structure of the questionnaire, the majority of evaluation consists of descriptive statistics. The descriptive statistic gives an insight into local people´s view, which is of great value for further stakeholder involvement. Regarding the Rethymno case study, the results were discussed during the second PEARL LAA stakeholder workshop. For further information, a workshop report by Gourgoura et al. (2016) is already available. The findings related to WP1 are summarized in Box 6.

Box 6: Case Study Example: RETHYMNO (Source: Gourgoura et al. 2016)

Risk perception, according to institutions and authorities' view was examined during the first event on October 2015, while a household survey was conducted by the University of Stuttgart during the same period in order to gain insight into citizens' perspective. The comparison of results and the identification of different aspects between citizens and authorities is really important and interesting for the formulation of the future LAA goals and axes of action. The results of the household survey results to key stakeholders of Rethymno during the 2nd LAA workshop in June 2016. Aim of the presentation was the comparison with results from questionnaires completed by Rethymno's authorities during 1st workshop (1 & 2/10/2015) and feedback perception regarding the household survey. Beyond the reactions the authorities' representatives agreed with citizens for the need of a reliable early warning system.

The first activity during the 2nd stakeholder workshop was the presentation of Household survey results. NTUA researchers presented to stakeholders in full the survey and its outcomes e.g. who conducted the survey, what was the population sample, which areas of Rethymno the surveyors covered, the groups of questions, aims and objectives of the survey, etc. Numbers, figures and key results were presented according to the analysis provided by the University of Stuttgart, while the presentation was enhanced with the interpretation and comments by researchers on responses, based on Greek reality.

On a second stage findings from the household survey were compared to the ones derived from discussions and questionnaires on risk perception of stakeholders. The researchers aimed to highlight not only the common views but also the contradictions.

A round table followed were all these aspects were fully discussed and stakeholders had the chance to object, agree, assess the content of the survey, and also self-criticize their work so far in terms of flood management. The discussion also served as a bridge to the next activity which was the design of LAA actions.

Main findings and feedback concerning the results of the household survey

i. Risk perception: Authorities vs. Citizens

Local authorities and stakeholders expressed an increased interest in Risk perception household survey. Although citizens' responses didn't fully satisfy the authorities' representatives and despite arguments on the content of the survey, the Round table followed the relevant presentation provided useful input in understanding the different approaches in risk perception as also the specific needs for the city of Rethymno.

The evaluation by respondents of Authorities' performance over the last years was rather low, fact which annoyed enough both Municipality and Water Company (mainly in charge for the city). It is important here to mention that Rethymno has the same local government the last 6 years and the relevant question was "How would you evaluate the action of local authority in improvement on flood risk management in your neighbourhood over the past 5/10 years". It turned that Municipality received the responses as an oppositional criticism to the work done over the last years. At this point stakeholders questioned the intentions of the respondents. For instance Area F has the highest rank of exposure in flood risk while rates city's performance very poor. When researchers asked the stakeholders what is going on in this area? Why these citizens feel exposed? What kind of risks exist there? The municipal representatives answered:

"This area has no flooding issues at all, we don't know why residents there feel exposed. Probably they are influenced by several publications in newspapers by political opponents, who aimed to downgrade the work done by current local government"

Objections were also expressed for the content of the survey, more specifically for the term "flood".

What exactly do we mean by flood or flood risk? They argued that when conducting a survey the risk should be determined, e.g. Is it a risk an event of 5cm water on the streets where no lives are in danger? From the discussion it proved that when stakeholders speak about floods they have in mind highly extreme events which threaten massively lives and properties. They don't perceive as a risk a low intensity event which might be very often and annoying to the city's daily life. On the other hand, respondents on the survey (as stated by representative from SINPOLIS who was also a volunteer in the survey) perceive as flood even an event of 5cm water on the streets. The volunteer explained that although there was no special question in the survey during the discussions with citizens it was clear that residents of Rethymno when speaking about floods have in mind mainly the problem of overtopping on harbour, while most of them are annoyed by the inundation of streets after heavy rainfalls or flash floods.

Another important objection related to the questions and the content of the survey was the term *"bad urban planning".* The relevant question to the households was *"Which is the most important driver of losses due to flooding in Rethymno"* and the majority (31.2%) of the respondents answered *Bad Urban planning*. Stakeholders mentioned that most of the times bad urban planning is actually violation of regulations by citizens or groups of people with special private interests. So they argued that this term as phrased is very generic and actually means nothing since it doesn't include the personal responsibility of each individual, but transpose the responsibility to someone else. Identical was one participant's statement *"Bad urban planning should be called delinquent planning".*

Another opposition was to the phrase *"Radical restructuring of certain area".* (The question was "*What is the most important action to be taken in Rethymno"* with on choice among Radical restructuring of certain area, Better protection measures, Better financing for citizens to take action, none, other). Although the majority 50% responded better protection measures (which by the way is also very generic and doesn't indicates what type of protection measures structural or not), the 35.6% a quite high percentage declared as the best solution the radical restructuring of certain areas. Stakeholders objected this since they really don't understand what this means. Identical is the quote from one participant: *"Is it the demolishing of the city and the rebuilding of it? If this is the case then these respondents should be also asked what personal interests do they have in specific areas".* The participants implied that in many cases there are personal interests related to changes of land uses and the corresponding urban plan reformation they would wish.

Finally a significant reaction was because of the ignorance that respondents seem to have on individual activities which intervene the flood risk evolution. Stakeholders were really surprised that only the 8.5% of respondents blame attitude of the people for flooding in Rethymno. It is remarkable that most of the citizens participated in the survey tend to ignore the personal responsibility of each individual and private actions which impair the situation. Stakeholders highlighted once again the numerous private activities, mainly violations in regulations, such as the coverage of inlets of the stormwater network by many restaurant owners in the Old Town which mainly causes the inundation of streets after a heavy rainfall, the arbitrary disposal of waste in the rivers, the illegal building of basements in areas where the elevation is lower than the mean sea level, etc.

Another interesting explanation was the one related to the insurance indemnities. Most of respondents who had an insurance coverage towards floods and were affected by floods in past, declared that they received no reimbursement. A municipal representative stated that *"usually the ones who don't receive the reimbursement are the ones who shouldn't claim it as they have proceeded to structural infringements in their properties (usually on buildings)".*

Beyond the above reactions stakeholders recognised that although citizens ignore personal responsibility the authorities on the other hand have not implemented any awareness raising activities in order to mitigate individual action which impair the situation. The necessity of operational measures and awareness raising campaigns was highlighted once again. Municipality raised the issue of proper education of citizens regarding risks and factors that affect floods, structural measures already done, private violations and bad practices that should stop, and in general information actions that will support the preparedness of citizens and the city.

Furthermore authorities agreed with respondents of the survey for the need of a reliable early warning system that could support flood management and minimize losses, i.e. representatives from Port Authority suggested the placement of monitoring equipment for wave warning in port infrastructures.
In conclusion stakeholders agreed that key result from the survey and interpretation of responses is that citizens need to be informed. Specific actions need to be designed targeting to education and awareness of Rethymno residents.

ii. Rethymno LAA activities

Based on the outcomes from discussion on Risk perception survey as analysed in previous section, the participants were asked to design concrete and realistic actions targeting awareness raising in Rethymno on flood risks and preparedness of the city.
The working groups provided actually three proposals:

a. Development of a special webpage in Municipality's website which will aim :
   - to inform citizens in flood issues in Rethymno and relevant protection measures
   - to promote best practices/dos & don'ts
   - to publish authorities' plans

   The webpage will be:
   - further disseminated through local press, media, portals and the water bills that local Water Company sends to citizens
   - coordinated by Municipality's IT services with support by all other stakeholders who will provide valuable input and information

b. Voluntary Clean-up of a river stream. The activity aims to the evidential experience and education of citizens on flood issues derived by the arbitrary disposal of waste in the rivers (usually individuals' activities)
   The action will be:
   - coordinated by Municipality with the support of all other stakeholders
   - widely disseminated by local media, press and portal
   - Addressed to the majority of population including schools

c. Extensive awareness raising campaign. The third proposal was actually very general and with no specifications in timetable, institutions involved, budget or resources needed etc. It was more like a strategy plan which could include the above and other more activities.

From the above proposals the participants agreed to promote the implementation of the clean-up and the webpage development. It was a common belief that both actions could be easily implemented with current resources and would be a good start of the Rethymno LAA work.

NTUA will support the organization although most of the work needs to be done by the departments and services of local authorities. Municipality and specifically the IT and the Civil Protection departments will need to play a crucial role. Stakeholders and researchers agreed to submit an official request to the Mayor while the present individuals committed themselves to participate in the design and organization of the activities, and promote internally in their institutions. Both activities will probably start after September 2016.

The results of the 2nd Stakeholder Workshop in Rethymno (Gourgoura et al. 2016) show, that the findings of the PEARL project can directly impact local politics. In this specific case, the local stakeholders agreed on the implementation of concrete non-structural measures, which comprise e.g. the development of a special webpage (to inform citizens, distribute official planning documents and to advise them on best practice methods) and the set-up of a voluntary clean-up of the river stream.

Even though some case study context conditions will it make impossible to conduct a fully structured Learning and Action Alliance (see e.g. Deliverable 5.1 for further information), stakeholder involvement (not only with regard to LAA) makes a significant contribution to the overall success of the project.

Another example of the application of the vulnerability and risk assessment approach with community and stakeholders engagement was done in Ayutthaya. Two different approaches were followed to derive risk maps. A traditional approach that uses hazard and vulnerability assessment and a risk perception map derive by the community. As presented in detail Annex II, the two maps are different. Which is expected since they are derived from different methods. Traditional approach provides raster flood risk map with fixed the cell size of a few metres, whereas people tend to assess risk on a large scale. This raises interesting questions over the best way to communicate flood risk. An over-reliance on the results of computational models may not be the most appropriate.
Social perspective on risk assessment focuses on the root causes of flood risk related to human mental processes and the human scale. The results obtained in the case of Ayutthaya demonstrated that flood risk is inherently a social process with social roots. The differences in the derived flood risk maps demonstrate that two different approaches for flood risk assessment reveal different insights of the phenomena and as such they both should be used in the process of flood risk management and mitigation.

References

Adger, W.N. (2006): Vulnerability. In *Global Environmental Change* 16 (3), pp. 268–281. DOI: 10.1016/j.gloenvcha.2006.02.006.

Aldunce, P., Beilin, R., Howden, M., & Handmer, J. (2014). Resilience for disaster risk management in a changing climate: Practitioners' frames and practices. Global Environmental Change, 30, 1-11.

Basurto, X., Kingsley, G., McQueen, K., Smith, M., and Weible, C.M. (2010). A Systematic Approach to Institutional Analysis: Applying Crawford and Ostrom's Grammar. Polit. Res. Q. 63, 523–537.

Birkmann, J. (2011). First-and second-order adaptation to natural hazards and extreme events in the context of climate change. Natural Hazards, 58(2), 811-840.

Birkmann, J. (2013): Data, indicators and criteria for measuring vulnerability: Theoretical bases and requirements. In Birkmann, J. (Ed.): Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. 2nd ed. Tokyo, New York: United Nations University Press, pp. 80–106.

Birkmann, J.; Buckle, P.; Jaeger, J.; Pelling, M.; Setiadi, N.; Garschagen, M. et al. (2010): Extreme events and disasters: a window of opportunity for change? Analysis of organizational, institutional and political changes, formal and informal responses after mega-disasters. In Nat Hazards 55 (3), pp. 637–655. DOI: 10.1007/s11069-008-9319-2.

Birkmann, J.; Welle, T.; Krause, D.; Wolfertz, J.; Suarez, D.C.; Setiadi, N. (2011): WorldRiskIndex: Concept and results. In Bündnis Entwicklung Hilft: WorldRiskReport 2011. Berlin, pp. 13–42.

Blaj, I. (2014) Contributing to the development of methods and tools for the holistic risk assessment. Unpublished Masters thesis, TUHH Institute for River and Coastal Engineering.

Bündnis Entwicklung Hilft (2011): WorldRiskReport 2011. Alliance Development Works. Berlin.

Bündnis Entwicklung Hilft (2015): Annex to the WorldRiskIndex 2015. Indicator update for the WorldRiskIndex 2015. Alliance Development Works. Berlin.

Crawford, S.E.S., and Ostrom, E. (1995). A Grammar of Institutions. Am. Polit. Sci. Rev. 89, 582–600.

Cutter, S. L., Ash, K. D., & Emrich, C. T. (2014). The geographies of community disaster resilience. Global Environmental Change, 29, 65-77.

DKKV [German Committee for Disaster Reduction] (Ed.) (2012): Detecting disaster root causes. A Framework and an Analytic Tool for Practioners. DKKV [German Committee for Disaster Reduction]. Bonn: DKKV [German Committee for Disaster Reduction] (DKKV publication series, 48).

Depietri, Y.; Welle, T.; Renaud, F.G. (2013): Social vulnerability assessment of the Cologne urban area (Germany) to heat waves: links to ecosystem services. In International Journal of Disaster Risk Reduction 6, pp. 98–117. DOI: 10.1016/j.ijdrr.2013.10.001.

European Commission Directorate-General for Research and Innovation (2013): Annex I - "Description of Work". Version date: 2013-10-02. THEME [ENV.2013.6.4-3]. In *European Commission Directorate-General for Research and Innovation (Ed.)*: Grant Agreement Number 603663 - PEARL. Preparing for Extreme And Rare Events in coastaL regions. Collaborative Project (generic) FP7-ENV-2013-two-stage.

European Commission Directorate-General for Environment (2010): MOVE D5 Generic conceptual framework for vulnerability assessment.

Fraser, A.; Pelling, M.; Blätgen, T.; Birkmann, J. (2014) PEARL Deliverable Report 1.1. The Risk and Root Cause Analysis (RRCA) Framework.

Ghorbani, A., Bots, P., Dignum, V., and Dijkema, G. (2013). MAIA: a Framework for Developing Agent-Based Social Simulations. J. Artif. Soc. Soc. Simul. 16, 9.

Gourgoura, P., Lykou, A., Koutiva, I. (2016) PEARL 2nd Stakeholder Workshop in Rethymno (01 & 08 June 2016) Report.

Greiving, S. (2013): Multi-risk and vulnerability assessment of Europe's regions. In *Birkmann, J. (Ed.)*: Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. 2nd ed. Tokyo, New York: United Nations University Press, pp. 277–303.

IPCC [Intergovernmental Panel on Climate Change] (Ed.) (2014): Climate Change 2014: Impacts, Adaptation, and Vulnerability. Summary for Policy Makers. With assistance of Christopher Field, Vicente Barros, Katharine Mach. IPCC [Intergovernmental Panel on Climate Change].

IPCC [Intergovernmental Panel on Climate Change] (Ed.) (2012): Managing the risks of extreme events and disasters to advance climate change adaption. A special report of working groups I and II of the Intergovernmental Panel on Climate Change. [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Intergovernmental Panel on Climate Change. New York, NY, USA: Cambridge University Press (582 pp.).

IRDR [Integrated Research on Disaster Risk] (2011): Forensic Investigations of Disasters. The FORIN Project. In *IRDR FORIN Publications* 1.

ISTAT [Italian National Institute of Statistics] (2014): Descrizione dei dati geografici e delle variabili censuarie per sezione di censimento Anni 1991, 2001, 2011. Versione definitive 25/02/2016.

Macal, C.M., and North, M.J. (2010). Tutorial on agent-based modelling and simulation. J. Simul. 4, 151–162.

Mucke, P. (2014): Urbanization - trends and risk assessment. In *WorldRiskReport 2014*. Berlin, pp. 5–10.

Newell, B., Wasson, R., 2002. Social system vs solar system: why policy makers need history. In: Castelein, S., Otte, A. (Eds.), Conflict and Cooperation Related to International Water Resources: Historical Perspectives. UNESCO, Grenoble, pp. 3–17.

Norris, F.H., Stevens, S.P., Pfefferbaum, B., Wyche, K.F., Pfefferbaum, R.L., 2008. Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. Am. J. Community Psychol. 41, 127–150.

North, M.J., Collier, N.T., Ozik, J., Tatara, E.R., Macal, C.M., Bragen, M., and Sydelko, P. (2013). Complex adaptive systems modeling with Repast Simphony. Complex Adaptive Systems Modeling, 1:3. doi:10.1186/2194-3206-1-3.

O'Brien, K.; Leichenko, R.; Kelkar, U.; Venema, H.; Aandahl, G.; Tompkins, H. et al. (2004): Mapping vulnerability to multiple stressors: climate change and globalization in India. In *Global Environmental Change* 14 (4), pp. 303–313.

Parnell, S. And E. Pieterse (2015) Translational Global Praxis: Rethinking Methods and Modes of African Urban Research. *International Journal of Urban and Regional Research*, online 15 Dec 2015.

Pelling, M. (2013): Review of global risk index projects: conclusions for sub-national and local approaches. In *Birkmann, J. (Ed.)*: Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. 2nd ed. Tokyo, New York: United Nations University Press, pp. 167–196.

Sorg L. (2016) PEARL RRCA work: Completion of two case study analysis and vulnerability assessment. Genoa (Italy) and Rethymno (Greece) – analysis of household surveys. Part of Work package 1 Milestone report 5 (MS5).

Sorg, L., Birkmann, J., Medina Peña, N., Feldmeyer, D. (2017) PEARL Vulnerability Assessment approach. Concept Note

Sorg, L; Blaetgen, T; Birkmann, J; Gougoura, P; Lykou, A and Makropoulos, N. (2016) A framework for stakeholder analysis and engagement when preparing for extreme and rare events in coastal regions. PEARL Deliverable Report 5.1.

Turner, B.L; Kasperson, Roger E.; Matson, P. A.; McCarthy, J. J.; Corell, R. W.; Christensen, L. et al. (2003): A framework for vulnerability analysis in sustainability science. In Proceedings of the National Academy of Sciences 100 (14), pp. 8074–8079.

United Nations (2007): Indicators of sustainable development. Guidelines and methodologies. 3rd ed. New York: United Nations.

van Dam, K.H., Nikolic, I., and Lukszo, Z. (2013). Agent-based modelling of socio-technical systems (Dordrecht: Springer).

Vojinovic, Z., Abbott, M. B. (2012). Flood risk and social justice : from quantitative to qualitative flood risk assessment and mitigation. London: IWA Publishing.

Vojinovic, Z.; Hammond, M.; Golub, D.; Hirunsalee, S.; Weesakul, S.; Meesuk, V. et al. (2015): Holistic approach to flood risk assessment in areas with cultural heritage. A practical application in Ayutthaya, Thailand. In Nat Hazards 81 (1), pp. 589–616. DOI: 10.1007/s11069-015-2098-7.

Watkins, C., and Westphal, L.M. (2015). People Don't Talk in Institutional Statements: A Methodological Case Study of the Institutional Analysis and Development Framework. Policy Stud. J. 44, S98–S112.

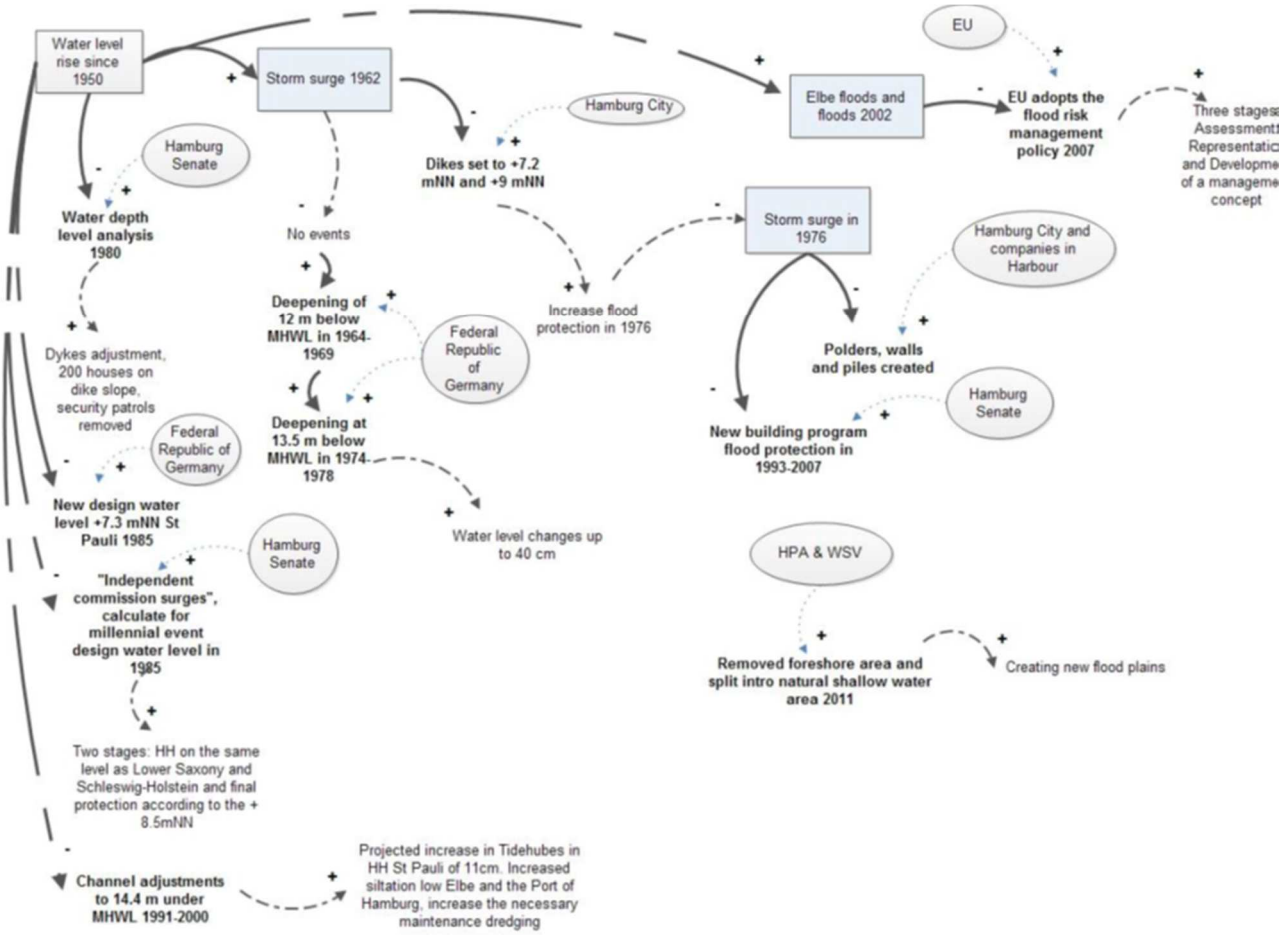
Welle, T.; Birkmann, J.; Krause, D.; Suarez, D. C.; Setiadi, N.; Wolfertz, J. (2013): The WorldRiskIndex: A concept for the assessment of risk and vulnerability at global/national scales. In *Birkmann, J. (Ed.)*: Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies. 2nd ed. Tokyo, New York: United Nations University Press, pp. 219–250.

Wilensky U. (1999). NetLogo. https://ccl.northwestern.edu/netlogo/. Centre for Connected Learning and Computer-Based Modelling, Northwestern University, Evanston, IL, USA.

Wisner, B. (2002): Who? What? Where? When? in an Emergency: Notes on Possible Indicators of Vulnerability and Resilience: By Phase of the Disaster Management Cycle and Social Actor. In Plate E.J. (Ed.): Environment and Human Security. Contributions to a workshop in Bonn. Bonn, 23-25 October. Bonn, pp. 12/7-12/14.

Annex – PEARL documents

Annex I: Causal loop map of stakeholders' role in structural flood risk management policy measures, Hamburg (Blaj, 2014)



Annex II: Vulnerability assessment and community participation in Ayutthaya (Source: UNESCO-IHE)

The city of Phra Nakhon Si Ayutthaya is located approximately 70km north of Bangkok, in the Chao Phraya River valley. The location is shown in Figure A.
Ayutthaya Island covers around 720 ha and has a population of over 40,000 people. The city is located within Phra Nakhon Si Ayutthaya district, which is in the Phra Nakhon Si Ayutthaya province. The total area of the World Heritage property is 289 ha and its boundaries are also depicted in Figure A. The Historic City of Ayutthaya was inscribed on the World Heritage List, since it bears "a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared" (UNESCO, 2013).

Figure A. Location of Ayutthaya Island.
Approximately one third of the island is protected by UNESCO as a World Heritage Site (WHS).

Ayutthaya Island has experienced two devastating flood events, in 1995 and 2011. During the 2011 flood event the entire island was inundated and the water depth at certain location exceeded two metres. Some images of the flooding are presented in Figure B. The 2011 flood event was caused by a series of consequent tropical storms in the Indian Ocean and lasted longer than one month.

Figure B. The 2011 flood event in Ayutthaya. The entire island was inundated for longer than four weeks.

Vulnerability and risk assessment

Methodologies for flood risk assessment have typically been based on the views and knowledge of experts, excluding the views of the community at large, while employing a technocratic or technocentric approach.
Vojinovic and Abbott (2012) consider stakeholder participation as a means for realising social justice in flood risk management. The purpose of stakeholder participation is to induce a change in the built and managed environment that aligns with a positive change in the social environment. The same authors state that successful stakeholder participation requires the traditional engineering way of thinking to change into one where ideas emerge from social concerns and which serve humanity.

The approach used in Ayutthaya combined both quantitative and qualitative data and methods, as represented in Figure C. Traditionally, there has been a focus on using quantitative methods alone to assess risk. The assessment of flood hazard relies on the collection of physical data such as topography and land cover, and combines these with hydrological data to produce physical models of the hazard. The four dimensions of vulnerability are assessed using quantitative data. Physical and economic vulnerability is assessed in monetary terms. A statistical analysis of social and cultural data is conducted to assess vulnerability in those two dimensions. The detail methodology and results of the vulnerability and risk assessment have been published as an open journal paper in Vojinovic et al 2016.

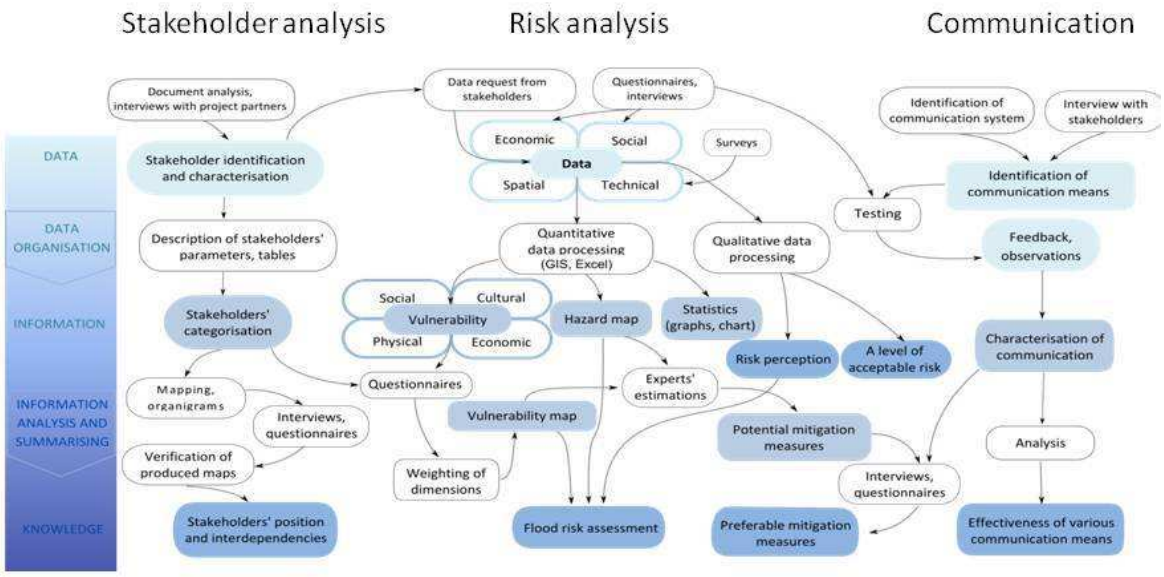


Figure C. *Connections between qualitative and quantitative approaches*

Stakeholder identification and mapping

Public involvement is critical in the flood risk assessment process and the development of a disaster risk mitigation plan. Communities living within the study area and other stakeholders know much about the flooding and the capacities required to cope with a disaster. Thus, a range of activities were organised in order to exploit local knowledge and to contribute to building capacity among stakeholders.
Stakeholders were invited to meetings and they were involved at different stages of the flood risk assessment process (e.g. data collection, evaluation of mitigation measures, vulnerability analysis, and evaluation of mitigation measures). Images of these events are shown in Figures D and E.

Figure D. Consultation meeting with stakeholders

Figure E. More than 100 participants attended the workshop with community representative.

The first step was to undertake an analysis of the relevant stakeholders and organisations in Ayutthaya. The identified stakeholders included organisations at different levels in the governmental hierarchy ranging from local government, through national government and international organisations. A socio-organigram of these organisations and their relations are shown in Figure F. This diagram presents the organisations, where they sit in the governmental hierarchy, the nature of their collaboration and communication flows, as well as their responsibilities related to flood risk management.

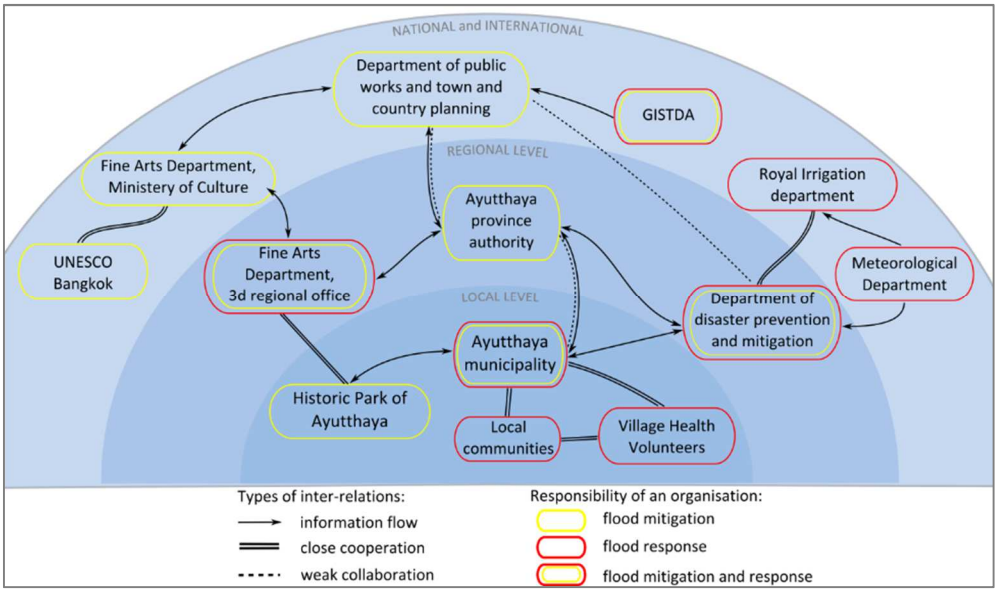


Figure F. The organi-sociogram produced for stakeholders involved in flood risk mitigation and response in Ayutthaya.

A range of relevant flood risk related information was identified during the execution of the workshops with the local community and stakeholders (e.g. flood magnitude, vulnerability level) which would aid communication in the project. Furthermore, various means and techniques could be employed for risk communication, such as maps, graphics, tables, and charts. Data to analyse the effectiveness of various means were gathered by direct observations during workshops and by questionnaires.

Perception of information from different means

Workshop activities demonstrated that local residents and stakeholders are able to share flood risk related information (e.g. flood magnitude of past events (duration, depths of flooding), vulnerable areas, and history of flood events). The preferred means of communication by residents was orally, by telling stories. Participants could easily and precisely describe flood levels during past events at different places beyond their own community with this method.

Figure G: Presentation of the model results to the stakeholders (left). Community representatives work with the satellite image at the municipality office (right).

Most of the workshop participants were literate and could read written materials or respond to questions in written form. However, it was noticed that residents had difficulty in interpreting information from maps and identifying locations. Residents preferred to receive illustrated information rather than written descriptions. For instance, they could easily understand the location when the references to local landmarks were used or photos of the places were provided. Residents talked about depths of inundation and described water levels above the ground, rather than mean sea level. Local units were used for spatial measurements instead of SI units. In contrast, local institutions and the key stakeholders preferred maps and statistical data, both as charts and graphs, as communication means.

Risk perception

A mapping exercise was conducted with a group from the community to assess the perception of risk. The facilitator of the exercise first provided an introduction to the concept of risk and then encouraged participants to share their feelings about flood risk in the area of their residence and to voice their thought process out loud. Afterwards, a group of 10-15 people worked together to create a map of the perceived risk for a given area. Participants were encouraged to express an agreed level of risk by colouring in a blank map. Three different colours were used to indicate areas of low, medium or high perceived risks, Figure H.

Figure H. The process and an output example of the group mapping exercise with community representatives**.**

The direct observations from the discussions demonstrated that from the outset participants tended to assign high level of risk for the entire island. The accompanying comments explain that: "We have an elevated road (U-Thong Road) but when a flood breaches this road, our island is turned into a basin. Inside the island, many roads are elevated to at least +.50 m, thus our small community in the low land area is like a puddle".

All the information received was converted into a GIS format and a single risk perception map was created for Ayutthaya Island, as shown in Figure I. Even though participants of each group were invited and encouraged to discuss and to colour the area of the Historic City of Ayutthaya, none of the groups did it. It was noticed, that participants were more interested in the areas of their own communities and did not show much interest in the World Heritage Site. Some participants commented that it is the responsibility of appropriate experts to judge the risk for the World Heritage Site and not local residents. Communities' representatives said that they were not aware of the vulnerability and condition, as well as the possible effects of flooding on the properties.

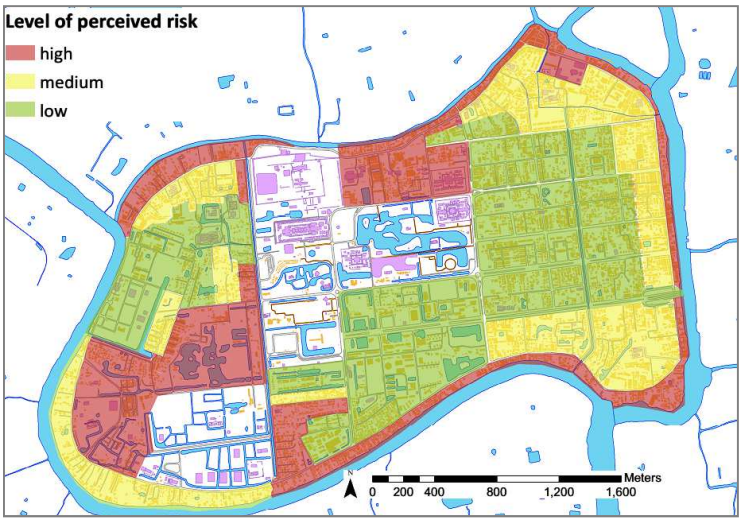


Figure I. Risk perception map based on group mapping exercises.

The risk perception map produced by the community can be contrasted with the flood risk map produced by combining the hazard assessment done with the hydrodynamic models and the data collected to assess the different components of vulnerability. The flood risk map is presented in figure J.

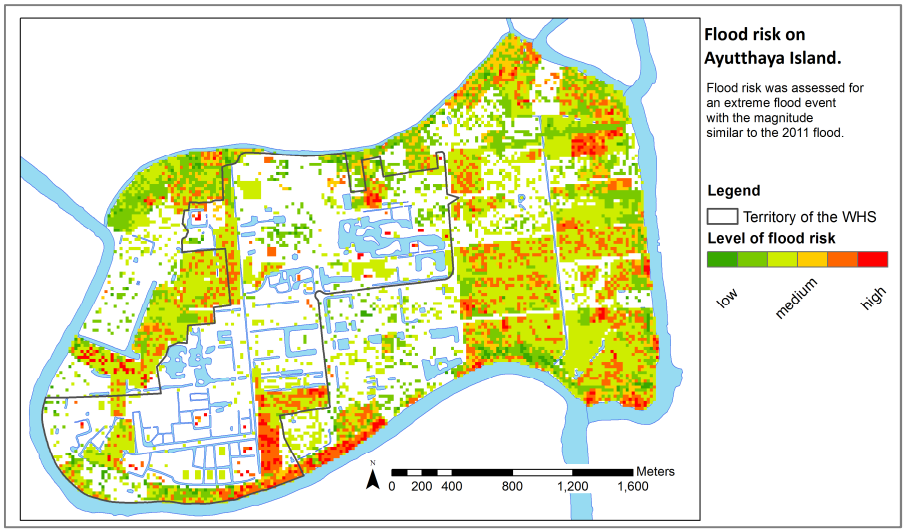


Figure J. Flood risk map of Ayutthaya Island with the current state of flood protection.

As it can be observed from figures I and J, the two maps are different. Which is expected since they are derived from different methods. However, decision makers can identify areas of the highest risk based with the traditional technical approach. The legitimacy of flood risk reduction plan and the behaviour towards risk of local residents rely heavily on the level of perceived risk.

These results suggests that there are still factors that traditional flood risk assessments leave out, and can be difficult to quantify. This arises in the case where there are disparities between the perceived risk and the calculated risk.

It is important to note that the two maps have different spatial resolutions. Traditional approach provides raster flood risk map with fixed the cell size of a few metres, whereas people tend to assess risk on a large scale. This raises interesting questions over the best way to communicate flood risk. An over-reliance on the results of computational models may not be the most appropriate.
Social perspective on risk assessment focuses on the root causes of flood risk related to human mental processes and the human scale. The results obtained in this case study demonstrated that flood risk is inherently a social process with social roots. The differences in the derived flood risk maps demonstrate that two different approaches for flood risk assessment reveal different insights of the phenomena and as such they both should be used in the process of flood risk management and mitigation.

Annex III:Description of indicators for the spatial vulnerability assessment

Susceptibility

1. DEMOGRAPHY

1.1. Vulnerable Age Groups

The first sub-indicator is determined by the percentage of population under 5 years and older than 65 years. It is assumed that these population groups are most vulnerable and need strong support in case of an emergency, because their mobility is presumed to be limited. The sub-indicator was already applied for other vulnerability analyses, for instance by Jelínek et al. (2012), and Welle et al. (2014).

1.2. Elderly living alone

Depending on the data availability, the number of elderly living alone can be assessed as a factor which highly increases susceptibility, since this section of the population needs particular support. The index can be calculated as a ratio by dividing the elderly living alone by total population.

1.3. Population density

The population density per km² is a suitable indicator for demography and therefore susceptibility of the population. The higher the population density, the more people are potentially susceptible in case the respective area is affected by a hazard. In case a hazard is affecting high populated areas, the consequences are assumed to be worse. The population density can be taken into consideration, e.g. with the unit persons per square kilometer. Though a min-max-normalization has to be conducted in order to have values ranging from 0 to 100.

1.4. Language Ability / Origin

Share of people whose main language is not the national language

The percentage of people whose main or first language is not the national language is a useful indicator for the direct interaction in case of an occurring extreme event. Cutter et al. (2014) state that this aspect is crucial when it comes to communication during disastrous events. Furthermore, the language ability has significant impact on the capacity to gather information, receive early warnings, increase preparedness, etc. In the PEARL context, barriers of language has also shown to be relevant, especially in the St. Maarten RRCA study.

Share of people who are foreigners

Depending on the availability of data, information regarding the language ability of inhabitants might not be sufficiently available. However, in the majority of cases, data on the nationality of citizens should exist. Depietri et al. (2013: 106) consider the amount of immigrants per spatial unit as a "proxy for low income and of disadvantageous condition due to difficulties in understanding warning messages". The share of foreigners is therefore influencing the susceptibility and can be used as a sub-indicator. For PEARL, this aspect of vulnerability has already been highlighted in the RRCA reports for St. Maarten and Genoa.

2. HEALTH

2.1. Number of disabled or chronically ill persons

As it applies for the number of elderly living alone, the number of disabled or chronically ill persons increases susceptibility in general. The index can be calculated as a ratio with regard of the disabled/chronically ill persons per total population.

3. POVERTY AND INCOME

3.1. Dependency ratio

The definition of the dependency ratio relates the number of children (age 0 to 14 years) and older people (older than 65 years) to the share of population who is at working-age (15 to 64 years). The numerator indicates persons, defined by age, who need economical support. The dependency ratio is a widely accepted indicator in literature to measure susceptibility and can be calculated as follows:

$$Dependency\ Ratio = 100 \times \frac{pop\ (0-14)+pop(65+)}{pop(15-64)} \qquad \text{(F.2)}$$

A high dependency ratio indicates that the working population group faces a major challenge to support the economically non-active population (United Nations 2007). This in turn means that the population is more susceptible. If an economically active person faces negative consequences due to an extreme event, it also indirectly influences the dependent population group (see Schneiderbauer 2007 in Bündnis Entwicklung Hilft 2015).

3.2. Share of population living under national poverty line

According to the indicators for sustainable development elaborated by the United Nations (2007), the proportion of population living below the national poverty line is a suitable indicator to assess poverty alleviation and a measure of living standards. The respective poverty line is defined by the national government. The indicator has to be a ratio, either the data is already published in percentages, or the number of people living under the poverty line has to be divided by the number of total population.

3.3. Unemployment rate

It is anticipated that unemployed persons are more susceptible to sustain damage or harm while facing extreme events.

4. HOUSING AND NEIGHBORHOOD CONDITION

Housing and neighbourhood conditions are crucial for the assessment of susceptibility. In the following two possibilities for sub-indicator calculation will be presented.

4.1. Building conditions

Due to different building conditions, the respective buildings are more or less resilient. Vojinovic et al. (2015) distinguish the built environment into three vulnerability classes (low/ medium / high). It might also be possible to classify the buildings depending on their construction period or building material.

4.2. Type of building

As it applies for building condition, the assessment of the type of buildings in different categories with regard to their resilience is also possible. Here, the evaluation of different usage is thinkable, for example by a categorization of low/medium/high into different building categories (residential buildings / institutional / critical infrastructure). Another consideration is to rank the different categories regarding their importance by stakeholder involvement or questionnaire survey.

Coping capacity

5. GOVERNMENT AND AUTHORITIES

The assessment of indicators relating to citizens confidence in government and actions of authorities is highly valuable for the assessment of coping capacities.

5.1. Crime rates per X population

If available, data concerning crime rates can be incorporated as an indicator for government and authorities.

5.2. Turnout at local election (in %)

The turnout at local election can be used as an index for general trust in and support of local authorities.

6. SOCIAL NETWORK

6.1. Household size, average number of members

Regarding the assessment of coping capacities a possible approach is the incorporation of household sizes. Welle et al. (2014) argue that the greater the number of household members, the more elderly, children or disabled persons can be assisted. Therefore the household size can be an indicator for social network and safety grid.

7. ECONOMIC COVERAGE

7.1. Household income

For the social vulnerability analysis, the household income can be used as an indicator for the evaluation of financial resources in order to cope with a hazardous event. For example, the household income can be taken into consideration with regard to the average income (ratio) or by defining classes and assigning values (ranging from 0 to 100), due to expert knowledge.

7.2. Insurance (life insurances excluded)

The status of insurance coverage per spatial unit can be can be used as an indicator for disaster risk transfer mechanism and preparedness level. Moreover, it allows to draw conclusions on the capacity for economic recovery and material coverage.

8. MEDICAL SERVICE

It might be challenging to assess the supply with medical service on the requested scale, still possible indicators will be mentioned in the following.

8.1. Number of physicians / hospital beds

The number of physicians and/or hospital beds can be assessed per inhabitant and then normalized on a scale between 0 and 100. Both, the number of physicians, as well as the number of hospital beds can serve as an indicator for the capacity of the health care system, which is crucial for coping capacity in the aftermath of a disaster (Bündnis Entwicklung Hilft 2015).

8.2. Access to medical service

If there is no data available for the number of hospital beds or practicing physicians, it is also possible to develop an indicator on the basis of accessibility to medical service, i.e. by determining the mean distance to the next hospital.

8.3. Vaccination coverage

In some cases the vaccination coverage for specific diseases (e.g. DTPa-IPV+Hib) might be available. The share of vaccinated persons allows a general statement on coping capacities.

9. IMMEDIATE ACTION

9.1. Immediate Action: Multi-storey buildings

The inclusion of the number of storeys in a building is based on the assumption that if there is more than one level, the inhabitants are able to reside in upper parts of the building. In case of flooding, this action increases their safety, lowers harming impacts and the exposed persons furthermore have the possibility to store their belongings safely from the hazard. The assessment of buildings with more than one level therefore provides information on the capacity for immediate action.

10. INFORMATION

The access to information and the use of specific information channels is crucial when it comes to the assessment of coping capacities. This key message was also emphasized by the findings of the household survey conducted in PEARL. It is important to mention that the here proposed indicators can only be seen as suggestions. Whilst "smart phone user per X habitants" might be a suitable indicator in one case study, the use of radio programs might be the most important medium in other cases (for example in St. Maarten). The indicators have to be chosen based on these individual preconditions.

10.1. Access to early warning and evacuation information

A possible sub-indicator for coping capacity is the level of information regarding early warning and evacuation routes. The procedure on how to take this aspect into consideration, needs to be discussed with regard to the respective case study location. It would be conceivable to assess this factor by household survey, if a sufficiently large sample size can be ensured. On the other hand, the sub-indicator could also be estimated based on stakeholder involvement and the presence or absence of particular spatial plans addressing these issues. Another possibility to include aspects of knowledge on previous events and related learning outcomes, might be the display of information on how long people generally have lived in the respective case study area.

10.2. Internet access per X habitants

As the internet is an information distribution system widely used by the population, the level of access to information can be assessed by evaluating the availability of access to the internet. Internet users are defined as "those who use the Internet from any location" (United Nations 2007: 80). If a person uses the internet on a regular basis, it is assumed that the person will also use it for information purposes (e.g. forecasting, education, early warnings, evacuation, etc.).

10.3. Smartphone user per X habitants

The smartphone as a communication tool has gained growing importance. There are already several mobile applications available regarding disaster management or forecasting. For PEARL, there is also application software: the Water Detective App. Smartphone applications are gaining significance, not only for early warning, but also for the direct disaster response.

11. AWARENESS / PREPAREDNESS

Factors which increase the preparedness of the population and contribute to the development of a risk awareness can be integrated into the calculation of the coping sub-index.
In this specific case the Awareness/ Preparedness sub-index can include aspects of flood risk knowledge and the perception of preparedness, which were derived from the household survey (see case study example for more information).

Adaptive capacity

Adaptation includes societal changes and adjustment processes in general. Therefore, adaptive capacities include a long-term and future-oriented view of vulnerability.

12. EDUCATION AND RESEARCH

12.1. Proportion of people holding higher qualification / education level

The assessment of education level serves as an indicator for adaptive capacity. It is assumed that people with higher education will be better positioned regarding future disastrous events. The proportion of people holding higher qualification or education level, can be evaluated by age groups. Following the United Nation´s approach for indicator development (United Nations 2007), we propose to calculate the indicator as the share of population at working age (25-64 years) which has completed not less than upper secondary education.

12.2. NEETs

As a general indicator for adaptation, the assessment of the proportion of young adolescents who are not in employment or training gives an insight on upcoming challenges. OECD (2016) define the indicator as "the share of young people who are not in employment, education or training (NEET), as a percentage of the total number of young people in the corresponding age group, by gender". According to OECD (2016) young adolescents can be defined as 15 to 24 year olds.

12.3. Literacy rate

Although the share of illiterates within Europe and within the different city districts and polygons will be presumably low, it can be still taken into consideration for the index calculation. Here we recommend to calculate the adult literacy rate, which is defined as the share of persons from the age of 15 who can understand, read and write a short, simple statement on their everyday lives (ADB 2004:19 in Bündnis Entwicklung Hilft 2015).

13. GENDER EQUITY

Gender equity is an important aspect for future development and adaptation processes.

13.1. Gender parity in education (primary, secondary and tertiary education)

As a measure of gender equity the gender parity in education will be taken into account if data on the respective level is available. Education is a valued component of adaptation and female participation can be seen as a contribution to gender equity. The values of the ratio of female to male can range from 0 to 1 in advantage of men, 1 for equality and larger than 1 in advantage of women. Nevertheless, a high value of the ratio does not necessarily mean a high access of females to education, it could in turn mean that the participation of male is rather low (Bündnis Entwicklung Hilft 2015).

13.2. Gender parity in annual gross pay (female – male)

If data is available on the requested scale, the gender parity in annual gross pay can be taken into account for the calculation of adaptive capacity. On European level, this indicator is presumably more meaningful than the gender parity in education.

14. ENVIRONMENTAL STATUS / ECOSYSTEM PROTECTION

The adaptive capacity index includes aspects that describe long-term transformation of societies and soci-ecological systems with regard to future events and climate change. The aim of the Environmental Status/Ecosystem Protection index is to shift away from usual short-term view, therefore, it can be useful to include environment-related aspects.

14.1. Air quality data

Air quality data, for example on basis of NOx allows a quantification of the environmental status of a spatial unit. The data can be classified into groups based on statutory limit values (good / medium / bad).

14.2. Green infrastructure

It is suggested to take the availability of green spaces, or in particular the percentage of people who have access to open space into account for the assessment of ecosystem protection and environmental status. The indicator “Green Infrastructure” represents possible adjustments or capabilities to face the challenges of climate change.

15. INVESTMENTS

15.1. Life expectancy

General statements about living conditions and health can be deduced by the life expectancy. The *WorldRiskIndex* uses this indicator on country level, but still it can be useful to identify spatial units where the life expectancies differ significantly. The life expectancy has to be displayed as a ratio – for example with regard to the average life expectancy in the spatial polygon.

15.2. Flood protection measures

The implementation of structural and non-structural flood protection measures can also be integrated into the adaptation indicator. For this purpose, it might be useful to conduct stakeholder interviews in order to obtain necessary information. If partners want to use this sub-indicator, they have to develop an approach on how to implement this information into an indicator. Possible approaches are the definition of categories (e.g. good / medium / bad), the development of a scale ranging from 0-100 % with regard to implementation of necessary measures, or normalized annual expenditures per spatial entity.

15.3. Risk awareness

As it applies for flood protection measures, an indicator concerning the risk awareness of exposed societies for the future could be developed. This index might include the quantification of activities, meetings, information campaigns, etc. which increase the risk awareness of the population. In the Genoa case study case, the risk awareness indicator includes the result of the household survey concerning the enhancement of early warning and behaviour of citizens.

Annex IV: Vulnerability Map Genoa