ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map

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SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE AND ECOSYSTEMS
ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map (Del. 3.1.1)

Aims
The aim of the report was to integrate the results, observations and solutions of various research activities in the project to the “ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map”.

Overview
The report describes the “ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map”. The methodology was developed through a continuous discussion between natural hazard experts and land use and management planners in order to overcome gaps and limits of the multi-hazard/risk theoretical approach (developed in Del 3.1) with the practical solution designed in Del 5.1 and 5.2. The paper takes into account the problems and the critical points of the ARMONIA methodology suggested in Del. 3.1 as well as how the ARMONIA partners and supporting group have developed a coherent, feasible and exhaustive approach in developing exposure, vulnerability and multi-risk analysis become the framework of the final Decision Support System structure.

Main output
A multi-hazard, multi-risk approach needs to consider cumulative consequences of different hazards affecting the same exposed element (e.g. landslides can be triggered by floods). Therefore the ARMONIA approach to multi-risk mapping should be guided by the following methodology:

1. Individual hazards should be defined for ARMONIA main spatial scales (strategic regional, local general and local site);
2. Vulnerability functions should be defined for any individual category of hazard, having as input the hazard intensity, hazard magnitude, hazard category and as output an average expected damage;
3. Fragility curves should be defined, when possible, for any individual category of hazard, obtaining the probability of damage (e.g. for seismic hazard the % of cracks in walls, the % of unsafe buildings, the % of collapsed buildings) for a given categories of exposed elements defined by spatial planners;
4. Risk should be assessed for any individual category of hazard;
5. Different individual values of likely damage (risk), should be summarized in terms of fragility curves (probabilities of different damages for the same stock), for the same return periods (e.g. 1:10 or 1:100).

Some specific aspects have been highlighted in the multi-risk procedure:
- Vulnerability analysis and the construction of vulnerability curves,
Risk maps.

Finally, the ARMONIA approach should then follow this line of reasoning according to the following:

1. The regional strategic domain will be enhanced through the development of matrices having in the horizontal axis the potential land use of the territory (Corine land cover, modified) and in vertical axis the degree of hazard, for any typology of events. In such a way it will be possible to manage and to plan the land use for a European standard data base of exposed elements (Corine land cover), providing rules that are depending from the typology of hazards and related severity;

2. The local level will follow a more standard procedure at the state of art of scientific knowledge. In particular the sustainable mitigation of natural hazard in land use planning and management will be conducted through the three classical steps: hazard identification, vulnerability assessment, and risk analysis.

**Recommendations and conclusions**

After many discussions between natural hazard experts and planners it has been decided that the best way to harmonise the risk procedures is to focus the attention on the harmonisation of effects. This is in terms of expected damage, from the analysis of potential impacts coming from various natural events affecting the same element at risk (e.g. buildings, population, infrastructure).

The most significant innovation and key issue of ARMONIA theoretical and methodological approach is the profound integration of planners, with distinct orientations and backgrounds, and natural hazard specialists that generally produce a single hazard-oriented scenarios, that has produced a practical, but not simplistic tool capable to help and support decision-makers, at various levels, to recognize the nature and severity of natural events that may occur in a specific area, define the impacts of natural events in terms of exposed elements and vulnerability and provide answers to understand the feasibility of present land-use and future planning decisions with geological and geophysical dynamics acting in that area.

The proposition of a Decision Support System design has been a coherent and feasible way to produce practical tools for developing a harmonised procedure of multi-risk assessment, at regional and local scales, considering all the key parameters (hazard, exposure, vulnerability and risk). With respect to the state of the art of the research, this procedure provides an improvement through the development of vulnerability matrices, at regional and local scales, considering the parametric intensity of natural events, potential exposed elements and a vulnerability analysis extended to coping capacity and considering different temporal scenarios considering also Climate Change potential effects at different temporal scales.

The main gap of the procedure remains the lack of fragility curves derived by intensity/severity vs. typology of exposed element. This topic can be considered as the most significant for future developments of multiple risk analysis, especially at local scale.

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**ARMONIA - Applied multi Risk Mapping of Natural Hazards for Impact Assessment**
WP3: Methodology for a harmonised integrated map and development of a guideline for an EU directive on harmonisation of multi-hazard risk mapping

Del. 3.1.1

ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map

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Deliverable 3.1.1 integrates the results, observations and solutions of Deliverables 3.1, 5.1 and 5.2 to the “ARMONIA methodology for multi-risk assessment and the harmonisation of different natural risk map”. The methodology was developed through a continuous discussion between natural hazard experts and land use and management planners in order to overcome gaps and limits of the multi-hazard/risk theoretical approach (developed in Del 3.1) with the practical solution designed in Del 5.1 and 5.2. The paper takes into account the problems and the critical points of the ARMONIA methodology suggested in Del. 3.1 as well as how the ARMONIA partners and supporting group have developed a coherent, feasible and exhaustive approach in developing exposure, vulnerability and multi-risk analysis become the framework of the final DSS structure.

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1 ARMONIA: the road to harmonisation

Del. 3.1 (Report on new methodology for multi-risk assessment and the harmonisation of different natural risk maps) focused on the definition of an integrated methodology applied to multi-hazard/risk analysis, starting from the main outcomes of WP2.

WP2 produced a scenario on individual risk assessment (Del. 2.1: Report on current availability and methodology for natural risk map production) where adopted approaches and tools of analysis and representation of risk display an advanced and quite satisfactory level on hazard analysis. On the contrary, exposure and vulnerability analysis, except for seismic risk assessment, are generally poorly developed, simplified or totally disregarded.

The main gap encountered during the development of a harmonised procedure on multi-hazard/risk assessment in Del. 3.1 was the missing involvement of spatial planners proposed in the original work plan. Therefore an integration of expertise between natural hazards experts and spatial planners for some fundamental steps of the methodological path became necessary. The analysis of exposed elements and vulnerability assessment in a quantitative, coherent or exhaustive manner was therefore envisaged as the main issues to be further and jointly implemented in the current Deliverable.

The importance of vulnerability, generally poorly developed or even disregarded in many of methodological approaches and practical applications analysed in European and other international projects, has convinced all ARMONIA partners to develop together the final part of the methodology. In such a way, starting from a common theoretical background developed in Del. 3.1, 3.2, 5.1 and 5.2 activities have been progressively and iteratively updated and revised through discussions, meetings and common works among WP3 coordinators and spatial planners.

Hence, at this stage of the research activities, it can be stated that the main result of ARMONIA will be a coherent and feasible way to produce practical tools (DSS) for developing a harmonised procedure of multi-risk assessment, at regional and local scales, considering all the key parameters (hazard, exposure, vulnerability and risk). With respect to the state of the art of the research, this procedure provides an improvement through the development of vulnerability matrices at regional and local scales, considering the parametric intensity of natural events, potential exposed elements and a vulnerability analysis extended to coping capacity and considering different temporal scenarios in the light of Climate Change.

The main gap of the procedure is the lack of fragility curves derived by intensity/severity vs. typology of exposed element. The development of such a functional links is beyond of the project purpose as this topic has been poorly developed in research or, where implemented, such as in seismic analysis, results cannot be generally adopted. This topic, at last, can be considered as highly significant for future developments of multiple risk analysis, especially at local scale.

To summarise: the most important innovation of ARMONIA is the profound integration of planners, with distinct orientation and background, and
natural hazard specialists that generally produce single hazard-oriented scenarios, that has produced a practical, but not simplistic tool capable to help and support decision-makers at various levels to recognize the nature and severity of natural events that may occur in a specific area, define the impacts of natural events in terms of exposed elements and vulnerability and provide answers to understand the feasibility of present land-use and future planning decisions with geological and geophysical dynamics acting in that area.

2 Multi-risk analysis and mapping: ARMONIA methodology

The analysis of individual natural events, in terms of hazard, vulnerability and risk mapping (WP2) and the possibility, from a theoretical point of view, on how to integrate and incorporate various hazards and risks in the production of a single multi hazard/risk map (WP3) have convinced ARMONIA researchers about the necessity to implement a rigorous, coherent but practicable approach. In fact, the main scope of the project is to produce a methodology that capably combines multiple risks on a meaningful basis, taking into account all the basic and indispensable parameters of risk analysis, such as hazard (where, when and how intense/severe a natural event can be), exposure (typologies of elements at risk located in a hazardous area), vulnerability (degree of potential damage expected by each relevant element at risk vs. natural event occurrence), risk (degree of total damage due to the occurrence of one or more different natural events in a given area).

Del. 3.1 (Report on new methodology for multi-risk assessment and the harmonisation of different natural risk maps) has discussed that multi-hazard (and multi-risk) cannot be the simple combination (e.g. by superimposition of individual hazard maps and summation of hazard degrees) of hazard categories together by assuming equivalence between a ‘high’ flood hazard and a ‘high’ earthquake hazard. This kind of approach, some time found in the state of the art, especially in practical applications, has not been recommended for the forthcoming activities of the project (WP5 and WP6). A feasible approach way may be combining different risk estimates but only if a common and meaningful risk metric which works between and across multiple forms of risk can be identified. There are also questions about whether both hazard and risk maps are needed for land use planning activities, as discussed at some length in Del. 1.3 (Report on the definition of possible common procedures and methodologies of spatial planning for natural hazards , to inform the development of a new spatial planning standard for the EU) and Del 3.1.

The best way to solve the problem has been envisaged in vulnerability analysis as key element that links together the natural event, in terms of type and ‘dimension’, with the exposed elements, both structural and non structural.

Recent perspectives on risk and hazard management have emphasised the need to take into consideration distinct forms of vulnerability. Del. 5.1 (Harmonised hazard, vulnerability and risk assessment methods informing mitigation strategies addressing land-use planning and management) identified a wide range of potentially exposed elements and vulnerabilities
and proposed ways in which some of these may be represented through indices constructed from census and other spatial data in area, line and point form.

Therefore the main effort to be addressed during the joint work (research for Deliverables 3.1, 5.1 and 5.2) between natural hazards specialists and spatial planners is how should the DSS make use of these and whether is it possible to utilise one set of vulnerability indicators that can be applied across all analysed forms of hazards addressed within the ARMONIA project.

Closely connected with the way to produce integrated risk maps is the methodology to be used to produce risk maps and risk indicators for particular areas of land. As reviewed in Del 3.1 there are both qualitative and quantitative approaches that can be used. Whilst quantitative measures (such as the calculation of annualised economic damage) may be attractive and could theoretically be used to produce aggregated risk indicators (combining the risks from different forms of hazard together) they are more developed for some forms of risk than others. This is an important limitation given that we are seeking an approach which can be used in common across five different forms of hazard. Qualitative approaches are more useable across the hazards but are not readily integrated together.

**2.1 Theoretical approach of multi-risk analysis and mapping**

As previously mentioned, ARMONIA achieved one important result: the clear definition of the possibility of mapping multi-hazard/risk scenarios, considering the cumulative consequences (i.e. economic, victims) of different natural events affecting the same exposed element. Theoretically, a rigorous multi-risk mapping procedure is based on the following steps:

**Step 1:** identification of individual hazards for ARMONIA main spatial scales (strategic regional, local general, local site);

**Step 2:** assessment of vulnerability functions for any individual category of natural event, having as input the event location, intensity or severity parameters hazard category and as output an average expected damage;

**Step 3:** assessment of fragility curves, when possible, for any individual category of hazard, obtaining the probability of damage (e.g. for seismic hazard the % of cracks in walls, the % of not statically safe buildings, the % of collapsing buildings) for a given categories of exposed elements defined by spatial planners;

**Step 4:** analysis of risk for any individual category of hazard;

**Step 5:** harmonisation of different individual values of damage (risk), likely in terms of fragility curves (probability of different damages for the same exposed element), for the same return period.

Finally, for the realisation of multi-risk maps, it becomes essential to construct vulnerability curves having as input (x-axis) the individual hazard (e.g. intensity, magnitude, category) and as output (y-axis) the average loss, possibly defined as probability of occurrence (fragility curve). In fact, vulnerability can be expressed as the degree of loss to a given element at risk, or a set of such elements (i.e. a system), resulting from the occurrence of a natural or technological phenomenon of a given size. The
induced aggression (e.g. caused by an earthquake, pollution, explosion, landslide) should be expressed in terms of a number of accessible and pertinent parameters when used for vulnerability analysis. The choice of the most appropriate techniques to be used depends on the size of the project area, the resources available and the data already collected. The reduction of vulnerability may be studied in the general framework of a disaster resilience assessment process. Vulnerability as well as resilience can be conceptualized along the four interrelated dimensions:

- Physical (e.g. destruction of a historical hotel)
- Human, social and functional (e.g. life loss, employment, lodging)
- Economical (e.g. reconstruction cost)
- Identity-related issues (e.g. impact on the image of the town, tourism).

In practical terms, the main expected result is the construction of vulnerability functions, possibly related with fragility functions, having a different x-axis for any natural event typology and a common y-axis. Therefore, it would be possible to define all the risk with the same factor.

Following discussions among ARMONIA partners at the Barcelona meeting and suggestion come from EC scientific advisors, a multi-risk approach should be based on the production of single and rigorous hazard maps. These maps have the main scope to depict all considered risks to orient the spatial planning process and should contain the following information in hazard analysis:

- site or area of occurrence and potential development of natural events;
- intensity/severity/magnitude of the potentially disastrous event through parametric scales;
- return time of event, possibly related to potential triggering factors;
- hazard analysis should take into account minor, but more frequent events, as well as major expected events characterised by highest intensity/lowest frequency since the latter are the most potentially disastrous.

The structure of data, that can be expressed as qualitative (regional approach) or quantitative way (local approach), should be clearly formalised and organised, standardised, generally accepted and updatable. According to the use of maps, the methodology will offer the production of various types of maps (probabilistic, deterministic and scenarios) and will leave it upon the decision-makers to decide which maps they need. A simplified procedure was also discussed for a regional approach, with the use a “low, medium, high” scheme for WP5. The legend of this multi-layered hazard map will be possibly qualitative (e.g. low, medium, high hazard). It has to be noted that such maps simply provide a general overview of problems and should not be used for relevant spatial planning purposes. Therefore, a common guideline and structure will be derived from the various contributions that may be considered as a starting point for the forthcoming work and activities, addressed to the suggestion and application of a methodology for integrated risk analysis and development of a guideline for EU directive on harmonisation of multiple risks mapping. The proposed
methodological approach and potential applications have to take into account exposure and vulnerability factors, as fundamental in risk analysis. These are often under-evaluated or neglected in most current scientific and practical applications. The measure of risk that can be the expected as loss or level of damage can be represented in qualitative or quantitative ways, depending on the spatial scales, such as:

- costs to be spent for reconstruction;
- damage index;
- mixed quantitative/qualitative description of the expected damage, calculated by means of probabilistic risk assessment and/or scenario approaches according to spatial planning decisions and requirements.

Vulnerability and risk should be evaluated possibly in a deterministic/parametric manner or qualitatively in case of systemic and organisational vulnerability. In any case, mapping exposure and vulnerability can be considered as the minimum standard since complex or complete models of vulnerability are actually inapplicable. Exposure and vulnerability levels have to be referred to each typology of hazard in relation with potential intensity of events, especially at local scale. After discussion with spatial planners, an important matter seems to be a differentiation between inhabited/developed areas and not inhabited/developed sectors of the territory in terms of hazard/risk analysis.

A possible guideline could be:

- Not developed areas: potential development should take into consideration the actual hazard conditions by implementing a cost/benefit analysis capable to suggest the feasibility of planned projects according to the expected hazard and possible mitigation strategies to implement for reducing hazard and/or risk levels (land use planning);
- Urbanised areas: the possible strategy to follow is mainly aiming at mitigating exposure and/or vulnerability levels through a cost/benefit analysis and investing in structural and non structural preventive measures (land use management).

In addition, the methodology developed in WP3, will be updated by adding the step of the production of a multi-layered hazard map (not aggregated hazards) by the overlapping of the single hazards maps, using a GIS environment. This kind of map will help spatial planners to detect areas where no hazard will likely occur as well as areas where two or more types of natural events may occur.

Future activities in WP3 and WP6 should be concentrated towards developing and implementing a practical approach aiming at producing prescriptions and guidelines for the correct land use planning and management.

At the local scale, the development of functions of potential damage/loss by comparing intensity or magnitude or severity of different types of hazard with potential damage of distinct types of element at risk indicators might be produced. Analysis of vulnerability of various elements at risk will be indispensable for addressing the type of decision-making which might be involved for spatial planners for both scales regional and local.
At the regional scale the use of vulnerability and exposure may overcome to the uncertainties of risk analysis, whereas, at local scale, risk mitigation will be a very important issue.

According to availability, format and typology of data, to be analysed during WP6, in addition to such information, a social vulnerability index comprising a number of social/demographic measures could be mapped (using census and socio-spatial data) in order to be used along with hazard and risk maps. Such an index would help convey the vulnerability of people to suffering from any sort of hazard event – for example, higher underlying poverty would indicate an increased vulnerability to harm.

According to the state of the art it was defined that the sustainable mitigation of natural hazard for land use planning and managements requires several tools that are case by case dependent on hazard, vulnerability, risk and an integrated risk analysis. Also, following the performed investigation and the state of art it was defined that harmonization of natural hazard processes for land use planning and management can be developed in the following way:

1. synthetic indicator of heuristic degree of multiple hazards affecting a given territory (e.g. high, medium, low) or integer number of affecting natural hazards or simplified multiple layers (hazards) summary map;
2. an integrated indicator of damage/losses, summing up, for a given time period (or heuristically), multiple risks, individually evaluated;
3. a holistic approach of managing different hazards (e.g. to investigate contemporary all the hazards affecting a given territory);
4. domino effects\(^1\) (e.g. landslide induced by earthquake).

\(^1\) As regarding the domino effect or cascading failure, this can be defined as a failure in a system of interconnected parts, where the service provided depends on the operation of a preceding part, and the failure of a preceding part can trigger the failure of successive parts. Redundant parts can lessen the impact of, but not prevent, a failure. Monitoring the operation of a system, in real-time, and judicious disconnection of parts can stop a cascade. Applied to natural hazards this definition means that there is a high probability that occurrence of certain natural hazard is likely to trigger secondary hazards. In other words, primary and secondary hazards tend to couple whereas the chain might be longer than just two events – e.g. an earthquake will cause a landslide that will dam the river valley and consequent failure of the dam creates a flash flood, etc.

There are basically two ways of how to assess the coupled hazards (domino effects). We can investigate the individual possible chains of hazardous events – one event triggering another - and try to assess probability values in order to transfer these phenomena into risk maps. This attitude seems to be extremely demanding for the input data about investigated areas and sometimes the complexity of the hazard chains can be overwhelming. Though we might obtain risk related to a particular series of events, which might be helpful in designing specific mitigation strategies. The other way is to assess the risk for coincidences of different hazards, even without supposing any direct linkage among them. This method seems to be more robust and less demanding for input data and their accurateness. Risk factors assessed by this method would simply consist of individual risk maps “overlay”. Such a rough outcome could still provide a relevant basic risk levels over the investigated area; possible local specifics could be added place-to-place.

The investigation of such effects is complicated and merit an individual project (in literature related to mitigation of natural hazards terms “domino effect” or “cascading failure” are frequent, though usually without proper definition and without any deeper explanation. Sometimes the effect is referred to as “multi-hazard”, the thesaurus is not common).
Nevertheless it was also recognised that land use planning and management do not necessarily need a harmonisation of data in a unique indicator. The ideal approach should require a GIS-based process (multi-layer), supported by the investigation of all hazards affecting a given territory, and, for some specific purposes, requiring a synthetic indicator(s).

The ARMONIA approach should then follow this line of reasoning according to the following:

1. The regional strategic domain will be enhanced through the development of matrices (see Table 18 of Del 3.1\(^2\)) having in the horizontal axis the potential land use of the territory (Corine land cover, modified) and in vertical axis the degree of hazard, for any typology of events. In such a way it will be possible to manage and to plan the land use for a European standard data base of exposed elements (Corine land cover), providing rules that are depending from the typology of hazards and related severity. The set of rules will be provided in WP5.

2. The local level will follow a more standard procedure, at the state of art of scientific knowledge. In particular the sustainable mitigation of natural hazard in land use planning and management will be conducted through the three classical steps: hazard identification (WP3), vulnerability assessment (WP5), risk analysis (WP3 and WP5). Hazard assessment has clearly been identified in Table 17 of Del 3.1. Vulnerability (fragility) is an intrinsic character of the exposed elements and will be assessed for homogeneous elements, similar to those of Corine land cover (with integration), but based on a cadastre spatial resolution. Local detailed level can also be spatially related to individual exposed elements (e.g. rural areas, cultural heritage, private houses), similar to those exposed categories identified at local general level. On the basis of the hazard identification expected losses will be analysed for the different vulnerability categories of exposed elements. A set of land use planning and management rules will be provided, starting from an harmonic view and analysis (GIS based approach) of different hazards affecting a given territory. The rules and regulations and codes will define the sustainable mitigation of natural hazards in land use planning and management. In fact, these rules have to be aimed at the mitigation of hazards and the reduction of the vulnerability, to enhance sustainability reducing risk in a given exposed element, considering its actual or potential land use. The indicator for hazard, vulnerability, risk and/or aggregated risk will depend upon the exposed element under investigation.

### 2.2 Integration of ARMONIA methodological approach with land use planning and management purposes

The theoretical approach for multi-risk analysis and mapping exposed in Del. 3.1, has been further on developed and implemented in WP5 by spatial planners (Del 5.1), by integrating the general framework of the

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methodology with important aspects related with vulnerability analysis in
order to design a DSS addressed to analyse multiple risk analysis, at local
and regional scales, that, starting from the theoretical approach, integrates
and adapts the ARMONIA method with typology, format and availability of
data, actual potentiality of exposure and vulnerability analysis, as well as
practical support of the DSS to planners scopes and expectations.

Therefore, the DSS main objectives are:

- To provide a basis for planning in an area prone to multiple risks
  related to natural hazards;
- To include assessments of exposure and vulnerability;
- To support planners understand the implications of uncertainties and
  probabilities in decision concerning land uses and location of
  strategic facilities.

The methodological framework of DSS is based on analysis of types of
preventative measures, structural and non-structural, that can be taken in
land use planning and management to reduce/mitigate the hazard, the
physical and systemic vulnerabilities and the risk resulting from the
combination of hazard and vulnerability (see Table 1 of Del 5.13). The risk
can be expressed with a synthetic measure, as expected damage, e.g. by
means of monetary terms or indexes. Regardless, it is intended to offer a
wide manner to express the degree of risk to which a certain area is subject
by also by considering, for instance, the social and physical relevant aspects
acting on the various and distinct components of the total risk (hazard,
exposure, vulnerability).

Another important aspect is related to scale and time factors. The concept
of scale incorporates at least three different aspects: (a) geometrical
interpretation of an area; (b) multi-scalar evaluation; and (c) administrative
levels.

In ARMONIA we conclude two distinct scales appear to be most relevant
(see WP1):
- local scale (municipalities);
- regional scale4.

Any risk approach has to consider that the scale of analysis has a direct
influence and implication on hazard types and mapping, data format, and
significance with respect to mitigation measures.

The structure of the DSS (see Fig. 1) is the result of many discussions,
mediations, integrations and revisions among ARMONIA partners. Despite
the continuous changes of the structure and adaptations, the final outcome
can be considered as a coherent methodological and structural path for
multi-risk analysis, rigorous with respect to all potential geological and
geophysical dynamics and well oriented to spatial and land use planning

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3 See ARMONIA Del. 5.1, 2006: Harmonised hazard, vulnerability and risk assessment
methods informing mitigation strategies addressing land-use planning and management, final
version 31.09.2006, page 15

harmonization of different natural risk maps, final version April 2005
purposes.
The conceived DSS structure is flexible for applications at local and regional scales and addressed to multi-scale plans that define land use and location of strategic facilities and infrastructures. The starting point (first line of the flow-chart) is a ‘land use’ type that represents exposed elements (from individual to general categories). The ‘land use’ is divided into two distinct definitions, that recognize two different approaches and paths along the DSS framework: urban and rural/natural areas. This distinction derives from different jurisdictional status as well as from the fact that the type of parameters to be considered for exposure and vulnerability analysis is quite different.

The second line considers the various natural hazards of ARMONIA that give a general scenario of what may happen in a given territory and influence the choice and analysis of parameters of physical vulnerability. Each typology of natural event has to be defined in terms of intensity/severity, frequency, location and potential enchaired effects.

The expected risk (third line), in terms of damage and losses, is the product of physical vulnerabilities and hazard characteristics. The analysis of the different vulnerabilities is mainly calculated through matrices of damage, for most of cases, or vulnerability curves when available.

Another important aspect is the analysis of socio-economic and urban coping capacity of exposed communities i.e. the capability/inability to face a given potentially disastrous event by implementing countermeasures for mitigating effects and impacts of natural hazards. Finally, multi-risk is expressed as a synthetic table or maps when it can be produced, where all the main factors of hazards, exposure, vulnerability and enchaired events are taken into account. This table/map will produce a scenario on potential multiple risk acting on the studied area and, substantially, the compatibility of socio-economic and structural systems with the expected consequences (damage/interference) of natural events on the exposed elements with respect to a plan. This, accordingly with the choice of preservation or transformation of present land uses, will lead planners to implement future actions for mitigating risk condition through actions on reducing hazards levels, reducing physical and social vulnerability, implementing measures for increasing the coping capacity in that area. The system allows one to re-analyse risk conditions by introducing structural and non structural mitigation strategies in order to assess the compatibility and acceptability of different planning choices with respect to actual risk conditions, also those induced by the different mitigation strategies for risk reduction. Therefore, the DSS has been conceived as a tool for addressing an exhaustive risk analysis and deciding the best planning choices, at local and strategic levels, by detecting the parts of the framework where the best options for reducing the total risk can be addressed, coherently with available budget and scopes of planning decisions.

A more detailed explanation of the conceptual analysis about harmonisation of risk maps and mitigation strategies addressed to land use planning and management, as basis of the DSS, is fully reported in Del. 5.1 where matrices of vulnerability at local and regional scale have been produced.
2.3 DSS architecture planning and implementation

The first version of the DSS was very simple and its use was essentially restricted to a local decision making process concerned with what could be allowed to be built on a particular parcel of land i.e. the compatibility between potential land uses and the hazards affecting the land parcel involved. This local decision making context was strongly influenced by the UK approach to land use planning and its emphasis on taking decisions on a case-by-case basis.

The system was also designed to use only hazard maps, following the established practice in the use of hazard maps for planning across most of Europe identified in WP1.

After this first approach the DSS structure has been reconsidered in order to produce and develop a more flexible system of support. A new best practice and more sophisticated approach to taking account of hazards, vulnerabilities and risks in land use management decision-making has been proposed (Figure 1).

The most important change of prospective in the structure are listed below:

- be designed for use in a wider range of decision contexts concerned with the management of land uses rather than just with specific planning decisions and should be able to investigate different options and scenarios for mitigation actions (relating both to land use and hazard measures);
- be designed for use in a more flexible way with applications at regional and local levels;
- make use of hazard, vulnerability and risk analyses including an integrated analysis of risk across hazard types, if that proved possible to implement.

Figure 1: Proposed skeleton of the revised DSS (source: ARMONIA Deliverable 5.1, 2006, p.23)
Through the brainstorming exercise for the development of Del 5.1 on physical vulnerability and its link with the intensity of the different hazard, a new approach of vulnerability and risk analysis has been delineated. The key features of this revised outline of the DSS. In synthesis they are:

1. the addition of the iterative loop around the diagram which indicates the need to look at the situation under different conditions of (in this case) land use preservation or transformation before making decisions;

2. the distinction between urban and rural/natural areas which was suggested as necessary as those two conditions can correspond to rather different juridical status that may be changed by plans and also because the type of parameters to be considered, especially with respect to exposed elements and vulnerabilities, can change between urban and rural environments;

3. the addition of vulnerability and risk assessment within the structure of the DSS;

4. the inclusion of the more systemic form of vulnerability relating to an exposed community’s, ability or inability to respond and face a given threat through countermeasures and institutional as well as informal structures. This notion of vulnerability is encapsulated by the term ‘urban coping capacity’ in the diagram;

5. the inclusion of a multi-risk synthesis table and map.

2.3.1 Functional and technical architectural design of a decision-support system for risk informed spatial planning (result of WP5 and Deliverable 5.2)

The final version of the DSS represents a significant step forward in conceiving a support system for multi-risk decision taking. A qualitative approach using risk matrices to derive risk indicators which could be compared under different scenarios for a given hazard was therefore developed. Different scenarios for different hazard or vulnerability mitigation measures could then be compared within a hazard category (e.g. different scenarios for forest fire risk).

The main stages through which the DSS progresses are:

1. Introduction/Logon procedure
2. Map and Scenario selection
3. Hazard analysis
4. Exposed elements analysis
5. Vulnerability analysis
6. Multiple Criteria Risk Evaluation
7. Coping Capacity analysis
8. Outputs
9. Output comparisons between scenarios

The complete structure of the final version of the DSS (see Figure 2) is amply explained in the Del.5.2, Chapter 4.2.5

5 ARMONIA Del. 5.2, 2006: Functional and technical architectural design of a decision-support system for risk informed spatial planning, final version 31.09.2006
Figure 2: Final skeleton of the DSS, method (source: ARMONIA Deliverable 5.2, 2006, p. 17)
3 Conclusions

The main objective of WP3 was the reconstruction and upgrading of multi-hazard and multi-risk assessment and mapping, through the worldwide analysis of the state of the art. This analysis has permitted to detect uncertainties, limits and strength of the various methodologies, from simplified approaches to innovative and advanced methods. Nevertheless, all reported studies contain important gaps when transformed into practical applications (e.g. exposure and vulnerability analysis, mapping multi-hazard and risk). Therefore, the efforts of proposing a harmonised methodology have been addressed in tabling a rigorous, well structured theoretical approach capable of being flexible when transformed in a DSS design architecture.

One of the crucial points has been the harmonisation of various hazards in ARMONIA. Two distinct issues have been analysed: the former was the attempt to preserve all technical information coming from hazard assessment such as quantitative intensity parameters that describe the "size" of potential natural events; the latter in a way of harmonising them by defining a synthetic indicator of multi-hazard. After many discussions between NH experts and planners it has been decided that the best way to harmonise the risk procedures (not a compromise but a scientific issue from WP2 and WP5 research activities) is to focus the attention on harmonisation of effects rather than define a synthetic multi-intensity, that makes no sense from a scientific point of view. This is in terms of expected damage, from the analysis of potential impacts coming from various natural events affecting the same element at risk (e.g. buildings, population, infrastructure).

Finally, the most significant innovation and key issue of ARMONIA theoretical and methodological approach, is the profound integration of planners, with distinct orientations and backgrounds, and NH specialists that generally produce a single hazard-oriented scenarios, that has produced a practical, but not simplistic tool capable to help and support decision-makers, at various levels, to recognize the nature and severity of natural events that may occur in a specific area, define the impacts of natural events in terms of exposed elements and vulnerability and provide answers to understand the feasibility of present land-use and future planning decisions with geological and geophysical dynamics acting in that area.

The proposition of a DSS design has been a coherent and feasible way to produce practical tools (DSS) for developing a harmonised procedure of multi-risk assessment, at regional and local scales, considering all the key parameters (hazard, exposure, vulnerability and risk). With respect to the state of the art of the research, this procedure provides an improvement through the development of vulnerability matrices, at regional and local scales, considering the parametric intensity of natural events, potential exposed elements and a vulnerability analysis extended to coping capacity and considering different temporal scenarios considering also Climate Change potential effects at different temporal scales. This approach, although rather complex, has been adopted in order to avoid dangerous simplifications that often are proposed in the field of multiple hazard/risk analysis, like, for example, superimposition of different hazard (usually
susceptibility or inventory) maps that produce a sort of qualitative scenario of potential natural events that may occur in a given area. This kind of approach cannot be useful to produce feasible mitigation measures.

The main gap of the procedure remains the lack of fragility curves derived by intensity/severity vs. typology of exposed element. The development of such a functional links is beyond of the project purposes since this topic has been poorly developed in research and also where implemented, such as in seismic analysis, results cannot be generally adopted. This topic, at last, can be considered as the most significant for future developments of multiple risk analysis, especially at local scale.

4 Bibliographical references

ARMONIA Del. 1.1, 2005: Report on the European scenario of technological and scientific standards reached in spatial planning vs. natural risk management, final version April 2005

ARMONIA Del. 1.3, 2005: Report on the definition of possible common procedures and methodologies of spatial planning for natural hazards, to inform the development of a new spatial planning standard for the EU, final version July 2005

ARMONIA Del. 2.1, 2005: Report on current availability and methodology for natural risk map production, final version June 2005


ARMONIA Del. 5.1, 2006: Harmonised hazard, vulnerability and risk assessment methods informing mitigation strategies addressing land-use planning and management, final version 31.09.2006

ARMONIA Del. 5.2, 2006: Functional and technical architectural design of a decision-support system for risk informed spatial planning, final version 31.09.2006