Report: Implementation of a case study simulation

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Report: Implementation of a case study simulation (Del. 6.1)

Aims
The aims of the case study were as follows:

• To validate and confirm the methods developed in Work Packages 3, 4 and 5;
• To identify gaps and limitations in the approaches and to suggest improvements;
• To assess the “usefulness” of the results using readily available data.

Overview
In order to achieve these aims the newly developed draft ARMONIA methodology was applied in the Arno River basin in Italy and at a national level in England and Wales. It was important to validate and confirm the draft methodology and to identify gaps and limitations of the approach so that in the future changes/adaptations can be made to it.

Main output
As part of the draft ARMONIA methodology, consequence indices were developed for a number of exposed elements including: people; buildings; road networks, pipelines and agriculture. These consequence indices take into account the following:

• The vulnerability of the exposed elements;
• The exposure of the exposed elements.

Consequence indices have been developed at a regional level for the following hazards: earthquakes; floods; landslides; volcanoes and forest fires. These consequence indices are combined with hazard indices to produce a risk index for each of the natural hazards being considered for the area of interest. Figure 1 shows the way in which risk is assessed using the draft ARMONIA methodology.

The case study investigated a number of issues related to the draft ARMONIA methodology including:

• Data selection and availability;
• The data required to assess different types of vulnerability to natural hazards;
• The use of indices as a proxy to measure natural hazards, vulnerability and risk;
• Representation of hazard and risk indices at different spatial scales;
• Validation and verification of the draft methodology;
• Usefulness of the results to decision makers.
Recommendations and conclusions
The following represents the main conclusions and recommendations that resulted from the case study:

- The draft ARMONIA methodology requires further validation in areas where quantifiable risk metrics such as economic damage and loss of life are available for a number of different hazards;
- Alternative multiple risk mapping methods that are not as data specific as the draft ARMONIA methodology need to be investigated further;
- Many decision makers require risk metrics that are quantifiable (e.g. economic damage, potential loss of life) in order to plan sustainable hazard mitigation measures. More work is required on vulnerability curves for a number of exposed elements and hazards to allow risk metrics to be quantified;
- There needs to be greater research into what the end users of risk maps actually require. Although spatial planners in many European countries only appear to require hazard maps, other decision makers responsible for implementing hazard mitigation measures need to know specific information in the form of quantifiable risk metrics, in order to assess whether the proposed mitigation measure is sustainable from both an environmental and economic point of view.

If you would like to receive the complete deliverable, please download it from www.armoniaproject.net or contact: info@armoniaproject.net.
WP6:
Case study and quality control

Del. 6.1
Report: Implementation of a case study simulation
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Title: 
Applied multi Risk Mapping of Natural Hazards for Impact Assessment

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Short Description:

This report details the work carried out as part of the Case Study component of Work Package (WP) 6. The results obtained from WP6 were based on the outcomes of WP 3, 4 and 5. The objectives of the case study are the following:

• To validate and confirm the methods developed in WPs 3, 4 and 5;
• To identify gaps and limitations in the approaches and to suggest improvements;
• To assess the “usefulness” of the results using readily available data.

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1 Introduction

This report details the piloting of a multi natural hazard and multi natural risk methodology developed as part of the European Commission (EC) sixth framework research project ARMONIA. A hazard may be defined as a physical event, phenomenon or human activity with the potential to result in harm. A hazard does not necessarily lead to harm. The vulnerability of populated areas to natural disaster is in part a consequence of spatial planning policies that have failed to take proper account of hazards and risks in land use zoning and development decisions. The ARMONIA project looked at the following specific hazards that are prevalent in Europe:

- Earthquakes;
- Floods;
- Forest fires;
- Landslides;
- Volcanoes.

1.1 Structure of the report

This report has been structured as follows:

- Chapter 1 provides an introduction to the project and the case study;
- Chapter 2 outlines the basic concepts in natural risk assessment;
- Chapter 3 details the draft ARMONIA methodology;
- Chapter 4 describes the use of legends for natural hazard and natural risk mapping;
- Chapter 5 provides an introduction to the piloting of the draft ARMONIA methodology in the Arno River basin in Tuscany, Italy;
- Chapter 6 details the production of forest fire hazard and risk maps for the Arno River basin;
- Chapter 7 describes the implementation of the draft ARMONIA methodology in the Arno River basin by HR Wallingford;
- Chapter 8 outlines the application of the draft ARMONIA methodology to the Mugello Region of the Arno River basin by the University of Naples;
- Chapter 9 provides an analysis of the impacts of climate change in the Arno River basin;
- Chapter 10 details the implementation of the draft ARMONIA methodology in England and Wales;
- Chapter 11 outlines recommended improvements to the consequence indices used in the draft ARMONIA methodology based on the results of the case studies;
- Chapter 12 presents an alternative simplified method for multi-hazard and multi-risk mapping;
- Chapter 13 summarises the conclusions and recommendations;
- Chapter 14 details the references that were used to compile this report.
1.2 Background

The overall aim of the ARMONIA project is to provide the European Union (EU) with a set of harmonised methodologies for producing integrated risk maps to achieve effective spatial planning procedures in areas prone to natural disasters in Europe.

The overall objectives of the project are as follows:

- The integration of methodologies for hazard and risk assessment for different types of natural hazards (e.g. earthquakes, floods, landslides, fires, heavy rainfall);
- The integration of different processes of risk mapping to standardise data collection, data analysis, monitoring, outputs and terminology in a form useful to end users;
- The design of a decision-making tool structure for applying hazard and risk mitigation through spatial planning in risk prone areas;
- The development of guidelines on natural hazard mitigation in the context of the EU Environmental Assessment Directive (2001/42/EC);
- A contribution to the implementation of natural hazard awareness into the improvement of Environmental Assessment policy (e.g. EU Environmental Assessment Directive - 2001/42/EC).

This report details the work carried out as part of the Case Study component of Work Package (WP) 6. The results obtained from WP6 were based on the outcomes of WPs 3, 4 and 5. The objectives of the case study are the following:

- To validate and confirm the methods developed in WPs 3, 4 and 5;
- To identify gaps and limitations in the approaches and to suggest improvements;
- To assess the “usefulness” of the results using readily available data.

1.3 Integration of the ARMONIA Work Packages (WPs)

The implementation of the ARMONIA project was planned in three logical steps. The steps were represented by six technical work packages (WPs). The WP structure was chosen to ensure achievement of the project goals in an efficient step-by-step manner. The three technical steps of the projects are detailed below.

Step1 Analysis of the state-of-the-art of spatial planning and of natural risk mapping (WP 1 and WP 2)

During this phase of the project the state-of-the-art of spatial planning and risk assessment at a European level was collected, described and defined. This step comprised two WPs as follows:
WP 1 State-of-the-art of spatial planning

The results of the state-of-the-art analysis on spatial planning of WP 1 showed that the major interest of spatial planners is on areas that are currently undeveloped. As a result planners are generally interested in hazard, rather than risk. However, organisations that are responsible for structural mitigation measures and emergency planning need information about the existing vulnerability and risk.

WP 2 Natural risk assessment methodologies

WP2 collected together the state-of-the-art for natural risk assessment methodologies for different natural hazards including:

- Floods;
- Earthquakes;
- Landslides;
- Forest fires;
- Volcanic activities;
- Possible secondary effects of natural hazard (e.g. groundwater pollution).

Step 2 Development of a harmonised decision-making tool structure and a guideline for a European standard for applying hazard and risk mitigation through spatial planning (WP3, WP4 and WP5)

Step 2 comprised the development of a harmonised decision-making tool structure and a guideline for a European standard for applying hazard and risk mitigation through spatial planning. This work was carried out via three WPs as follows:

WP 3 Methodology for a harmonised integrated map

The main goal of WP 3 was to define a new harmonised methodology for an integrated approach to different risk analysis methodologies, and to set-up basic principles for an EU directive on harmonized hazard and risk maps for land use planning and management. The work was developed into the following stages:

- Development of a new harmonised methodology for an integrated management of data from different risk analysis methodologies;
- Development of an integrated natural risk legend and standards, with the goal to enable a coherent production, presentation and communication for producing multi-risk maps;
- Harmonised design for integrated risk maps in order to enable multi-risk assessments to be carried out;
- Guideline for an EU directive on harmonized risk maps for land-use and management planning.
WP 4 Development of a harmonized knowledge base of terminology

A technical glossary of risk assessment language was developed with objective of harmonising the scientific language through the application of recent techniques and methodologies with special attention to GIS development and capabilities. The glossary concentrates on multi-hazard and -risk with a special focus on spatial planning relevance, thus addressing a key issue of the current hazard discussion in Europe. It provides a concise overview on the most important terms used in multi-hazard and -risk assessment relevant for spatial planning.

WP 5 Integration of harmonized risk maps with spatial planning decision processes

A methodology was developed to integrate risk maps with the aim of assisting the spatial planning decision-making processes. A framework and a GIS based prototype decision support tool were developed to help to ensure that spatial planning decision makers are fully informed about the risks affecting particular areas of land, the vulnerability of different land uses and populations (taking account of social factors such as age, gender and disability) and the options that are available to mitigate the risks. The data integration was implemented within a GIS environment, utilising the capabilities of advanced spatial database structures and GIS programing to create a flexible and powerful environment for analysing data, examining varied risk and decision-making scenarios and visualising both data and decision options in an effective manner.

Step 3 Case study and quality control (WP6)

WP 6 was based on the outcomes of WP 3, 4 and 5. The results of the case study are described in this report. The application of the newly developed methodologies was necessary to validate and confirm the procedure, to identify gaps and limitations of the approach, so that changes/adaptations can be made. In order to test out the new approaches they were applied in the Arno River basin in Italy and at a national level in England and Wales

The way in which the six WPs and three stages are linked together is shown in Figure 1.1. The results of the case study are described in this report.
Figure 1.1  The links between the ARMONIA technical Work Packages (WPs)
2 The assessment of risks generated by natural hazards

2.1 What is risk?

The term “risk” has a range of meanings and multiple dimensions relating to the following:

- Safety;
- Economic;
- Environmental; and
- Social issues.

These different meanings often reflect the needs of particular decision-makers and as a result there is no unique specific definition for risk and any attempt to develop one would inevitably satisfy only a proportion of risk managers. Indeed the very adaptability of the concept of risk is one of its strengths. A difficulty with the terminology of risk is that it has been developed across a wide range of disciplines and activities, there is therefore potential for misunderstanding in technical terminology associated with risk assessment, since important technical distinctions are made between words which in common usage are normally treated as synonyms (i.e. understood to have the same or similar meanings). Most important is the distinction that is drawn between the words “hazard” and “risk” (Reference: 47).

To understand the linkage between hazard and risk it is useful to consider the commonly adopted Source-Pathway-Receptor-Consequence (S-P-R-C) model. This is shown in Figure 2.1. This is, essentially, a simple conceptual model for representing systems and processes that lead to a particular consequence. For a risk to arise there must be hazard that consists of the following:

- A “source” or initiator event (e.g. a landslide, high water level, erupting volcano);
- A “pathway” between the source and the receptor (e.g. hill slope for a landslide, floodplain for a flood, hill slope or air for a volcano);
- A “receptor” or exposed element (e.g. buildings, people).

It is important to note that a hazard does not automatically lead to a harmful outcome, but identification of a hazard does mean that there is a possibility of harm occurring, with the actual harm depending upon the exposure to the hazard and the characteristics of the receptor (i.e. the exposed element).
Figure 2.1  Source – Pathway – Receptor – Consequence model  
(Source: Reference:47)

It is also important to note that the receptors (or exposed elements) and consequences can be the same for different natural hazards. For example, if the risk being considered is loss of life then the receptor (or the exposed element) will be people for all the natural hazards being considered and the consequences will be loss of life.

2.2 The evaluation of risk

To evaluate the risk, consideration needs to be made of a number of components:

- The nature and probability of the hazard (p);
- The degree of exposure of the elements at risk (e.g. numbers of people and property) to the hazard (e);
- The susceptibility of the elements at risk to the hazard (s); and
- The “value” of the elements at risk (v) (e.g. economic cost, loss of life).

Risk can thus be defined as follows:

\[ \text{Risk} = \text{function} \ (p, e, s, v) \]

In this context vulnerability is a sub-function of risk. Vulnerability encompasses the characteristics of a system that describes its potential to be harmed. Vulnerability can thus be expressed in terms of a function as follows:

\[ \text{Vulnerability} = \text{function} \ (s, v) \]
In practice the exposure and vulnerability are often captured in the assessment of the consequences and hence risk can be viewed in simple terms as:

\[
\text{Risk} = (\text{Probability}) \times (\text{Consequence})
\]

Where the probability is the probability of exposure of the element at risk (Reference: 47).

### 2.3 Units of risk

In general, risk has units. However, the units of risk depend on how the likelihood and consequence are defined. For example, both the likelihood and consequence may be expressed in a number of equally valid ways. Likelihood can be considered as a general concept that describes how likely a particular natural hazard is to occur. Frequency and probability can be used to express likelihood. However, these terms have different meanings and are often confused. It is important to understand the difference between them:

- **Probability** can be defined as the chance of occurrence of one event compared to the population of all events. Therefore, although probability is dimensionless it is however, often referenced to a specific time frame, for example, as an annual exceedance probability or lifetime exceedance probability;
- **Frequency** defines the expected number of occurrences of an (particular extreme) event within a specific number of events, often related to a timeframe;
- **Consequence** represents an impact such as economic, social or environmental damage or improvement, and may be expressed quantitatively (e.g. monetary value, numbers of lives lost), by category (e.g. High, Medium, Low) or descriptively.

The issue of how some of the consequences of natural hazards can be valued continues to be the subject of contemporary research. However, risk-based decision-making would be greatly simplified if common units of consequence could be agreed. It is therefore often better to use “surrogate” measures or indicators of consequence for which data are available. For example, “Number of buildings affected” may be a reasonable surrogate for the degree of harm caused by a natural hazard and has the advantage of being easier to evaluate than, for example, economic damage or social impact.

An important part of the design of a risk assessment method is to decide on how the impacts are to be evaluated. Some descriptions of “consequence” are:

- Economic damage (e.g. national, community and individual);
- Number of people or buildings affected;
- Harm to individuals (e.g. fatalities, injury, stress);
• Environmental and ecological damage, which is sometimes expressed in monetary terms.

Clearly these differ in what is described. The following sections detail the methods by which natural hazards can be assessed and the vulnerability of the receptors can be quantified.

2.4 Methods for assessing natural hazards

The methods for assessing natural hazards have been detailed in the ARMONIA project report entitled “WP2: Collection and evaluation of current methodologies for risk map production” (Reference:10). The reader is referred to this report for further information on the state-of-the-art methods for mapping and assessing flood, seismic, landslide, volcanic and forest fire hazards.

2.5 Methods for determining the vulnerability of receptors

One of the key factors to assessing the risk from a natural hazard is the assessment of the vulnerability. The key question to be answered is how is vulnerability determined? This is dependent upon the following:

• The nature of the receptor (or exposed element) e.g. people, buildings, the environment;
• The type of hazard (e.g. volcanic, seismic, flood);
• The nature of the risk to be assessed.

The following sections detail examples of commonly used methods to assess the vulnerability of different receptors.

2.5.1 Vulnerability functions for buildings

The vulnerability of buildings to a natural hazard is often expressed in terms of a function that relates the intensity of a hazard to the degree of damage that will be incurred by the building. The degree of damage may be expressed in economic terms or as a susceptibility factor. Vulnerability functions for buildings have been derived for a number of natural hazards including floods, earthquakes, volcanoes and landslides. However, it is important to note that the vulnerability functions that have already been developed have usually been produced for a specific country, region or city. Figure 2.2 shows a vulnerability curve relating the susceptibility of buildings to avalanche impact in Güter, Austria. Figure 2.3 shows various vulnerability curves relating flood depth to economic damage for a variety of different building types in the UK.
In general vulnerability functions for building are related to the size and/or age and type of construction of the building.
2.5.2 Vulnerability of transport networks

There has been some work carried out on assessing the vulnerability of transport networks to natural hazards. One approach is to assess the frequency of occurrence of various natural hazards and the duration of the road closure. The effects of road closures on traffic patterns can then be assessed using a traffic management model and the annual economic impact of road closure can be assessed for each hazard. Figure 2.4 shows a relationship between the frequency of occurrence of a natural hazard and the duration of closure of a road. Figure 2.5 shows functions developed for a state highway in New Zealand relating the probability of exceedance of a particular natural hazard to the average annual cost of closure of the state highway.

![Figure 2.4 Frequency of closure of a road related to the frequency of occurrence of a natural hazard (Source: Reference:31)](image)
2.5.3 Agricultural vulnerability

The damage to agriculture is often orders of magnitude less than damage to buildings during hazardous events hence there tends to be have been less work carried out to assess agricultural vulnerability. General considerations that are taken into account in developing agricultural vulnerability functions include:

- Crop value per unit area;
- Investment required in planting;
- Sensitivity of crop to the hazard;
- Cost of returning the land to former productivity after flood.

2.5.4 Environmental vulnerability

The environmental vulnerability to natural hazards is often difficult to quantify. There has been a number of vulnerability functions developed throughout the world. These are often based on variables such as:

- Number of species that inhabit an area;
- Type of species that inhabit an area;
- Type of vegetation.

These variables are often combined to produce an index that can be used as a proxy for the vulnerability of the environment.
2.5.5 Vulnerability of people in terms of loss of life or injuries

There are number of methods that have been developed to assess risk to people for a number of natural hazards. The number of people injured or killed during a natural hazard is usually a function of the following:

- **The nature of the hazard** – For example the speed of onset of the hazard, the intensity;
- **The people vulnerability** – this is often defined by variables such as age and other socio-economic indices such as wealth and long term illness;
- **The area vulnerability** in terms of for example the type of property in which people reside;
- **The effectiveness of warning of the hazard** – this is a function of the coverage of the warning system, warning time, the preparedness of the population and the action taken.

These factors can be combined to assess the likely lose of life or injuries as a result of a particular hazard (Reference:36).

2.5.6 Social vulnerability

The nature of social vulnerability is dependent upon the nature of the hazard to which the human system in question is exposed. However, although social vulnerability is not a function of hazard, certain properties of a system will make it more vulnerable to certain types of hazard than to others. For example, quality of housing will be an important determinant of a community’s social vulnerability to a flood or windstorm, but is less likely to influence its vulnerability to drought. So, although social vulnerability is not a function of hazard, it is, to a certain extent at least, hazard specific. Nonetheless, certain factors such as poverty, inequality, health, access to resources and social status are likely to determine the vulnerability of communities and individuals to a range of different hazards (including non-climate hazards). These factors may be viewed as “generic” determinants of social vulnerability and others such as the location of dwellings in relation to a source (e.g. a river, volcano) as determinants that are “specific” to particular hazards.

There are numerous methods of measuring social vulnerability to natural hazards. The parameters that are commonly combined to assess social vulnerability are as follows:

- Age;
- Measures of health (e.g. disability);
- Gender;
- Car ownership;
- Employment;
- Measures of wealth.
The concept of “measuring” aspects of social vulnerability to natural hazards is one that has been explored widely in emergency and disaster literature for more than 30 years. However, research has largely focused on qualitative assessment methodologies rather than quantitative risk modelling. In part, this is due to the complex nature of people, social structures and culture, however, it is also due to the multi-disciplinary approach required to undertake such research. No single investigation into vulnerability indicators will provide a holistic and comprehensive answer, however, there are aspects of vulnerability that can be explored and represented through the development and application of quantitative vulnerability indicators.

It is interesting to note that, in general, social vulnerability indices for natural hazards have largely been based on quantitative indicators for individuals in a household. Figure 2.6 shows a schematic representation of some of the various factors that contribute to the overall social vulnerability of society. These can be broadly be classified into:

- Individual;
- Community
- Access to services;
- Organisational/institutional.

![Social vulnerability model](source)
3 The draft ARMONIA methodology for natural risk mapping

3.1 Introduction

The key question that was required to be addressed as part of the draft ARMONIA methodology is how to map risks from multiple natural hazards. Conceptually it is simple to map and aggregate risk from a number of different natural hazards. This can be done by assessing the annual average risk for a particular risk metric for a particular hazard. This risk may be measured in terms of loss of life, direct economic damage, measures of environmental degradation or another quantifiable parameter. However, for this approach to be implemented the following need to be available:

- The extent and intensity of the hazard for a number of different return periods (i.e. annual probabilities) ranging from “frequent” events (e.g. 1 in 2 year events) to “rare” events such as those with a 1 in 1,000 year return period;
- Vulnerability functions for each hazard relating the intensity of the hazard to the risk. It is often the case that where such functions are available they are specific to geographical areas or countries.

The theoretical method for assessing risk in this manner is shown in Figures 3.1 and 3.2. It should be noted that these are purely hypothetical vulnerability curves that have been used to illustrate how assess the risk generated by natural hazards can be quantified.

![Diagram of hypothetical vulnerability functions](image_url)

*Figure 3.1  Hypothetical vulnerability functions relating the intensity of a hazard to a risk metric*
Figure 3.1 shows the form that different vulnerability curves relating the intensity of a particular hazard to a particular risk metric could take. Assessing the area under a curve of annual probability versus risk, such as those shown in Figure 3.2, allows the average annual risk for each natural hazard to be calculated. The total risk from the multiple natural hazards can then be assessed by simply adding each of the separate average annual risks together.

Note: The above curves are hypothetical probability versus risk metric curves to illustrate the method by which risk metrics from different natural hazards can be combined.

The draft ARMONIA methodology looks to overcome the lack of detailed vulnerability functions relating hazard intensity to a quantitative risk metric by using a variety of indices to assess the risk for a particular natural hazard. These indices are as follows:

- Hazard indices;
- Consequence indices for different receptors or exposed elements (e.g. building, people and infrastructure). It should be noted that the consequence indices comprise a measure of vulnerability and exposure. These are combined to give a consequence index.

The hazard and consequence indices are combined to produce a risk index for each hazard. The draft ARMONIA methodology allows a weighting factor that must total 20 to be applied to each consequence...
index by the relevant stakeholder. Figure 3.3 shows the way in which risk is assessed using the draft ARMONIA methodology.

It should be noted that the draft ARMONIA methodology produces a combined risk score for each individual natural hazard. It does not allow the risk from multiple natural hazards to be combined. The sections below detail the development of the ARMONIA hazard, vulnerability and consequence indices.

### 3.2 Development of hazard indices

In Deliverables WP3.1 (Reference:11) and WP5.1 (Reference:13) hazard indices have been developed. However, these indices are generally only related to hazard intensity and do not take into account the probability of occurrence of the hazard. For example the simplified approach for the regional scale, taken from WP3.1, shown in Table 3.1 does not incorporate the probability of the hazard occurring, it only incorporates the intensity. The assessment of natural risk requires the incorporation of both the intensity and probability of the hazard in the index.

It is recommended that an approach that takes into account both intensity and probability of the hazard is used. Such an approach is shown diagrammatically in Figure 3.4. The intensity scales defined in Table 3.1 could be used in conjunction with four return periods corresponding to a high, medium, low and very low probability. These return periods could be as follows:
- <1 in 25 years High;
- 1 in 25 to 1 in 100 years Medium;
- >1 in 100 years to 1 in 300 years Low;
- >1 in 300 years Very low.

It should be noted that the final category of “very low” may not be applicable to all natural hazards.

<table>
<thead>
<tr>
<th>Natural hazard</th>
<th>Intensity scale</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Flood</td>
<td>&lt;0.25</td>
<td>0.25 to 1.25</td>
</tr>
<tr>
<td>Forest fire</td>
<td>&lt;350</td>
<td>350 to 1750</td>
</tr>
<tr>
<td>Volcanoes</td>
<td>&lt;5</td>
<td>5 to 10</td>
</tr>
<tr>
<td>Landslides</td>
<td>&lt;5%</td>
<td>5 to 10%</td>
</tr>
<tr>
<td>Seismic</td>
<td>&lt;10%g</td>
<td>10 to 30%g</td>
</tr>
</tbody>
</table>

*Table 3.1 Simplified ARMONIA approach for assessing intensities at the regional scale (Reference:11)*

*Figure 3.4 Diagram to show hazard levels and indices as a function of probability and intensity*
Figure 3.4 provides four classes and indices of hazard. This could be graphically identified with colours with red being high, blue being medium and yellow being low. For example a medium hazard with an index of 2 can result from a hazard with a low to medium intensity and a probability of occurrence ranging from low to high.

The draft ARMONIA methodology requires hazards to be classified into non-dimensionalised indices. In practice hazards classified into more than 10 categories become difficult to clearly display within a GIS environment. The conversion of hazard data that represents a wide variety of units into integer values may lead an end-user to interpret equal scores as representing an equal level of hazard for different hazard types. For example, a flood with a “Class 2 hazard” should have the same intensity and probability as a “Class 2 seismic hazard” if multi-hazard risk maps are to be comparable.

The WP3.1 report (Reference:11) identifies hazard classifications based on hazard intensity. It should be noted that in the WP3.1 report the relationship between the probability and intensity is not defined. For example, a 1 in 10 year flood is considered as hazardous as a 0.25 m depth flood. A more suitable universal method of classifying hazards would be to given the annual probability of exceedance of a given hazard intensity. This is a useful measure since it returns a value between 0 and 1 and is thus more readily compared across hazard types.
3.3 Development of the ARMONIA consequence indices

3.3.1 Introduction

As part of the draft ARMONIA methodology, consequence indices have been developed for a number of receptors (i.e. exposed elements). This section details the development of these indices for the following receptors:

- People;
- Buildings;
- Road network;
- Agriculture;
- Other buildings (e.g. commercial and industrial areas, airports).

The consequence indices take into account the following:

- The vulnerability of the exposed elements (i.e. receptors);
- The exposure of the exposed elements (i.e. receptors).

Consequence indices have been developed at a regional level only for the following hazards:

- Earthquakes;
- Floods;
- Landslides;
- Volcanoes;
- Forest fires.

The general process for computing the consequence indices is shown in Figure 3.5. It should be noted that for forest fires a specific consequence index has been developed relating to fires as part of the draft ARMONIA methodology and also by the Joint Research Centre at Ispra. The latter is detailed in Chapter 6. The various consequence indices are discussed below.
3.3.2 Consequence index for people

The ARMONIA index for people vulnerability is the same for the following hazards:

- Earthquakes;
- Floods;
- Landslides;
- Volcanoes;
- Forest fires.

The vulnerability of people is based on the percentage of people under five years of age and over 65 years of age. The population vulnerability is calculated from the following equation:

\[ P_{vi} = \frac{Pop(<5\text{years}) + Pop(>65\text{years})}{P_{\text{total}}} \times 100\% \]
Where:

\( P_{vi} \) is the people vulnerability for a particular area;
\( \text{Pop(<5 years)} \) is the number of people less than five years of age within a particular area;
\( \text{Pop(>65 years)} \) is the number of people older than 65 years of age within a particular area;
\( \text{Poptotal} \) is the total population within a particular area.

The population vulnerability is then normalised into a value between 0 and 1 by dividing by the maximum value within a particular spatial extent.

The exposure for a particular area is defined as the population density of an area and is defined by the following equation:

\[
\text{Pe} = \frac{\text{Poptotal}}{\text{Area}}
\]

Where:

\( \text{Pe} \) is the population density that in this case acts as a proxy for exposure;
\( \text{Poptotal} \) is the total population with a particular area;
\( \text{Area} \) is the area of interest in hectares.

It should be noted that the exposure of a receptor (i.e. an element at risk), in this case people, is usually defined by the number of people not by the population density.

A consequence index is produced using the following equation:

\[
\text{FP}_v = \text{PeP}_{vi}
\]

In most cases the analysis would be undertaken at a census area level and the results would be aggregated up for different spatial scales, for example, regional or a national scale. No details are given in the draft ARMONIA methodology as to how to aggregate indices up from a local scale to a regional scale.

The consequence values are then ranked into four classes that are numbered 1 to 4. The draft ARMONIA methodology does not describe how this ranking is to be undertaken. For the purposes of map display it has been assumed to that the data is ranked into quartiles rather than equal class divisions. However, this has not been made clear in the methodology.
3.3.3 Consequence indices for buildings

Introduction

The building vulnerability index in the draft ARMONIA methodology is based on a number of different measures of building vulnerability including:

- Construction type;
- Age;
- Height of the building;
- Maintenance level;
- Density of buildings.

It is important that the following are noted concerning the ARMONIA building vulnerability index:

- It is based on a method developed to assess the vulnerability of buildings to earthquakes in Italy;
- It is based on data that is readily available from the Italian census. This data may not be available in many other countries in Europe;
- A building vulnerability index has not been developed for forest fires owing to the limited amount of information that is available concerning structures to this type of hazard.

The variables that are utilised to assess building vulnerability for the different natural hazards are detailed in Table 3.2.

<table>
<thead>
<tr>
<th>Building characteristic</th>
<th>Seismic</th>
<th>Landslide</th>
<th>Flood</th>
<th>Volcano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction type</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Age</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Height</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Density of buildings</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 3.2 Variables incorporated into the building vulnerability index

The manner in which the building vulnerability and consequence indices for the different natural hazards are calculated is detailed below.

Consequence and vulnerability index for buildings for seismic hazards

The building vulnerability for seismic hazards is calculated from the following equation:

\[ Bvi = Bmr + Bar + Bhr + Bct \]

Where:
Bvi is the building vulnerability index for a particular area; 
Bmr is proportion of masonry buildings in an area. This is ranked into 
four classes with scores given from 1 to 4; 
Bar is an indicator of the age of the buildings given by the following 
function:

\[
\text{Bar} = \frac{(6BnA + 5BnB + 4BnC + 3BnD + 2BnE + BnF)}{Bn}
\]

Where: 
BnA is the number of buildings constructed before 1919; 
BnB is the number of buildings constructed between 1919 and 
1945; 
BnC is the number of buildings constructed between 1946 and 
1960; 
BnD is the number of buildings constructed between 1961 and 
1971; 
BnE is the number of buildings constructed between 1972 and 
1981; 
BnF is the number of buildings constructed after 1981; 
Bn is the number of buildings; 
Bar is ranked into four classes with scores given from 1 to 4;

\[
\text{Bhr} = \frac{(2BnG + 3BnH)}{Bn}
\]

Where: 
BnG is the number of buildings with up to two floors 
BnH is the number of buildings with over two floors 
Bhr is ranked into four classes with scores given from 1 to 4;

\[
\text{Bmar} = \frac{(2Bml + 3BmL)}{Bn}
\]

Where: 
Bml is the number of high maintenance buildings; 
BmL is the number of low maintenance buildings; 
The maintenance status of a buildings is related to its water 
supply, sanitation system and heating system.

Bmar is ranked into four classes with scores given from 1 to 4;

\[
\text{Bct} = \frac{(2Bcti + 2Bcta)}{Bn}
\]

Where: 
Bct is a factor related to the building density ranked into four classes 
with scores given from 1 to 4 
Where: 
Bcti is the number of isolated building
Bcta is the number of buildings that are close together or “aggregated”.

It should be noted that the Bct index is incorrect as an equal weighting of two is given to isolated and aggregated buildings. The equation above for Bct will always produce a value of 1.

A consequence index is produced using the following equation:

\[ SBv = BnBvi \]

In most cases the analysis would be undertaken at a census area level and the results would be aggregated up for different spatial scales, for example, regional or a national scale, although no guidance is given in the methodology as to how this would be done.

The consequence values are then ranked into four classes that are numbered 1 to 4. The draft ARMONIA methodology does not describe how this ranking is to be undertaken. For the purposes of map displays it has been assumed to that the data is ranked into quartiles rather than equal class divisions. However, this has not been made clear in the methodology.

**Consequence and vulnerability index for buildings for landslide and flood hazards**

The building vulnerability for landslide and flood hazards is calculated from the following equation:

\[ Bvi = Bmr + Bhr \]

These variables are described above. A consequence index is produced using the following equation:

\[ SBv = BnBvi \]

**Consequence and vulnerability index for buildings for volcanic hazards**

The building vulnerability for volcanic hazards is calculated from the following equation:

\[ Bvi = Bmr + Bar \]

Bmr is calculated in a similar way to described above; Bar is the age of the buildings ranked into four classes as follows:

\[ Bar = \frac{(3BnA + 2BnB + BnC)}{Bn} \]

Where:

- BnA is the number of buildings constructed before 1945;
BnB is the number of buildings constructed between 1946 and 1981; BnC is the number of buildings constructed after 1981.

It should be noted that the parameter Bar for volcanoes is different from that used earthquakes in that there are only three age of building categories as opposed to six for seismic events. No explanation is given in the methodology as to why this is the case.

These variables are described above. A consequence index is produced using the following equation:

\[ SBv = BnBvi \]

### 3.3.4 Consequence index for linear features such as roads and other linear networks (e.g. pipelines)

The draft ARMONIA methodology details a method to estimate the vulnerability of linear features such as roads and pipelines (e.g. water and gas). The vulnerability index for roads to natural hazards is estimated from the following equation:

\[ Re = WiLi \]

Where:

Re is the road vulnerability index;
Wi is a weighting factor that is dependent on the class of the road. This is used as a proxy for vulnerability. With a weighting of 1 being assigned to minor roads, 2 to regional roads and 3 to national roads;
Li is the total length of each type of road within a certain area, this acts as a proxy measure for the exposure.

For other linear networks such as gas pipelines and water supply distribution networks the exposure is estimated using the following equation:

\[ Ne = HiLi \]

Where:

Ne is the network consequence index;
Hi is a weighting factor that is dependent on the network. A weighting of 1 being assigned to “secondary networks” and 2 to “primary networks”;
Li is the length of each type of network within a certain area, i.e. a proxy measure for the exposure.

The consequence index of a linear network within a particular area is given by the index SEn. This is calculated as follows:
The values produced by this equation are then normalised and divided into four classes numbered one to four. It is important to note that there is no guidance given in the methodology as to what constitutes a “primary” or “secondary” network or “minor”, “regional” or “national” road.

### 3.3.5 Consequence index for forest fires

A forest fire consequence index has been developed specifically for forest fires

\[
FE_a = FaF_p
\]

Where:

- \(FE_a\) is the forest fire consequence index
- \(Fa\) is the surface area of the forest, this acts as a proxy for the exposure
- \(F_p\) is a score based on the percentage of the forest that is in a protected area, this acts as a proxy for the vulnerability. This is divided into four classes as follows:
  - 0% to 25% in the protected area \(F_p = 1\);
  - >25% to 50% in the protected area \(F_p = 2\);
  - >50% to 75% in the protected area \(F_p = 3\);
  - >75% to 100% in the protected area \(F_p = 4\).

Another index has also been established for the Joint Research Centre at Ispra, Italy. This is reported on in Chapter 6.
4 Legends for natural hazard and risk mapping

This chapter was written by GTK and details the recommended legends for natural hazard and risk mapping detailing the following issues:

- Scale;
- Hazard, symbols and colours;
- Vulnerability colours;
- Risk colours.

4.1 Scale

ARMONIA Deliverable 1.3 (Reference:9) states that the regional scale, the local general scale and local detailed scale are the most relevant levels for spatial planning and development. The scale used to display information has a considerable influence on how a hazard or risk is measured and displayed.

4.1.1 Regional

At a regional scale, choropleth maps are often most suitable to illustrate risk on a map. In a choropleth map shades and colours are used in proportion to the measurement of the statistical variable being displayed on the map, such as population density or risk. It provides an easy way to visualise how a measurement varies across a geographic area.

One value (qualitative data or derived quantitative data such as densities or rates) characterises a certain geographic area. Administrative borders, natural units, land use classifications or the homogeneity of other characteristics such as population density, Gross Domestic Product (GDP), economic structure or any combination of these criteria can delineate an area. The unit area is likely to be determined by the level of detail in the available data.

4.1.2 Local general

The local general level allows for a more detailed legend. Assuming that data are available or can be collected on a cadastre spatial resolution, there is no need for derived data referred to a given geographic unit, but homogeneous areas in term of risk classification can be displayed. This can coincide with units of actual (land) use, if the risk level results from the sensitivity of a land use type and a homogeneous level of hazard intensity. For example a homogeneous risk level might be given for an area with single-family houses (homogeneous use) situated in a region prone to earthquakes (with similar horizontal peak ground acceleration).
4.1.3 Local detailed

On a local detailed scale or possibly in a site-specific assessment, areas can be delineated in a similar way to the local general scale. Additionally, single entities or spots of interest can be pointed out by symbols. The style of lines and areas can give further information on the type and intensity of hazard as well as on the specific vulnerability or sensitivity of single objects towards a hazard. Symbols typically representing streets, railways or single houses on maps can be used for specific exposed elements; a number of such items are listed in Table 6 in ARMONIA Deliverable 5.1 (Reference:13).

In the WP6 pilot study, census areas are used for the regional level as well as for the local level. Census areas comprise a certain number of households (approximately the same number for each area) and preferably a homogeneous population. The information concerning risk from natural hazards has to be given as derived data referring to each census area. Although the hazard intensity may vary within one census area, there can be only one risk value for the entire census area, since the spatial distribution of households exposed to the hazard is not taken into account. Choropleth maps are a suitable way of illustration in this case.

4.2 Symbols and colours used for hazard mapping

A consensus of opinion exists among experts\(^1\), as well as through our own investigations and the results of WP 2.1, that specific symbols or patterns for a hazard seem to be rare. The classification is frequently displayed in sequential colour schemes, often following a scheme from green to red. As long as the focus is on a single hazard there is no explicit need for a distinctive set of symbols or patterns. Taking into account the possible users the main requirements for a map in the ARMONIA context are legibility and a manageable amount of information.

A scheme with a colour transition can be divided in three to five classes. This is dependent on the chosen intensity measure. This is detailed in Tables 3 and 4 of ARMONIA Del. 5.1 (Reference:13). The colour transition with a strong statement can go from green to red; for a more low-key and less highlighting scheme a transition from (light and unsaturated) green to blue.

The requirements for a legend are more demanding, when several hazards should be looked at simultaneously. Even if the hazards are presented on different maps, differences in colouring and pattern could assist the end user. For flood hazards a sequential scheme from light to dark blue might be appropriate and would be

\(^1\) The answers of the following natural hazard experts were taken into account: Andrea Camia and Giuseppe Amatulli, JRC Institute for Environment and Sustainability (forest fire hazard); Silvia Cozzi, Politecnico di Milano (seismic hazard); Darren Lumbroso, HR Wallingford (flood hazard)
understood. For other hazards the development of a unique legend is more challenging intuitively. Figure 4.1 shows a legend for forest fire hazard. Triangles are sometimes used to report forest and wild fires on maps (e.g. Reference:52) and therefore might be suitable for a general pattern as well.

![Figure 4.1 Possible patterns for a choropleth forest and wild fire hazard map](image)

Landslides and related hazards may be supported by a legend as shown in Figure 4.2. The shape of the pattern is derived from the style of the symbols for slope failures on maps from 1:10,000 to 1:25,000 of the icons kit of the Swiss Federal Office for Water and Geology (Reference:20).

![Figure 4.2 Possible patterns for a choropleth landslide hazard map](image)

However, since only a few symbols and patterns for single hazards are commonly used and easily understood, a clear separation of hazard types with specific patterns remains a challenging task. Other methods might be needed to indicate, which hazard contributes to the risk. An additional pie-diagram can indicate the distribution of hazard intensity within one census area or the hazard types that contribute to the multi-hazard risk. Figure 4.3 gives an example how such a pie-diagram might look like for a multi-hazard approach.
A large number of these diagrams, however, make the map difficult to read. Therefore this kind of additional information is most probably limited to the regional scale, where a certain level of risk is attached to a geographic area. For the local general and local detailed scaled other methods might be more appropriate. ARMONIA report Deliverable 5.2 (Reference:14) suggests hazard graphs as part of the Decision Support System (DSS). These graphs are not included in the actual map, but are shown in a separate window on request.

### 4.3 Colours used for vulnerability mapping

Mapping conventions give a good starting point for a vulnerability legend. For example, the illustration of Corine land cover data uses a certain colour scheme. Figure 4.4 is taken from the European Environment Agency (EEA) Report 11/2006 (Reference:45) and gives an example how different land cover types are labelled. The Red-Green-Blue (RGB) values for the colours are available at the EEA data service. The American Planning Association offers a colour code for Land-Based Classification Standards similar to that of Corine Land cover (Reference:8). This is shown in Figure 4.5. If one colour is given to represent each land use type, then vulnerability could be displayed by the change from light to dark in that colour.
A natural choice for the building vulnerability index in Europe is a red colour ramp, following the colour code of Corine land cover. In the ARMONIA report Deliverable 5.1 (Reference:13), there are a number of other vulnerability categories that could be illustrated in a similar way: productive areas in purple, network infrastructure in less saturated red or forest and agriculture in green.
4.4 Risk legends

In stage 8 of the DSS, detailed in the ARMONIA report Deliverable 5.2 (Reference:14), the risk factor for each census area is calculated by multiplying the hazard class and consequence class. In addition to multiplying these two parameters, there is the possibility to assess the resulting risk using two interacting colour ramps. This approach was utilised in the ESPON 1.3.1 project on natural and technological hazards at the European level (Reference:44). The integrated risk index allows a distinction to be made between those areas where there are only hazard and those where there is also a risk.

In order to combine the vulnerability and hazard potential, a 5 x 5 matrix is used. The value of a region’s hazard intensity and degree of vulnerability are summed up to yield the region’s integrated risk value. This aggregation procedure yields nine risk classes. (References: 56 and 64), see also Table 6 in ARMONIA Deliverable 3.2 (Reference:12). The colour scheme for two risk parameters presented in ARMONIA Deliverable 3.2 can be easily applied in the same way as the risk matrix presented by the ESPON 1.3.1 project. The original parameters “risk based on non-monetary values” and “risk based on monetary values” are replaced by “vulnerability” and “hazard intensity”.

---

**Figure 4.5** Colour scheme for the Land-Based Classification Standards of the American Planning Association (Source:Reference:8)
The two parameters are merged in a colour scheme of two intersecting sequential schemes. Each risk parameter is represented by one hue; the level of lightness represents the risk level, which results in white for the lowest risk and black for the highest risk. Along each of the axes one hue is dominant. The hazard intensity is represented by orange that decreases in lightness, the vulnerability is represented by blue that decreases in lightness. The colours representing a risk with both risk parameters contributing from the proportionate shares of orange and blue of the same level of lightness. This results in a clear ordinal statement for each single risk parameter, but the differences between the risk parameters remain nominal, i.e. there is no statement, whether “low vulnerability” and “high hazard intensity” should be judged higher or lower than “high vulnerability” and “low hazard intensity”. Figure 4.6 shows how such a colour scheme might look. In the colour squares, the values for the RGB system and the Cyan, Magenta, Yellow and Black (CMYK) system are given. Owing to the fact that this deliverable is supposed to be a print-document the colours are based on the CMYK system, i.e. the colours for the RGB system might look slightly different. It is recommended to use the RGB colours for documents on screen and the CMYK colours for printed documents. However, because every printer works slightly different, it is important to check that the printed document looks as expected. Colour values may have to be adjusted for a suitable result.

Figure 4.6  A colour scheme for a two-parametric risk assessment. R, G, B is the values for the RGB system. C,M,Y and K are the variables of the CMYK-system, S represents the value for saturation
The colour scheme in Figure 4.6 uses colours that may be perceived as relatively neutral. Whereas blue and orange work comparably well together in this sense, red and green would lead to a much stronger statement. This concept can be suitable for the regional and local general level. The exact definition and delineation of a phenomenon might work better for the local detailed level or even for a site-specific approach.

An alternative colour scheme for choropleth risk mapping can be based on a colour transition from green to red. This is shown in Figure 4.7. This is suitable, if a stronger highlighting of areas at risk is explicitly wanted. The basic green-red transition is placed diagonally in the matrix, the colours become lighter towards high hazard intensity and low vulnerability and the colours are perceived darker towards high vulnerability and low hazard intensity. However, there are some drawbacks related to this matrix. Saturation of a colour is often used to express uncertainty, i.e. the value represented by a more greyish version of a hue might be perceived as more uncertain. Additionally, the colour yellow is perceived as a very light hue, whereas green is perceived darker (Reference:19). In the matrix presented in this report a lighter yellow follows a darker green with increasing hazard intensity, although the initial perception of the colours on the map would suggest the opposite order. This mismatch can lead to some confusion for areas low vulnerability and low hazard intensity.

Figure 4.7 Another colour scheme for a two-parametric assessment. R, G, B is the values for the RGB system. C,M,Y and K are the variables of the CMYK-system, S represents the value for saturation and B brightness according to CorelDraw terminology.
Nevertheless, both colour schemes work well as can be seen in Figure 4.8. View 1 in Figure 4.8 is the original version of the aggregated risk map from ESPON 1.3.1 project. The maps in Views 2 and 3 have the same database, but the colour schemes presented in Figures 4.6 and 4.7 respectively have been applied.
In addition to the application shown above, the colour schemes are suitable for other parameters that are not comparable directly in quantitative terms but should be shown together. Another possibility would be the mapping of the people and building vulnerability index described in ARMONIA Deliverable 5.1 and 5.2 for a certain hazard (References: 13 and 14). Figure 4.9 shows the use of a dual colour ramp for the Mugello Region and Impruneta and San Miniato municipalities in the upper Arno River basin in Italy to illustrate the landslide risk to buildings. It should be noted that the draft ARMONIA methodology employs a linear scale and as a consequence it is not possible to employ a dual colour ramp.
Figure 4.9 Landslide risk to buildings map for the Mugello Region, San Miniato and Impruneta municipalities in Tuscany, Italy using a dual colour ramp.
4.5 Conclusions

Whilst the dual colour ramps proposed above may be suitable for displaying hazard and vulnerability it can not be used with the method for producing risk maps outlined in WP5.2. The draft ARMONIA methodology detailed in WP5.1 and WP5.2 (References: 13 and 14) produces one single value for risk that can only be displayed on a single colour ramp. The advantage of producing a map using one risk metric is that the risk data behind the map may take continuous values allowing different approaches in data display. However, the dual colour ramp approach requires that the hazard and vulnerability data be in discrete classes, representing a loss of data precision. Another problem with this approach is that the integration of weighted vulnerability scores for different receptors is more difficult. One approach may be to average vulnerability scores for different receptors and then reclassify them on a 1 to 4 scale. The draft ARMONIA methodology produces a measure of risk which is readily manipulated. However, the dual colour ramp displays risk in an intuitive manner which allows the differentiation between hazard and vulnerability so each method has its advantages. The trade off between aggregation of data and loss of detail is again apparent here.
5 Piloting of the draft ARMONIA multi risk assessment methodology in the Arno River basin

5.1 Background to the Arno River basin

Part of the Arno River basin has been used as the pilot area for testing the hazard, vulnerability and risk mapping methodology developed under the ARMONIA project. The Arno River basin is located almost entirely within the Tuscany region of central Italy. The river is 241 km long and drains a catchment with an area of about 8,228 km². The catchment area is located within the mountainous region of the Northern Apennines (Reference:21). The location of the Arno River basin is shown in Figure 5.1. The Arno River basin includes 163 municipalities and has a total of some 2.6 million inhabitants.

The basin falls into the temperate climatic zone with a dry summer. The annual rainfall pattern of the Arno River basin is characterised by a summer minimum in July, and two maxima, one in November and the other at the end of the winter. The average annual precipitation varies with the altitude ranging from 800 mm in the Chiana valley to about 1800 mm on the Apennine ridge. With respect to the annual peak discharges these figures range from 321 m³/s to 2290 m³/s (Reference:21).

One of the key organisations with regards to collecting data on natural hazards for the Arno River basin is the Arno Basin Authority (ARBA). The ARBA is a government body that is responsible for policies on the identification, prevention and mitigation of hydro-geological hazards. The ARBA has collected a wide variety of GIS based data.
5.2 Background to natural hazards in the Arno River basin

The Arno River basin is subject to a number of natural hazards including:

- Floods;
- Landslides;
- Earthquakes;
- Forest fires.

The number of natural hazards that occur was one of the reasons for choosing the Arno River basin to pilot the methods developed as part of the ARMONIA project. A brief background to the various hazards that occur in the Arno River basin is given below.

5.2.1 Flooding

There have been numerous significant flood events in the Arno River Basin. Figure 5.2 shows the occurrence of "high", "medium" and "low" flood events in the past 800 years in the city of Florence. In the last 50 years the two largest flood events in the Arno River basin occurred in 1966 and 1992. Figure 5.3 shows the flood extent for these two events. Figure 5.4 shows some of the damage that was caused by the 1966 flood in Florence.

![Distribution of flood events of the Arno River, ranked by intensity, which caused damage in Florence between the 12th and 20th centuries (Source: Reference 21)](image)
**Figure 5.3** Flood extents in the Arno River basin for the 1966 and 1992 floods (Source: Reference 21)

**Figure 5.4** Photographs of flooding in the city of Florence in 1966 (Source: Reference 21)
5.2.2 Landslides

A landslide hazard map of the entire Arno River basin has been completed as part of the Service for Landslides Monitoring (SLAM) research project funded by the Arno River Basin Authority and by the European Space Agency (Reference:84). Using a variety of data sets the research identified and mapped 28,000 individual landslides, which fell in to the following categories:

- 75% were earth slides earth flows;
- 17% were solifluctions and other shallow slow movements;
- 5% were mud flows (5%);
- Soil slips, and in shallow landslides, were found to be of limited importance within the basin.

5.2.3 Earthquakes

In the Tuscany region there have been two major earthquakes in the past 100 years. These are as follows:

- Mugello earthquake that occurred in 1919 and resulted in some 100 deaths and approximately 400 injured;
- The Lunigiana/Garfagnana earthquake in 1920 that resulted in 171 deaths and approximately 650 people being injured.

Figure 5.5 gives an indication of the relative earthquake hazard for the Arno River basin compared to the rest of Italy.

![Figure 5.5](image)
5.2.4 Forest fires

Areas of Tuscany are affected by forest fires. The most recent statistics available to the project team for forest fires in Tuscany indicated that in the Tuscany Region in 1998 there were:

- 567 fires;
- 3,640 ha of wooded area that was burnt;
- 1,040 of non-wooded area that was burnt;
- Five fires with an area exceeding 100 ha. The average area of these fires was 376 ha.

No forest fire mapping available for Tuscany was readily available to the project team. Forest fire mapping for the Tuscany region was developed by JRC in Ispra. The development of this forest fire mapping for Tuscany is detailed in Chapter 6.

5.3 Boundaries of the pilot areas

Figure 5.6 shows the boundaries of the pilot areas. There were three areas within the Arno River basin where data on natural hazards were provided to the study team. These were:

- The Mugello Region which is located in the north-east corner of the Arno River basin;
- Impruneta, which is a town and comune of the Province of Florence in the Italian region of Tuscany. It is located at 289 m above sea level. The population is about 15,000. The area of the comune is about 28 km²;
- San Miniato is a town and commune in the province of Pisa, in the region of Tuscany, Italy. It covers an area of 102 km² and has a population of some 26,000.

5.4 Availability of data

This section briefly details the data available to the project team.

5.4.1 Natural hazard data

The availability of data to the project team is shown in Figure 5.6. Details of the extent and intensity of natural hazards were available for the Mugello, Impruneta and San Miniato areas. Details of the forest fire hazard were available for the whole of the Arno River Basin.
5.4.2 Receptor data

The following data on receptors (i.e. exposed elements) were made available to the project team:

- Census data were available for most of the Tuscany Region;
- Details of receptors such as buildings, linear infrastructure were available within the boundaries of Mugello, Impruneta and San Miniato.

5.5 Structure of the pilot study

The pilot study was structured as follows:

- JRC produced forest fire hazard, intensity and vulnerability maps for the Arno River Basin. This process is detailed in Chapter 6 of this report;
- HR Wallingford was responsible for implementing the methodology at census level for the whole of Tuscany and also in Mugello, Impruneta and San Miniato. The various findings are detailed in Chapter 7;
- The University of Naples carried out an analysis using the draft ARMONIA methodology of the Mugello region. This is detailed in Chapter 8 of the report.
6 Forest fire hazard and risk in the Arno River basin

This chapter details the work carried out by JRC in Ispra, Italy. The Arno River Basin Authority did not have forest fire probability, intensity or vulnerability mapping available. Forest fire experts at JRC utilised readily available data to produce these. This chapter has been structured as follows:

- Section 6.1 details the production of forest fire probability maps;
- Section 6.2 outlines the process used to map fire behaviour.

6.1 Fire probability

6.1.1 Introduction

Wildfires are the main cause of land and forest degradation particularly in countries adjacent to the Mediterranean. The understanding of the wildfire phenomena and its management lies in the principle of considering wildfires in an integrated approach in which all the phases of fire management must be seen as a unified concept. For technical reasons fire management can be divided in three main phases (Reference:23) as follows:

- Pre-fire planning (fire risk/danger);
- Fire suppression (detection and fighting);
- Post-fire evaluation (fire effects).

Considering these three phases in an integrated manner is fundamental to maximise the returns of government investment into fire suppression and rehabilitation phases. It is important that there is a good knowledge of the area for which the tools and mapping will be developed. This will allow the trends and dynamics of the phenomenon to be investigated and accurate and effective fire hazard and risk prediction/provision methods to be developed. To conclude, the prevention of wild fires should take into consideration a wide range of factors, affecting fire ignition, fire propagation and fire effects.

One of the components of forest fire hazard is the probability of an outbreak of a fire i.e. the ignition probability. The causative factors can be natural and/or human. The fire hazard varies according to two scales:

(i) Spatial scale – local and regional fire hazard

(ii) Temporal scale

The long-term fire risk refers to factors associated with fire ignition or fire propagation such as the following:
• Topography;
• Vegetation structure;
• Human activities;
• Climatic trends.

The above “long-term” indices do not generally change vary rapidly. Hence, these indices are computed before the fire season and provide useful information for the pre-fire planning phase, improving the preparedness for forest fire fighting (Reference:81). In contrast, the “short-term” fire hazard, is related to dynamic agents, such as weather patterns, which in turn influence fuel moisture content and change in relatively short periods of time (Reference:25). The dynamic indices, are focused on determining the probability of forest fire ignition and on the possibility of fires spreading (Reference:81). The short-term fire risk estimation is needed to take up-to-date decisions on fire pre-suppression and suppression activities.

Using these definitions the long-term fire hazard for the pilot area in terms of the “predicted fire occurrence probability” was assessed from a regression of explanatory variables against the “observed fire occurrence probability”. The “fire occurrence probability” is often expressed in terms of the number of fire ignition points per unit area and is called the “density of fire events”. To model fire occurrence, the use of heterogeneous explanatory variables implies the presence of local variations and multivariate relationships among the variables, requiring flexible, unbiased, objective and self-setting models that are structured in a GIS environment.

6.1.2 Problem statement

Until recently the models commonly used to assess forest fire probability have two main limitations:

(i) They require a priori setting of the modelling parameters.
(ii) They are “stationary” regarding spatial relationship changes.

The preliminary setting of the parameters is based on an expert’s knowledge, or on the implementation of a regression analysis where the coefficients represent the weights of the considered predictor variables (References: 4 and 5). Traditional regression models are “stationary”. This means they assume that the relationships between the response variable and the predictor ones are constant, regardless of their geographical location. This assumption is often not true in real world situations (Reference:68). Therefore, scientists are testing models able, not only to consider the several relationships among them, but also to reveal non-additive variable’s behaviour and that yield an understandable output readily available to the final users (Reference:6).

Recently the above limitations have been taken and the users’ requirements scientists have used spatial (Reference:68) and non-spatial (References: 72 and 6) non-parametric prediction models to
investigate the complex relationships among wildfire variables. The main aim was to overcome the assumption of spatial “stationarity” in the relationship among the response variable and the predictors, assumed by the traditional regression techniques. In particular, Reference 6 and 72 highlighted the potential of the Classification and Regression Tree (CART) (Reference:18) technique to identify and express in a relatively simple form non-linear and non-additive relationships among wildfire occurrence variables. These researchers have addressed two main problems. These are:

(i) The regression rules created by the CART analysis produce fire occurrence map in form of a zonal map that does not present a continuous field, as the fire occurrence probability will occur in reality.

(ii) A potential problem that might arise in the use of the CART analysis is that the decision rules do not take into account the values of the neighbouring cells, in other words, they do not consider their spatial relationships.

Recent work attempts to overcome these limitations by testing alternative models, such as Geographically Weighted Regression (GWR) and Multivariate Adaptive Regression Splines (MARS) against CART. These models were applied to Arno River Basin case study using common fire occurrence predictors such as road network, population density, land cover and topographic variables. The objectives was to produce reliable fire risk map in the framework of a multi-risk analysis implementation.

6.1.3 Methodology and dataset

Implementation of the models

To assess the fire occurrence based on predictors variables, tree models were take in to account to identify the following regression rules and/or regression coefficients:

1. Geographically Weighted Regression (GWR) (Reference:49);
2. Classification and Regression Tree (CART) (Reference:18);

From an initial analysis of the models requirements the GWR was discarded owing to its inability to handle discrete variables. The use of dummy variables that are able to transform discrete variables into continuous variables was also considered. However, the large number of classes would have created multiple dummy variables making the model results difficult to interpret and to compare. As a consequence the CART and MARS models were investigated in detail. These models have several advantages including:
The assumptions made in the models are less restrictive; the models are non-parametric and are able to retrieve data distribution from the training dataset. However, they can not be considered pure spatial models such as GWR.

Therefore, the introduction of spatial predictors such as the x and y coordinates are fundamental to provide spatial relationship to the other predictors. On this basis the x and y coordinates will be used as predictors besides the most frequently used fire risk predictor variables.

Background to the CART/MARS theories

The CART model (Reference:18) operates by recursively splitting the data until “ending points”, or “terminal nodes”, are achieved (Reference:86). It begins by analysing all the input variables and determining which binary division of a single predictor variable best reduces deviance in the response variable. The process is repeated for each portion of the data resulting from the first split, continuing until homogeneous terminal nodes are reached in the hierarchical tree. The technique creates a tree that explains substantially all of the deviance in the original data. The CART model returns response average values for a delimited area, giving the typical aspect of a zonal map.

The MARS model is an innovative and flexible tool that automates the building of accurate predictive models for continuous and binary dependent variables. MARS excels at finding optimal variable transformations and interactions that are commonly present in large geodata sets. The main functions are defined in pairs, using “a knot” or value of a variable that identify an inflection point along the range of predictor. When fitting a MARS model the knots are chosen automatically in a forward stepwise manner (Reference:57). The results of a MARS model is a map predicting smoothed response values.

Data sets

Commonly the predictor models enforce the identification of regression rules on regression coefficients based on a response variable against several predictors. For this case study the response variable was based on the fire occurrence recorded in the Italian national fire database during the period 1997 to 2003. The National Forest Service coordinates the activity of the Nucleo Antincendio Boschivi (AIB) units, which are responsible for wildfire control and suppression. Details about each single fire come from the AIB forms, and are collected and processed to compile the national fire database. To verify whether the fire ignition point coordinates correspond to the place where the event really occurred the coordinates are cross validated by comparing them with ancillary data contained in the database (e.g., the municipality, locality, wood name). A preliminary spatial representation of the ignition points was performed to give an
idea of their distribution, to allow the spatial query of the points falling in Arno River basin, and to highlight possible coordinate mistakes.

A “reliability index” (RI) (References: 4 and 5) was attributed to each ignition point using ArcView 3.2 GIS software (Reference: 42). This code was attributed to each fire event classifying it according to three different categories as follows:

- Records with no geographic coordinates and/or no municipality information data;
- Records with geographic coordinates correctly located;
- Records with geographic coordinates incorrectly located.

In the case of records that were incorrectly located, the municipality or other information coming from the complete fire records of events happening in the same area, were used to assign coordinates to the fire event (References: 4 and 5). As a consequence, 1621 ignition points having a reliability of 99.81% were used to build up a fire probability/density fire occurrence map following the technique and the relative calibration procedure described in (Reference: 3). For the Arno River basin case study the fire occurrence was expressed in number of ignition points for square kilometre (ip/km²). The fire occurrence was referred to all the study period (i.e. seven years) and not each year, as often is done, to avoid long decimal numbers.

The predictor variables are listed in Table 6.1. The predictor variables can be associated to two main groups:

(i) Physical;
(ii) Human variables.

Among the former, the choice was down to the availability of the geodata set in the study area. The road network was used to build up two kinds of predictors: road density and road distance. These variables are often used to give information on the accessibility to the forest for fire fighting but also for ignition purposes. The aim was to use both of variables to test which one when combined with the response variable gives information on fire occurrence pattern. The fire occurrence analysis was performed in the “wildland” areas obtained by selecting the land covers prone to wild fires from the CORINE land cover. Wildland may be defined as “land covered mainly by native vegetation and that does not include agricultural, urban, or industrial areas”. A 100 m pixel resolution was available for the whole geodata set. Finally in order to provide information concerning the spatial relationship x and y coordinates were added as predictors. The correlation coefficient (r) was calculated to provide an estimation of the correlation between the predictor and the response and reported in Table 6.2.
Table 6.1 Response and predictor variables used in the fire occurrence model prediction.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Variable type</th>
<th>Variable file-name</th>
<th>Explanation notes</th>
<th>Range From</th>
<th>Range To</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response</td>
<td>Dk³</td>
<td>Ignition point density – adaptive kernel density</td>
<td>0 3.74</td>
<td>ip km²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>CORINE (Code)</td>
<td>Wild land cover by CORINE (CLC90)</td>
<td>422532 39084</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>21</td>
<td>Agriculture land with significant areas of natural vegetation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>22</td>
<td>Agro-forestry areas</td>
<td>32</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>23</td>
<td>Broad-leaved forest</td>
<td>260746</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>24</td>
<td>Coniferous forest</td>
<td>19934</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>25</td>
<td>Mixed forest</td>
<td>762663</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>26</td>
<td>Natural grasslands</td>
<td>1561</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>28</td>
<td>Sclerophyllous vegetation</td>
<td>1799</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>29</td>
<td>Transitional woodland-shrub</td>
<td>22606</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>32</td>
<td>Sparsely vegetated areas</td>
<td>424</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>33</td>
<td>Burnt areas</td>
<td>83</td>
<td>n. of pixels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>ALT</td>
<td>Altitude</td>
<td>0 1651</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>POP</td>
<td>Population distribution by CORINE (CLC90)</td>
<td>0 59.6</td>
<td>Citizen/km²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>ASP_SIN</td>
<td>Sine of aspect</td>
<td>-1 +1</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>ASP_COS</td>
<td>Cosine of aspect</td>
<td>-1 +1</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>SLOPE</td>
<td>Slope</td>
<td>0 46</td>
<td>Degree</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>PARK</td>
<td>Mask with Protected areas limits</td>
<td>0 1</td>
<td>1=park; 0=outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>R1DENS</td>
<td>Continuous grid distance from secondary roads</td>
<td>0 1073</td>
<td>m/km²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>R2DENS</td>
<td>Continuous grid distance from primary roads</td>
<td>205 9</td>
<td>m/km²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>R1DIST</td>
<td>Continuous grid distance from secondary roads</td>
<td>0 2352</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>R2DIST</td>
<td>Continuous grid distance from primary roads</td>
<td>0 3252</td>
<td>m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>Y</td>
<td>Latitude</td>
<td>47.58 48.85</td>
<td>747 247</td>
<td>m UTM</td>
<td></td>
</tr>
<tr>
<td>Predictor</td>
<td>X</td>
<td>Longitude</td>
<td>16.02 17.58</td>
<td>201 401</td>
<td>m UTM</td>
<td></td>
</tr>
</tbody>
</table>

Table 6.2 Correlation Coefficient (r) of each continuous predictors and the response variable.

<table>
<thead>
<tr>
<th>Predictor Variables</th>
<th>Correlation Coefficient (r) against the response variable.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT</td>
<td>-0.076</td>
</tr>
<tr>
<td>POP</td>
<td>0.071</td>
</tr>
<tr>
<td>ASP_SIN</td>
<td>0.002</td>
</tr>
<tr>
<td>ASP_COS</td>
<td>-0.003</td>
</tr>
<tr>
<td>SLOPE</td>
<td>0.116</td>
</tr>
<tr>
<td>R1DENS</td>
<td>0.002</td>
</tr>
<tr>
<td>R2DENS</td>
<td>0.402</td>
</tr>
<tr>
<td>R1DIST</td>
<td>-0.121</td>
</tr>
<tr>
<td>R2DIST</td>
<td>-0.159</td>
</tr>
<tr>
<td>Y</td>
<td>0.284</td>
</tr>
<tr>
<td>X</td>
<td>-0.265</td>
</tr>
</tbody>
</table>
6.1.4 Results

Fire occurrence

The map shown in Figure 6.1 shows the fire ignition density in terms of fire ignition points per km$^2$ in wildland areas. Two main hotspot areas can be identified. The largest one, located in the central north-western part, consists of several peaks ranging from 2.5 to 3.5 ip/km$^2$. The smaller one is situated in the central south-eastern part and has a main peak of 3.74 ip/km$^2$ and smaller ones of 2 ip/km$^2$. In the remaining part of the study area the fire occurrence decreases to values close to 0 ip/km$^2$. The spatial pattern of the fire distribution has the typical behaviour of clustered phenomenon, owing to the persistence of the human induced wildfires. The areas most prone to wildfires are the wildland in contact with agriculture areas and subjected to high levels of fragmentation. The typical spatial pattern of the fire occurrence is quite well known in forest fire literature and is very common in Mediterranean landscape where the human pressure is very high (References: 70, 71, 37 and 3).

![Figure 6.1 Ignition points in the Arno River basin](image)
The CART model

The fire hazard map obtained by the CART model is shown in Figure 6.2. The number of predictor variables, the high heterogeneity of the study area, with respect to the topography and wildland patches, and the strong variability of the fire occurrence map, created a very complex tree with 67 nodes. The rules identified several thresholds unique for each variable and specific for each unit, useful to predict 67 average densities, ranging from 0 to 2.65 ip/km$^2$, smoothing the maximum values (3.74 ip/km$^2$) of the fire occurrence map. The size units range from quite large (47,303 grid cells) to small areas (51 grid cells). Analysing the spatial shape of the resulting units, a squared pattern was detected in some units. This is due to the use of coordinates as predictors. Figure 6.3 shows a graph of the correlation between the fire occurrence and the fire hazard map obtained by the CART model. The straight line distribution is due to the typical output of the regression tree models: average values for unit areas. The correlation coefficient (r) was 0.83.
The MARS model

The final fire hazard map was derived from the implementation of regression coefficients obtained by the MARS model. This is shown in Figure 6.4. A visual interpretation shows that the predicted fire occurrence assumes a smoothed surface compared to the CART model. It reaches a very low maximum value (0.70 ip/km²) and a negative minimum value (-0.66 ip/km²). This underestimation is due to the difficulty in modelling the fire phenomena by means of unique coefficients. Figure 6.5 is a correlation graph between the fire occurrence and the fire hazard map obtained by the MARS model. The graph shows the typical scatter plot of two continuous variables. The extreme values are not very well estimated. The correlation coefficient (r) was 0.56. Figure 6.5 shows that the estimated data are too smooth giving evident homogeneity in the predicted values.
Figure 6.4 Fire hazard map obtained implementing the regression coefficients of the MARS model.

Figure 6.5 Correlation analysis of the fire occurrence against the fire probability obtained by the MARS model.
6.1.5 Conclusion

The CART method delivered fire occurrence maps best able to represent the spatial distribution of the fire phenomena. The maps may be combined with other hazard maps in the view of multi hazard risk analysis.

6.2 Fire behaviour map

6.2.1 Introduction

In the context of fire suppression, the fire behaviour models produce output that can support fire fighters during a single fire event. The fire behaviour is a combination of three main elements:

- Topographic variables;
- Fuel condition in terms of moisture and biomass structure and quantity;
- Weather condition such as wind.

The action plans and the suppression actions are different depending on fire power. The power of a fire can be evaluated based on the flame length which is strongly correlated with the fire line intensity. In this case study a fire behaviour scenario is modelled using FLAMMAP. This fire behaviour mapping and analysis program computes potential fire behaviour characteristics (e.g. spread rate, flame length, fire line intensity,) over an entire landscape for constant weather and fuel moisture conditions.

6.2.2 Dataset

The FLAMMAP behaviour model needs five main thematic layers to be set up. Three of them (altitude, aspect and slope) are topographic variables and they can be extracted from a Digital Elevation Model (DEM). The other two (fuel model and canopy cover) were defined based on one-to-one relationship with the CORINE land cover based on experts’ knowledge. The wind speed and the humidity of the dead fine fuel were set to 10 km/hour and 3%, respectively. These values were calculated based on the weather conditions during the fire events recorded in the study areas.

6.2.3 Results

The flame length and fire line intensity maps are reported in Figure 6.6 and 6.7, respectively. The two maps show the potential intensity or flame length that a common fire event can have. The high intensity fires are concentrated on the steep slopes with coniferous/shrubs wildland. Conversely, the low intensity fires are present in the broad-leaved forest where biomass stratification and high levels of moisture do not allow fast and intense fire propagation.
Figure 6.6 Flame Length map under common weather conditions

Figure 6.7 Fire-Line Intensity map under common weather conditions
6.3 Fire risk map

As detailed in Chapter 2, risk is considered to be a function of the probability of the hazard occurring and the consequences. The consequences are a function of vulnerability and exposure.

In the case of a fire risk scenario the vulnerability and the consequences were identified by the following concept. The ecological response was defined as the combination of erosion potential and regeneration potential. The vulnerability is calculated as the product of the ecology response and the intensity. The resource value is defined by the combination of the quality of the habitat and presence of protection. Finally the consequences are determined by the vulnerability for the exposure. Figure 6.8 provides a flow chart illustrating the method by which the forest fire risk is estimated. Figure 6.9 shows the estimate of the consequences of the given fire intensity. The overall fire risk map was then calculated combining the consequence for probability of having a fire. The fire risk map is shown in Figure 6.10.
Figure 6.8 Flow chart illustrating how forest fire risk is estimated
Figure 6.9 Ecological consequence map for the given fire intensity

Figure 6.10 Fire risk map
7 Implementation of the draft ARMONIA methodology in the Arno River basin

This chapter details the implementation of the draft ARMONIA methodology in the Arno River basin. The background to the draft ARMONIA methodology itself is detailed in Chapter 3. This chapter has been structured as follows:

- Availability of hazard data;
- Development of vulnerability indices;
- Use of the Decision Support System (DSS);
- Production of risk maps for the Arno River basin;
- Issues related to the draft ARMONIA methodology;
- Comparability of mapping;
- Development of coping capacity indices.

7.1 Hazards data available for the case study

This section examines the hazard data available for use in the case study and the manipulation that was required in order for it to be processed using the draft ARMONIA methodology. The hazard data used in the risk analysis were:

- Flood;
- Landslide;
- Forest fire.

The source and format of these hazard data sets are detailed below.

The GIS hazards layers had to be integrated so that each census area was assigned a mean hazard score. This score was then combined with the consequence index of the census area to return a value of risk. The process of integration used was a weighted average based on the proportion of the census area within each hazard zone.

7.1.1 Landslide hazard data

The landslide data used in the pilot study took the form of a raster dataset with each pixel taking an integer value between 1 and 5; with a score of 1 representing minimum hazard. The average landslide hazard was calculated for each census area. This process loses some of the resolution of the hazard data. The map below illustrates this point. However, if the landslide hazard is to be overlaid with vulnerability data which is stored at census level resolution, this generalisation is unavoidable. Other risk methodologies used in the UK and other parts of Europe have used point based receptor and associated vulnerability functions to avoid this aggregation process. However, a very detailed census dataset is required to undertake this process. Figure 7.1 shows an example of the landslide mapping that is available.
Figure 7.1 Comparison of landslide hazard by averaged over census area with the raw landslide hazard
7.1.2 Flood hazard maps

The flood hazard maps took the form of a GIS shape file with four integer hazard classes. This GIS shape file covered the same areal extent as the landslide hazard layer. However, whereas the minimum landslide hazard class was 1, the minimum flood hazard is effectively zero since areas with flood hazard below category 1 were not mapped.

The flood hazard layer needed to be averaged over the census area. The results of this process are shown in Figure 7.2. It is important to note that large census areas that only cross a small portion of the floodplain are assigned a hazard value. For instance the large census area in the north-west corner of Figure 7.2 that is assigned a uniform hazard score when in reality the only hazardous portion of that census area is along the floodplain margin. Figure 7.3 shows the flood hazard mapping that is available at a regional scale.

![Flood hazard map averaged by census area and in its raw form](image)

**Legend**

- Census area boundaries

**Flood hazard class**

- 1 - (low)
- 2
- 3
- 4 - (high)

**Legend**

- none
- >0 - 1 (low)
- 1 - 2
- 2 - 3
- 3 - 4 (high)

*Figure 7.2 Flood hazard map averaged by census area and in its raw form*
Forest fire hazard maps

Forest fire data comprised two layers as follows:

- Forest fire probability of occurrence;
- Forest fire intensity.

The draft ARMONIA methodology requires a single metric for each hazard; hence these layers required integration to give the overall forest fire hazard. This integration accounts for the intensity/probability relationship. The forest fire data was in raster format. The process for integrating the layers was as follows:

1. Data in both layers was reclassified as integer values between 1 and 10 based on an equal class interval basis. This allowed a direct comparison to be made between intensity and probability.
2. The layers were added together giving a combined hazard of between 2 and 20. The addition of these layers implies an equal weighting of probability and intensity. A more rigorous analysis may assume various scenarios such as the probability of forest fire being more important than its intensity.

3. The average hazard in each census area was then calculated by converting the combined hazard layer to a shape file. This was overlaid with the census area shape file that had been clipped to exclude any census areas outside the forest fire data. This clipping is important since if a large census area extends slightly into the forest fire data area, only the portion of that census area overlapping with the data can assume its hazard score.

The census area aggregation process is shown in Figure 7.4. Figures 7.5 and 7.6 show the forest fire hazard data in raster format (i.e. the output from stage 2) and the forest fire hazard by census area (i.e. output from stage 3).

The forest fire risk map does not strictly require aggregation at the census level since it does not use any census data. The receptors are the forest areas and the vulnerability is a function of whether the forest is in a protected area. However, census units have been used in risk mapping so that comparison can be drawn between risk maps.

### 7.2 Vulnerability and consequence indices

The draft ARMONIA methodology uses data from the Italian Istituto Nazionale di Statistica (ISTAT) 2001 (Reference:62) census to calculate the vulnerability and consequence indices for humans and buildings in the Arno River basin. The vulnerability of linear infrastructure such as roads was derived from a GIS road layer for the Mugello Region and the San Miniato and Impruneta communes in the Arno basin. Further information concerning the way in which the vulnerability and consequence indices have been estimated is given Chapter 3.

### 7.3 Census data

A summary of the ISTAT census data is shown in Tables 7.1, 7.2 and 7.3.

These Tables provide the following information:

- Data type;
- Number of categories;
- The number of categories used in the draft ARMONIA methodology.
Probability of occurrence

Intensity

Data range
Min 0.02 Max 3.75

1 2 3 4 5 6 7 8 9 10

Intensity

Data range
Min 21.24 Max 19134.85

1 2 3 4 5 6 7 8 9 10

Data reclassified in 10 classes using equal interval.

Probability of occurrence

Intensity

Figure 7.4 Process used for producing forest fire hazard at a census area level.
Figure 7.5 Forest fire map output from Stage 2

Figure 7.6 Forest fire map output from Stage 3
Table 7.1 provides information on the population data, Table 7.2 provides information on dwellings and Table 7.3 provides information on building construction. The pilot study uses census data from the Tuscany region of Italy, although hazard data was only available to the project team for the Mugello Region and the San Miniato and Impruneta communes. The unit area over which census data is collected varies across the region in an attempt to maintain a constant number of residents in each census area. However, a number of census areas exist with no population or buildings or both. This is either due to no data being collected in that area (if for example it is mapped as a lake) or there are genuinely no people living in the area. Such areas are regarded as having zero vulnerability and hence zero risk, despite potentially high levels of hazard.

<table>
<thead>
<tr>
<th>Data type</th>
<th>Number of categories</th>
<th>Categories used in ARMONIA method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Male</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Status; Married/Single/Divorced etc</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Demographics - all residents in 5 year increments up to 74 years of age</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Demographics – male residents in 5 year increments up to 74 years of age</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Educational status - all residents living &gt;6 years in area</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Educational status - male residents living &gt;6 years in area</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Work force, total employed and unemployed</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Male work force, total employed and unemployed</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Occupation by sector (e.g. agriculture/commercial)</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Occupation by sector (males) (e.g. agriculture/commercial)</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status - Agriculture (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status - Industry (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status - Other (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status (male) (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status – agriculture (male) (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status - Industry (male) (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Occupational status - Other (male) (e.g. employer/employee)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Residents not in the work force</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Residents not in the work force (male)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Status of residents not in work force (retired/student etc.)</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Status of residents not in work force (male) (e.g. retired/student)</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Residents travelling outside the census area on a daily basis</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total number of families</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Number of families of 1, 2, 3, 4, 5, greater than 5 people</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Number of resident foreigners from Europe, Africa, Asia, America, Oceania, other, and total.</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 7.1  Population data available from the ISTAT 2001 Italian census
### 7.4 Data availability

The vulnerability and consequence indices used in the draft ARMONIA methodology require a wide range of census data, especially to assess the indices related to buildings. The lack of a harmonised census data collection system across Europe is likely to hamper efforts at producing pan-European vulnerability and consequence indices. It is important to note that the draft ARMONIA methodology requires building construction materials as an indicator of building vulnerability to landslides, floods, volcanic activity and seismic events. Only a minority of countries listed provide such metadata. However, projects such as Integrated European Census Microdata (IECM) (Reference:43) are underway to attempt a more harmonised approach to census data collection and storage. If all metadata are harmonised in future censuses then the development of vulnerability indices across Europe may be possible.
7.5 The Decision Support System (DSS)

7.5.1 Introduction

The aim of ARMONIA WP5 was to produce a framework and decision support tool structure for risk informed planning, that would help to ensure that planning decisions are fully informed about the multiple risks affecting particular areas of land, the vulnerability of different land uses and population and the options that are available to mitigate the risks (Reference:14).

The purpose of WP5 was not to produce a working DSS, but to undertake the essential conceptual and detailed design work before various elements of the recommended approach were piloted in the Arno River basin. The proposed Multi Risk Land Use Management Support System (MURLUMSS) DSS architecture encompasses the methodology developed in WP5.1 that has been detailed in Chapter 3 of this report.

It is important to recognise that the DSS has the objective of informing decision-making, rather than provide answers to decision problems. The development of the DSS was intended to help ensure that decisions are made on the basis of a sound foundation of information and analysis about hazard, risk and vulnerability and the possible actions that could be taken in order to mitigate and reduce these (Reference:14).

7.5.2 The structure of the Decision Support System

The stages through which the DSS progresses are as follows:

1. Introduction/Logon procedure
2. Map and Scenario selection
3. Hazard analysis
4. Exposed elements analysis
5. Vulnerability analysis
6. Consequence index development
7. Multiple criteria risk evaluation
8. Coping capacity analysis
9. Outputs
10. Output comparisons between scenarios

The Decision Support System takes a consequence index (where consequence = vulnerability x exposure) and average hazard index in each census area and integrates them to produce a risk score between a theoretical minimum of zero and maximum of 1. Figure 7.7 details the steps taken in the DSS to produce a risk score for each census area. The DSS uses only one hazard per risk score but may use an unlimited number of consequence indices. The weighting procedure allows stakeholder participation through the subjective relative valuation of receptors within the risk score.
The risk score is normalised between the theoretical maximum and minimum possible considering a census area under worst case conditions (highest hazard and consequence indices). The minimum theoretical risk depends on whether all the census areas contain receptors (i.e. exposed elements). The dataset used here contains a significant number of census areas without buildings, roads or people, which therefore possess no vulnerability. However, if mapping a small area, all census areas may have vulnerability and will require normalisation against a theoretical minimum risk greater than zero.

It must be noted at this stage that the DSS integrates hazard and consequence in a simple multiplication. Hence, it will accept hazard and consequence values that are not integers. However, the method outlined in WP5.1 produces consequence indices that are integers. This loss of data resolution is unnecessary and the resulting rounding errors can lead to inaccurate total risk values.

### 7.5.3 Multi-criteria analysis in the Decision Support System

The output of the draft ARMONIA methodology and DSS is not an aggregation of risk across different hazards but is presented as the level of risk in relation to each discrete hazard. Decision-makers have to interpret these different levels of risk and formulate their land use management strategies accordingly. Risk analyses within the DSS is carried out through the implementation of a Multiple Criteria Evaluation (MCE) ranking process.

In the ranking process every criterion under consideration is ranked in the order of the decision maker's preference. To generate criterion values for each evaluation unit, the risk for each receptor is weighted according to its estimated significance. In the draft ARMONIA methodology the total weighting score assigned to each risk index must total 20. The higher the weighting factor the more prominence is given to the risk value for the receptor. For example if three receptors (e.g. people, buildings and roads) were being considered the end user may choose to weight the risk factors for each of these as follows:

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Weighting factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>People</td>
<td>12</td>
</tr>
<tr>
<td>Buildings</td>
<td>5</td>
</tr>
<tr>
<td>Roads</td>
<td>3</td>
</tr>
</tbody>
</table>

| Total    | 20              |
7.5.4 Implementation of the draft ARMONIA methodology in the Arno River basin

The draft ARMONIA methodology employed by the conceptual DSS was implemented for all the census areas in the Arno River basin which contained census and hazard data. Of the 2479 census areas covered in the flood and landslide hazard data 2263 were used in the DSS since the remainder did not possess census data. The forest fire data encompassed a larger area, a total of 17,318 census areas, although only 4007 contained forest. Although the conceptual DSS provides a tool for integrating hazard, vulnerability and exposure it is only as precise and accurate as the input hazard and consequence...
indices and the weightings given to each consequence index by end users.

7.6 Risk maps produced for the Arno River Basin

The following section shows flood and landslide risk maps for various parts of the Arno River basin produced using the draft ARMONIA methodology. The risk is displayed in two ways:

(i) **Quantiles** - The dataset is divided on a percentile basis with equal numbers of census areas in each category.

(ii) **Equal intervals** - The DSS returns a risk value between 0 and 1. If these are categorised in equal divisions, for example 5 categories with a 0.2 range the distribution of the data will be maintained and risk hotspots can be identified. However, if the distribution of the data is skewed it is possible that the majority of the data set will fall into one category.

If it is important to note that the impression conveyed by a map is a function not only of reality but of the following:

- Data quality;
- Definition of the variables mapped;
- Class interval (i.e. the grouping of the data);
- Graphic design.

The selection of the class interval is important in determining how the various data is mapped. This is further discussed below.

This section displays risk using equal intervals in order to allow the reader to view the risk metric on the scale intended in the DSS. It must be stressed that both methods have their merits under different circumstances.

7.6.1 Flood risk maps

Views 1, 2 and 3 of Figure 7.8 shows flood risk maps for the Mugello region and Impruneta commune of Tuscany for people, buildings and roads respectively. The inset map is the urban area of Sesto Fiorentino municipality. The maps show the differences in risk value when people, buildings and roads are considered. The different receptors are incorporated in the DSS using the stakeholder subjective weightings. Figure 7.9 shows the combined flood risk for the three receptors. The three risk maps shown in Figure 7.8 have been combined by giving an equal weighting to each of the three receptors.
Figure 7.8  Flood risk for various receptors calculated using the draft ARMONIA methodology
7.6.2 Landslide risk

Views 1, 2 and 3 of Figure 7.10 shows landslide risk maps for the Mugello region and Impruneta commune of Tuscany for people, buildings and roads respectively. It should be noted that due to the different way in which building and people exposure are measured, the maps display quite differently. People exposure is measured as population density whereas the building exposure is the number of buildings within each census area. The risk “hotspots” for landslide risk to people can be seen in small population centres which lie within areas of high hazard. Conversely the areas of highest risk for buildings are in the south of the Mugello region where the census areas with scattered buildings in are located within zones of high hazard. Figure 7.11 shows the combined landslide risk for the three receptors. The three risk maps shown in Figure 7.10 have been combined by giving an equal weighting to each of the three receptors.
Figure 7.10 Landslide risk for various receptors calculated using the draft ARMONIA methodology
7.6.3 What do the ARMONIA risk maps tell end users?

The ARMONIA risk maps shown in Sections 7.6.1 and 7.6.2 above are a product of the consequence and the hazard indices. The development of the risk indices is convoluted and the process by which the data is non-dimensionalised and normalised at the various steps means that the hazard, vulnerability, exposure and consequence metrics lose their units.

The computation of a risk index using a scale of 0 to 1 raises the question of whether risk values are directly comparable, or only comparable in a relative sense. If one census area has a risk value of 0.2 and another 0.4, can the risk in the latter be described as being twice that of the former? Given the various transformations on the data this is unlikely to be the case. This is not necessarily helpful for decision makers who are looking to target mitigation strategies within an area.

The matter of comparability of indices is partly dependent on the ranking method used in the consequence index, if quantile ranking is used risk values are no longer comparable in the context above, if equal intervals are used then risk is more comparable in a relative sense. It is important that a consistent method is adhered to in the use of indices. If a quantile ranking method is used in the construction of indices then displaying the map using quantiles is appropriate whereas if equal intervals are used then equal intervals
are appropriate in the map. It is important to note that owing to the normalisation process risk values for different hazards are not comparable.

The mapping of risk adds another element of complexity to the processes since maps may be displayed quite subjectively. GIS software provides a great deal of flexibility with respect to displaying data sets. Figure 7.12 shows two maps using the same dataset with the risk divided into four categories using equal interval and quartile methods. The map in View 1 shows a very different distribution of the risk to people compared with that in View 2. A complete discussion of the subjectivity surrounding map display may be found in Reference 74.

![Legend](image)

**Legend**

**Landslide risk to people**

**Equal interval division**

- 0 - 0.25
- 0.25 - 0.5
- 0.5 - 0.75
- 0.75 - 1

**View 1**

**Legend**

**Landslide risk to people**

**Quartile divisions**

- 1st
- 2nd
- 3rd
- 4th

- 0 0.5 1 2 km

![View 2](image)

Figure 7.12 Landslide risk to people around the town of Pontassieve, Mugello displayed using equal intervals and quartiles
7.7 Issues with the draft ARMONIA methodology

7.7.1 Vulnerability and consequence indices

The consequence indices used in the draft ARMONIA methodology are based on vulnerability indices and the exposure at census area. In creating the consequence indices a number of normalisation, ranking and classification operations are carried out to integrate the different indicators and to produce a relative scale. The resulting indices take the form of an integer value between 1 and 4. This section details some of the main issues.

7.7.2 Transformation of data

There are a number of issues related to the transformation of skewed data sets that are not dealt with by the draft ARMONIA methodology. These are detailed below in the context of the pilot study for the Arno River basin. Figure 7.13 shows a graph of the population density by census area for Tuscany. The population density distribution is highly skewed. This type of distribution is often known as a "J-distribution". The average population density for Tuscany is 1.94 people/ha. However, the maximum population density is 3,670 people/ha for one census area. This highly skewed distribution can have a significant effect on how data is displayed on the risk maps as detailed below.

![Figure 7.13 Population density distribution for Tuscany](image)
Figure 7.14 shows the distribution of vulnerable people in Tuscany where the vulnerable people are defined as the number of people less than 5 years and older than 65 years of age. It can be seen that this distribution is almost normal.

Figures 7.13 and 7.14 above are combined to give a consequence index. If the population consequence indices produced are divided up on an equal interval basis then it can be seen in Figure 7.15 that 23,000 of the census areas in Tuscany fall into the low consequence category and only 2 fall into the high consequence category. Figure 7.16 shows a graph where the population consequence indices are divided up on a quartile basis. This results in an equal number of census areas falling into each of the four categories. The draft ARMONIA methodology makes no mention with respect to how the data should be categorised and if it should be transformed. If the population consequence index is produced using an equal interval basis then the map shown in Figure 7.17 will be produced. Figure 7.18 shows a map that would be produced if quartiles were used.
Figure 7.15 Consequence category divided up on an equal interval basis

Range of consequence index goes from 0 to 636 people/ha hence dividing into equal intervals of 159 people/ha gives skewed results.

This gives 23,000 census areas in the low consequence category.

2 census areas in the high consequence category.

Consequence category

Number of census areas

Low High

Consequence category

Low High

Range of consequence index goes from 0 to 636 people/ha hence dividing into equal intervals of 159 people/ha gives skewed results.

This gives 23,000 census areas in the low consequence category.

2 census areas in the high consequence category.

Consequence category

Number of census areas

Low High

Consequence category

Low High

Figure 7.16 Consequence category divided up on a quartile basis
Figure 7.17 People consequence index estimated using an equal interval in Borgo San Lorenzo, Mugello

Figure 7.18 People consequence index estimated using quartiles in Borgo San Lorenzo, Mugello
It can be seen from Figures 7.17 and 7.18 that the equal interval approach tells the end user little about the risk because almost all the people consequence indices fall into the low category. Figure 7.18 provides a much better relative indication of the consequences to people and therefore risk. Another approach that could have been taken would be to transform the data. Figure 7.19 shows a graph of the population density for Tuscany when it has been transformed using a natural log function. This gives a much less skewed distribution than Figure 7.13 and would be more useful in terms of the mapping produced for the end user. Transformation has the added advantage that intervals between consequence classes can be the same for any dataset meaning that consequence classes could be comparable across any area in Europe. They also provide a greater degree of transparency.

![Figure 7.19 Population density distribution for Tuscany transformed using a natural log function](image-url)
7.8 Units of exposure

The draft ARMONIA methodology uses the risk model which states;

Risk = Consequence x Hazard

Where:

Consequence = Vulnerability x Exposure

Exposure quantifies the receptors which are present to be acted on by a hazard event. The ARMONIA method takes two very different approaches to quantifying exposure. People exposure is measured as population density whereas building exposure is measured as the number of buildings per census area. The use of density and number of exposed elements produces differing results in the consequence index. Figure 7.20 demonstrates the almost inverse relationship between consequence indices using these methods.

![Figure 7.20 Flood building consequence (quartiles) computed using building number (left) and building density (right) as units of exposure](image-url)
The number of buildings per census area is not related to the size of the census area whereas the building density is. Thus, using building density gives high consequence in small densely packed census areas. Conversely building number gives a more random distribution of consequence.

A worked example is shown in Figure 7.21. The philosophy of most censuses is to have approximately the same number of people and/or residential properties within a census area. The area of the unit used to collect census data will vary considerably between rural and urban areas. As a consequence the density of buildings in a rural census area will be much lower than the density of buildings in an urban census area. As a consequence the number of buildings within census areas is often less variable than their density. A large rural and small urban census area will have different building density, yet have a similar overall number of buildings.

<table>
<thead>
<tr>
<th>Census area A</th>
<th>Urban area</th>
<th>Census area B</th>
<th>Rural area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example building vulnerability = 0.5</td>
<td>Number of buildings = 74</td>
<td>Example building vulnerability = 0.5</td>
<td>Number of buildings = 36</td>
</tr>
<tr>
<td><strong>ARMONIA consequence = 74x0.5 = 37</strong></td>
<td><strong>ARMONIA consequence = 36x0.5 = 18</strong></td>
<td><strong>Alternative consequence = 256.5</strong></td>
<td><strong>Alternative consequence = 4.5</strong></td>
</tr>
<tr>
<td>Area of census unit = 0.14 km²</td>
<td>Building density per km² = 74/0.14 = 513</td>
<td>Area of census unit = 3.97 km²</td>
<td>Building density per km² = 36/3.97 = 9</td>
</tr>
</tbody>
</table>

In this example census area A obtains a higher consequence value than area B when both methods are employed. However the difference in consequence is an order of magnitude larger when the alternative consequence index is used compared to the ARMONIA index. If fewer buildings existed in census area A than B then the index could actually be reversed using the different methods.

*Figure 7.21  Worked examples illustrating how units of exposure dramatically change consequence indices*
7.9 Unit area used for risk mapping

The draft ARMONIA methodology uses census areas as the basic unit area for risk calculation. This resolution is suited to the consequence indices since vulnerability and exposure data are available at a census level. Areas of equal hazard do not generally follow census boundaries and as a consequence, the hazard data must be averaged over each census area to produce a risk map. The problem with this approach is that the spatial distribution of hazard is lost. Figure 7.22 illustrates this point. The right hand map shows the flood risk to people returned using the draft ARMONIA methodology. The left hand map shows the risk returned when instead of aggregating flood hazard into census areas it is intersected with the census areas. This results in a map which gives increased resolution to areas of high risk.
7.10 Spatial extent issues

The final process in creating the consequence indices is to rank the consequence score into four categories. The ranking procedure is subject to the various issues that have been discussed in the sections above. The final ranking is also critical in the cross comparability of vulnerability indices. As detailed in Chapter 3 the various indices that are used in the draft ARMONIA methodology are normalised using the following equation:

\[
\text{IndexVal} = \frac{(\text{ActualVal} - \text{MinVal})}{(\text{MaxVal} - \text{MinVal})}
\]

Where:

- IndexVal is the value of the index
- MinVal is the minimum value of the variable
- MaxVal is the maximum value of the variable

The above equation produces an index that is between 1 and 0. No guidance is given in the draft ARMONIA methodology as to what spatial area the variables should be normalised over. It is important that the limitations of normalisation of data are pointed out to the user as part of the methodology. In the example shown in Figure 7.23 the consequence indices for people have been normalised over two different spatial extents as follows:

- The Mugello area;
- The Tuscany Region.

Figure 7.23 shows the difference in normalising the people consequence over these two areas for the town of Rufina in Mugello. The causes of this difference are illustrated in Figure 3.6. It is interesting to note that a number of census areas are downgraded into lower consequence classes in the map produced using data from the whole of Tuscany relative to the Mugello dataset.
Figure 7.23 People consequence using quartiles, left map is constructed using the Upper Arno dataset, the right map using the whole Tuscany census data.
7.11 Coping capacity

Coping capacity is defined in WP5.1 (Reference:13) by the proportion and importance of strategic facilities, infrastructures and accessibility in a given census area. Each of the three coping metrics is returned in an integer between 1 and 4 in a similar manner to the vulnerability indices. Thus, overall coping capacity may be considered as the sum of these metrics or the components may be considered individually. A brief description of the coping capacity metrics follows;

(i) **Strategic facilities** – The number of emergency facilities weighted according to their importance (micro/meso/macro scale of influence) in the census area divided by the size of the census area. This value is then ranked into four classes.

(ii) **Linear infrastructure** – Infrastructure is not defined but is assumed to refer to linear networks such as the road network, water network and gas network. The metric is the length of infrastructure weighted according to its importance (micro/meso/macro scale of influence) in the census area divided by the size of the census area. This value is then ranked into four classes.

(iii) **Accessibility** – Number of road entries into the census area weighted by the importance of the road (micro/meso/macro scale of influence) in the census area divided by the size of the census area. This value is then ranked into four classes.

With respect to the coping capacity the following two points are important:

(i) Owing to the fact that the coping capacity is calculated on a census area basis no account of the sphere of influence of large emergency facilities is taken into account in the method. For example those census areas immediately surrounding a large hospital will not have their coping capacity influenced by it. This problem could be rectified by using distance weighting rather than a simple intersection process in the GIS. The calculation of coping capacity at local scale will suffer from this affect more than if the unit areas are aggregated over larger areas, although this is no justification for not using a relatively simple distance weighting procedure.

(ii) The coping capacity assumes those areas which contain a greater density of emergency facilities, networks and accesses will cope more readily than those without. However, this view neglects the potential damage to such infrastructure during a hazard event. Damage to infrastructure may render an area which would otherwise readily cope with disaster helpless to it. A more detailed analysis should include the likelihood of damage to infrastructure in the measurement of coping
capacity. This may aid in the scenario analysis in the DSS as different infrastructure damage scenarios may be explored.

An example map of coping capacity using only proximity to roads and hospitals is shown in Figure 7.24.

The advantages of mapping coping capacity separately from risk become apparent when the spheres of influence of coping units are considered. Each municipality contains a range of road proximity zones which would be averaged, losing their resolution, if mapped at administrative units. The disadvantage of mapping coping capacity for this relatively small area is apparent in edge effects. Any roads or hospitals outside the map extent will have no influence on the map area. A correct coping capacity map will be constructed using data from a larger area than the map display area to allow buffers to operate into the map extent.
8 Application of the draft ARMONIA methodology to the Mugello Region of Tuscany

8.1 Introduction

The Mugello Region of Tuscany has been used to test the draft ARMONIA methodology and to provide an example of how it may be used to inform decisions within a spatial planning context. In this case study Corine Land Cover maps were used to compute exposure, vulnerability and hazard. The coping capacity of the Mugello Region was computed at municipality level. Corine Land Cover (CLC) is a map of the European environmental landscape intended for use by policy makers as well as others. Based on interpretation of satellite images, CLC provides comparable digital maps of land cover for each country for much of Europe. This is useful for environmental analysis and comparisons as well as for policy making and assessment.

8.2 The case study area

The Mugello region consists of 21 municipalities and was selected as representing a range of natural hazards and as having a readily available dataset. The population in the region was estimated to be some 191,000 in the 2001 Italian census. The Mugello region consists largely of the upper and central catchment of the Sieve River, which is a tributary of the Arno River. The region is bordered by mountains and contains three towns, Pontassieve, Borgo san Lorenzo and Barbarino di Mugello. The case study area is shown in Figure 8.1.
8.3 Mapping units

This section details the mapping units that were used in the Mugello Region. The Corine land cover map was used to aggregate areas by land use for mapping hazards, exposure and vulnerability. This meant that rather than displaying the vulnerability class for each census area within a town the entire town would be assigned a median vulnerability class. Figure 8.2 shows an example of two areas in the Mugello Region. The census units are delineated by yellow boundaries. The urban areas that are taken from the Corine Land Cover maps are delineated using red lines.

The coping capacity was calculated at the municipality level as detailed in WP5.1 (Reference:13). Four dimensions of coping capacity have been mapped:

- The presence of strategic emergency equipment;
- Road network;
- Rail network;
- The accessibility by road and accessibility by rail.

![Figure 8.2 Example of the Corine land cover mapping for two areas in the Mugello Region](image)
8.4 Data used

This section details the data that is available in terms of hazard and the exposed elements.

8.4.1 Hazard mapping

The following hazard data sourced from the Arno River Basin Authority (ARBA):

- Landslide maps at 1:10,000 and 1:25,000 scale;
- Flood hazard maps at 1:10,000 and 1:25,000 scale;
- Seismic hazard maps at a variety of scales.

An example of the hazard mapping available is shown in Figure 8.3.

Figure 8.3 Example of hazard mapping for the Mugello Region

8.4.2 Exposed elements (receivers)

Exposed element (i.e. receptors) data were available in three GIS formats as follows:

- Population, buildings, natural, agricultural areas and other land uses were available as polygons;
- Road, rail and electrical networks were available as lines;
• Information on emergency facilities, such as hospitals and fire stations, monuments and hazardous industries were available as geo-referenced points.

An example of the elements exposed to earthquakes is shown in Figure 8.4.

![Figure 8.4 Example of the exposed elements in the Mugello Region](image)

8.4.3 Vulnerability indicators

Vulnerability of the exposed elements (i.e. the receptors) was computed using data from the 2001 Italian census. The following data was used:

• Census unit area;
• Population and age classes (under 5 years and over 65 years);
• Number of buildings;
• Number of masonry buildings;
• Building age (before 1919; between 1920 and 1945; between 1946 and 1960, between 1961 and 1971; between 1972 and 1981; after 1981);
• Building height (up to 2 storeys, over 2 storeys);
• Sanitary and other fittings (e.g. drinking water, heating).
Vulnerability is computed using the methods in Chapter 3. Human vulnerability is based on age and is not hazard specific while building vulnerability is based on a variety of indicators and is hazard specific. Many indicators are from pioneering studies (eg Reference:55) or have been proposed for the first time in the ARMONIA project. Few, except the seismic vulnerability indices for buildings (Reference:73) have been tested in real situations.

Rather than mapping hazard, exposure and vulnerability at census area resolution mapping was undertaken at Corine Land Cover unit resolution. The following land uses were extracted from the Corine Land Cover unit in order to map:

- Urban fabric;
- Arable lands;
- Forest;
- Permanent crops;

It should be noted that there is no guidance in the draft ARMONIA methodology as to how to aggregate data up from a census area level resolution to a Corine Land Cover resolution.

### 8.5 Exposure, vulnerability and consequence indices

The vulnerability of the exposed elements (i.e. receptors) has been evaluated taking into account the following components:

- Physical vulnerability, related to building vulnerability to each hazard;
- Vulnerability of population with respect to their age.

Parameters and indices have been provided in WP5.1 (Reference:13) to assess the hazard specific building vulnerability and the population vulnerability. The procedure aimed at assessing vulnerability of exposed elements at regional scale requires data and information generally provided with respect to census units. However, at a regional scale, vulnerability indices cannot be represented at census unit resolution; instead they are aggregated with respect to the different land uses within a municipality.

For each hazard that has been considered the consequence related to the exposed elements (i.e. the receptors) has been expressed through an index that has been ranked in four classes. This consequence index has been obtained by the product of the exposure index (population density and building number) and the vulnerability index which is variable between 0 and 1. Figure 8.5 shows an example of the various indices computed for people for earthquakes.
Figure 8.5 Example of the people vulnerability and consequence indices for earthquakes in the Mugello Region
The census area consequence classes are expressed as integers between 1 and 4. These census area scores were aggregated into Corine land use classes by taking the median value in each Corine based area.

Networks such as roads, railways and pipelines been weighted based on importance. The exposure of the networks is defined as the length of any given network section multiplied by its importance and then ranked into four classes to give a consequence index.

Flooding and landslide hazard was overlaid with the monument point data to give a measure of their exposure. Seismic hazard affects all exposed point elements equally. Seventeen of the 83 monuments are located in flood prone areas, with 2 in very high flood hazard areas. Twelve of the 83 are located in category 2 landslide areas and 1 in category 3 landslide area. All monuments fall into the class 2 seismic zone which dominates Mugello.

### 8.6 Coping capacity

The coping capacity may be defined as the level of resources and the manner in which people or organisations use these resources and abilities to face the adverse consequences of a disaster. Coping capacity is often broken down into:

- Individual coping capacity;
- Institutional coping capacity.

It should be noted that in the draft ARMONIA methodology the transport network and location of emergency facilities is used as a proxy indicator of the coping capacity of the region. However, the coping capacity of a region is related to a number of parameters as detailed in Table 8.1.

A coping capacity assessment at regional scale has been carried out. The objective was to evaluate the level of strategic emergency equipment of different spatial units (i.e. municipalities) for coping with an emergency following a natural hazard and the accessibility to each municipality. Data and information for coping capacity assessment have been represented at municipal level. Figure 8.6 shows an example of a coping capacity map that has been produced for the Mugello Region.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Reason for indicator</th>
<th>Potential indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livelihood security</td>
<td>Ability to absorb losses through an assured supply of employment or other strategies.</td>
<td>Wealth, income security</td>
</tr>
<tr>
<td>Access to crisis support – formal and informal.</td>
<td>Rich or poor, crises demand support from kin, the state or insurance. Much work especially in social capital suggests that active networks are key. Must be visible to be noticed.</td>
<td>Welfare access, insurance coverage, health and emergency service coverage and quality. Household structure. Personal networks. Visibility.</td>
</tr>
<tr>
<td>Housing quality</td>
<td>Housing can protect us from most hazards, provides identity and well-being.</td>
<td>House age, condition, insurance, locally appropriate (eg raised)</td>
</tr>
<tr>
<td>Self assessment of resilience.</td>
<td>Psychological state, strong coping ability, and awareness of personal networks, are important factors enhancing resilience. Even if these factors could be measured externally, it is likely that the most useful assessment is internal.</td>
<td>Interviews, well-being indicators. Strength of informal ties and life skills</td>
</tr>
<tr>
<td>Local economic security. Business &amp; service continuity management</td>
<td>May indicate marginal economic status. But welfare income is independent of commercial continuity.</td>
<td>% of significant local businesses with continuity planning in place.</td>
</tr>
</tbody>
</table>

*Table 8.1 Possible indicators of coping capacity*
8.6.1 Coping capacity related to the road and rail infrastructure

The coping capacity for road and rail is defined as the density of road and rail network in each municipality, weighted according to the importance of the networks. This is detailed in Chapter 3.

Coping capacity (for either road or rail) (Ip1 or 2) = ($\sum Wi*Ri$)/$Sa$

Where $Wi$ = the weight of the network (1 to 3)
$Ri$ = the length of each weight of network
$Sa$ = the area of the municipality

Total coping capacity (Ip) is the sum of the coping capacities for the networks under consideration. Figure 8.7 gives an example of the network infrastructure coping capacity based on the road and railway network infrastructure density.
Figure 8.7 Coping capacity based on the road and railway network infrastructure density for the Mugello Region

The Ip values are listed in Table 8.2. The Ip values show a medium-high road infrastructure density in the area that extends southwards from Florence to Barberino di Mugello, due to the presence of the highway and railway Florence-Bologna on medium size territories. This area includes, in addition to Barberino di Mugello, the municipalities of Fiesole, Pelago, Vernio, Calenzano, Vaiano, Vaglia, Borgo San Lorenzo and San Piero a Sieve. Low values of network infrastructure density have been obtained for the municipalities of Cantagallo, Vicchio, Dicomano and Pontassieve. These have very few transport networks crossing their territory. These municipalities are characterised by a low coping capacity during the emergency phase in terms of rescue teams.
<table>
<thead>
<tr>
<th>Name of area</th>
<th>Coping capacity Ip1</th>
<th>Coping capacity Ip2</th>
<th>Total coping capacity Ip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiesole</td>
<td>10,507</td>
<td>5,885</td>
<td>16,392</td>
</tr>
<tr>
<td>Rufina</td>
<td>7,619</td>
<td>4,224</td>
<td>11,843</td>
</tr>
<tr>
<td>Pelago</td>
<td>9,346</td>
<td>2,372</td>
<td>11,718</td>
</tr>
<tr>
<td>Vernio</td>
<td>6,182</td>
<td>4,839</td>
<td>11,021</td>
</tr>
<tr>
<td>Calenzano</td>
<td>9,992</td>
<td>999</td>
<td>10,991</td>
</tr>
<tr>
<td>Vaiano</td>
<td>4,053</td>
<td>6,146</td>
<td>10,199</td>
</tr>
<tr>
<td>Vaglia</td>
<td>7,439</td>
<td>2,625</td>
<td>10,064</td>
</tr>
<tr>
<td>Barberino di Mugello</td>
<td>9,915</td>
<td>0</td>
<td>9,915</td>
</tr>
<tr>
<td>Borgo San Lorenzo</td>
<td>6,964</td>
<td>2,559</td>
<td>9,523</td>
</tr>
<tr>
<td>San Piero a Sieve</td>
<td>5,819</td>
<td>3,133</td>
<td>8,952</td>
</tr>
<tr>
<td>Pratovecchio</td>
<td>8,184</td>
<td>483</td>
<td>8,667</td>
</tr>
<tr>
<td>Sesto Fiorentino</td>
<td>4,345</td>
<td>4,149</td>
<td>8,494</td>
</tr>
<tr>
<td>Montemignaio</td>
<td>6,998</td>
<td>0</td>
<td>6,998</td>
</tr>
<tr>
<td>Stia</td>
<td>5,974</td>
<td>56</td>
<td>6,030</td>
</tr>
<tr>
<td>Scarperia</td>
<td>5,563</td>
<td>358</td>
<td>5,921</td>
</tr>
<tr>
<td>Londa</td>
<td>5,659</td>
<td>0</td>
<td>5,659</td>
</tr>
<tr>
<td>Dicomano</td>
<td>3,867</td>
<td>1,699</td>
<td>5,566</td>
</tr>
<tr>
<td>San Godenzo</td>
<td>5,049</td>
<td>0</td>
<td>5,049</td>
</tr>
<tr>
<td>Vicchio</td>
<td>2,098</td>
<td>2,297</td>
<td>4,395</td>
</tr>
<tr>
<td>Pontassieve</td>
<td>1,934</td>
<td>1,750</td>
<td>3,684</td>
</tr>
<tr>
<td>Cantagallo</td>
<td>1,810</td>
<td>1,533</td>
<td>3,343</td>
</tr>
</tbody>
</table>

Table 8.2  Coping capacity using the transport infrastructure as a proxy indicator

### 8.6.2 Accessibility

The accessibility is defined as the number of road intersections with the municipality boundaries, where roads are weighted according to their importance as described above. In the case of highways, the number of exit junctions per municipality was used rather than intersections since this more closely represents the actual accessibility. Where a road followed municipality boundaries, each municipality was assigned one intersection.

The results were deemed unsatisfactory since the presence of a network of small regional roads skewed the output against those municipalities with highway access. An improved method, using the distance from the nearest highway exit was used. This method measured the minimum distance from the nearest highway exit to urban centres across the Mugello Region. These weighted distances were then averaged to give the mean accessibility of that municipality and normalised to a value between 0 and 1. The minimum distance was measured for 52 urban areas.

Figure 8.8 shows the declining accessibility score as distance from the main highway route increases. This method does have the
disadvantage that highways outside the map extent are not included in the scoring. For small areas such as Mugello these edge effects may be significant as the municipalities in the east are almost the entire width of the map away from a highway.

Railway accessibility is defined more simply. A municipality receives a value of 2 if it possesses a railway station, 1 if a railway crosses its territory and 0 if neither is true. It must be noted that Rufina possesses two railway stations. Although a railway passing through an area is less convenient for managing a disaster struck area it must be considered preferable to the absence of a railway altogether.

8.6.3 Emergency equipment

The emergency equipment score for each municipality was defined as the number of emergency facilities in a municipality multiplied by their respective weights. The weighting used for these facilities are in Table 8.3.

<table>
<thead>
<tr>
<th>Emergency service</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital with first aid unit</td>
<td>3</td>
</tr>
<tr>
<td>Civil protection facility</td>
<td>3</td>
</tr>
<tr>
<td>Fire station</td>
<td>3</td>
</tr>
<tr>
<td>Voluntary emergency centre</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 8.3 Scoring assigned to different types of emergency facilities

By summing up the scores of the emergency facilities in each municipality within the case-study area, an emergency facilities index (Iem) has been calculated. The total of the Iem values was subdivided into 4 classes (Low, Medium, High, Very High) by means of the threshold values 0, 2 and 4. Municipalities without any emergency equipment fall into the low class; those municipalities including one centre of voluntary services or civil protection facility are classified as medium class; municipalities with an Iem between 3 and 4 are classified as high because of the presence of one facility with a high score or two voluntary centres. Municipalities with Iem exceeding 4 (very high) are those where at least two equipments, one of them with a high score, are located.
8.7 Case study in a land use planning context

The following section shows potential outputs from the draft ARMONIA methodology and DSS that could use to help inform future planning. It should be noted that the DSS risk values have not been incorporated into the various tables that have been presented. The guidance represents expert opinion which would be gathered during decision making processes.

Two types of table are proposed:

(i) **A coping capacity table (Table 8.4)**
A coping capacity table would illustrate how a given municipality could cope with natural hazards both in term of its coping elements and relative to the other municipalities in the surrounding area. The table also indicates how the coping capacity fits into provincial strategic planning.

(ii) **Land use table (Table 8.5 and 8.6)**
The land use table outlines hazard, vulnerability and exposure characteristics of a given land use within a municipality. In this example a table has been generated for the urban area of Sesto Fiorentino and another for the arable land use.

Sample tables are presented on the following pages with descriptions of the various elements making up the table.
Example of the land use planning table for the coping capacity of Sesto Fiorentino

The table highlights the high degree of accessibility to the municipality and its proximity to Florence where many strategic emergency centres are located. It should be noted that planning forecasts, related to the new university campus and new developments could influence current accessibility. Moreover, attention has to be paid to the presence of three hazardous installations which require new fire stations that would be needed to deal with possible simultaneous Na-Tech events.

Table 8.4 Example land use planning table based on the coping capacity of Sesto Fiorentino
Example of the land use planning table for the urban area of Sesto Fiorentino

General information for the identification of the land use (type, municipality, short description) with aerial photo or cartography and some photos of the considered land use.

Short description of the planning forecasts at provincial scale (the most appropriate one for the case-study area) and highlights the potential “impact” of land use option (in terms of conservation or transformation) on hazard, vulnerability and coping capacity.

Short description of the coping capacity of the Municipality which the considered land use belongs to, with a link to the coping capacity table of the Municipality.

Guide-lines for general or specify planning forecasts.

This provides a synthesis of the hazard conditions within the considered land use and of the exposure and vulnerability features. In case of conserving the current land use, the table provides a matrix in which maps of the different hazard levels (earthquake, floods, landslides), the exposure, vulnerability and synthetic index calculated with reference to the census units and the synthetic index (vulnerability of exposed elements) are shown. In the case of current land use the table provides information about hazard levels of the land use, current and future exposure, current and future vulnerability. At regional or provincial scale, information about future exposure and vulnerability can be just provided in a qualitative way. Quantitative parameters detailing planning forecasts are not generally provided by regional and provincial planning tools. The last column provides the level of compatibility between planning choices and characteristics of hazard, exposure and vulnerability of the land use. The last row is referred to a brief qualitative description of multi-hazard and Na-tech events which could occur near or within the considered land use area.

Table 8.5 Example land use planning table based on the urban area of Sesto Fiorentino
These tables indicate the need for conservation of land use in Sesto Fiorentino and need for mitigation measures for flood and landslide to the north of the urban area. The arable land use table provides some useful information to planners given that it is being considered for development of a university campus. The table highlights the flood hazard on the site and the potential for secondary hazards due to nearby hazardous installations.
8.8 Conclusions

The following conclusions can be drawn from the work carried out:

- Accessibility in terms of the transport network, the transport network itself and the number of emergency facilities have been used as a proxy for coping capacity. The coping capacity of an area is dependent on a number of socio-economic variables. It is questionable as to whether the number of emergency facilities and indicators related to the transport network truly reflect the coping capacity of an area;
- No rationale is given as to whether it is statistically acceptable to aggregate indicators from a census level to a regional level using the median value;
- The pilot testing was carried out at regional scale. As a consequence the vulnerability and consequence indices are displayed at land use level rather than at census unit level despite being calculated at census unit level. While land use scale vulnerability may be useful for large map areas the census unit vulnerability layer may be included in the tables to provide a detailed inter-land use resolution of hazard and vulnerability hotspots.
- Changes to the coping capacity units defined in WPS are proposed here as the accessibility index was found to be unrepresentative of real conditions. The new accessibility index involves the computation of the minimum distance from highway exit to the urban centres of the municipality.
9 Impacts of climate change in the Arno River basin

9.1 Introduction

This chapter examines the impacts of climate change in Tuscany on the following:

- Sea level rise;
- Temperature;
- Precipitation.

Two emission scenarios were utilised as “forcings” in the climate change models. All predictions were run up to 2100 which is the timeframe for the carbon dioxide (CO₂) emissions scenarios used.

Sea level rise was assessed using the CLIMBER-2 model developed by the Potsdam Climate Institute (PIK). Alongside sea level rise the model computed the floodplain area and the number of floodplain residents at 20 year time slices. Temperature and precipitation predictions were developed using the HadCM3 model data downscaled from 0.5°x0.5° to 10’x10’ resolution. Climate predictions are presented for two contrasting intervals, 2001 and 2099.

The findings indicate that Tuscany will suffer hotter summers and to a lesser extent winters. Summer precipitation will generally decrease while winter precipitation is more spatially variable in its changes, some areas decrease and others increase. Overall available water resources will decrease, exacerbated by higher evapotranspiration. Intense rain events may also be more likely in the future.

The assumption of stationarity in long term datasets for design and decision making is no longer applicable and records must be analysed for trends.

9.2 Underlying Special Report on Emission Scenarios (SRES) storylines and basic assumptions

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (Reference:61) (SRES) storylines were used as “forcing” for Global Climate Model (GCM) model runs of climate change scenarios in the Arno River basin. These were published in 2000 by the IPCC as the basis for the Third Assessment Report. These are often referred to as IPCC-SRES scenarios (References: 59, 60 and 77). The SRES scenarios were developed between 1996 and 1999 and were constructed to explore future developments in the global environment with special reference to the
production of greenhouse gases and aerosol precursor emissions. They are based on the following three essentials:

(i) **Storyline** A narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.

(ii) **Scenario** Projections of a potential future, based on a clear logic and a quantified storyline.

(iii) **Scenario family** One or more scenarios (A1, B2, etc.) that have the same demographic, socio-political, economic and technological storyline.

The SRES team defined four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the twenty-first century for large world regions and globally. These are shown in Figure 9.1. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. These storylines are potential and consistent “futures” of our world. The A1 family is additionally separated into subfamilies referring to energy technologies, i.e. A1FI: fossil intensive, A1T: predominantly non-fossil fuel and A1B: balanced. The A1 and the A2 scenario family is used as the basis for the examinations presented in this report.

![Figure 9.1: The four IPCC SRES families](image)

The four IPCC SRES families have been checked for consistency, but they are also uncertain to some extent, since no one can provide exact prognoses for the economic and demographic development of humankind for the next 100 years. Hence, it is also difficult to estimate exact emission trajectories for the next 100 years as well.
This is the reason why the IPCC provides upper and lower bounds for temperature scenarios. For the examination of impacts on the Arno River Basin and the coast of Tuscany the A1FI and the A2 storylines were used as forcing.

### 9.3 Sea level rise scenarios for the coast of Tuscany, Italy

Potsdam Climate Institute’s (PIK) climate model of intermediate complexity CLIMBER–2 (Reference:51) was used to translate the SRES emission scenarios shown in Figure 9.1 into a corresponding set of atmospheric carbon dioxide (CO₂) concentration scenarios and associated temperature changes. It was also used for the calculation of sea-level rise scenarios until 2100. A set of four (A1FI/high/low and A2/high/low SLR) scenarios were calculated using the Dynamic Interactive Vulnerability Assessment (DIVA) tool (Reference:38) for some provinces in Italy. The following variables were calculated:

- The relative sea-level rise in centimetres comprising human induced climate change and land uplift/submergence due to glacial isostatic adjustments;
- The coastal flood plain area (km²). This considered the area below the level of a flood with a 1 in 1,000 year return level assuming no coastal flood defences are in place;
- The average number of people flooded per year allowing for the effect of flood protection buildings;
- People in a flood hazard zone. This correspond to the number of people living below the level of a flood with a 1 in 1.000 year return level.

The effects on of the four scenarios are shown in Table 9.1. The results show that for the simulated scenario a consistent sea-level rise will occur at least until 2100. This is shown in Figures 9.2 and 9.3. The floodplain areas as well as the number of people living in these areas will also increase in the future. This is true even when it is assumed that the low sea-level rise scenario occurs.
<table>
<thead>
<tr>
<th>Year</th>
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Table 9.1 Coastal threats in the Tuscany Region

Figure 9.2 Sea-level rise [m] for the A1FI scenario and for some Italian provinces; upper panel: high scenario, lower panel.

Note: The yellow graph for Tuscany is hidden by the Abruzzi and Lazio graphs.
These results show that the coast of Tuscany is threatened by impacts (SLR) of human-induced climate change. Considering the number of people living in the hazardous zone it might be necessary in the future to relocate coastal buildings, at least in the low-lying coastal regions. This is a distinct possibility because recent climate change results indicate that the level of sea-level rise could be possibly underestimated (References: 79 and 22).

9.4 Climate change scenarios for the Arno River basin

The climate change scenarios presented here were calculated by the HadCM3 climate model. These data are publicly available via the IPCC Data Distribution Centre (Reference:58) or via the Climatic Research Unit (CRU) (Reference:26). The results were subsequently downscaled from 0.5°x0.5° to 10’x10’ resolution. They have already been used by an assessment of ecosystem services for Europe (see Reference:83). In principle it is possible to use other model outcomes, but the resources in the ARMONIA project were limited. The latter holds also for the decision to use only A1FI and A2 as forcing scenarios. Although desirable there are currently no obvious signs that humankind will change the basis of energy production. Thus on the current level one can state that A1FI and A2 are probable developments for the twenty first century.

It should also be noted that a comparison of different models showed that they differ, most notably, with respect to a small regional scale, although they all agree on a considerable increase in the average European temperature. Regarding planning issues; decision makers often demand exact values for example on temperature rise or development of precipitation. This, in principle, has limitations. Whilst an extreme event e.g. a river or sea flood is a singular “weather” event, climate scenarios considers the long-term (i.e. 30 year average of weather) development. In this respect it is difficult, for instance, to refer to the future occurrence and intensity of, for instance, river runoff levels. Thus, the scenarios presented in the
following are only temperature and precipitation trends for the region of Tuscany, Italy.

### 9.4.1 The temperature and precipitation prognoses for scenario A1FI

For the A1FI scenario and for the summer season (i.e. June, July, August) the Arno River basin faces a considerably warming which ranges for the most regions (comparison 2001/2099) between 11°C to 12°C (monthly average). This is a very large rise, especially considering that in this case also the evapotranspiration will increase. These are shown in the three views in Figure 9.4.

![View 1](image1.png)  
**View 1** June, July, August mean temperature for 2001

![View 2](image2.png)  
**View 2** June, July, August mean temperature for 2099
View 3 Difference between 2001 and 2099 for June, July, August mean temperature

Figure 9.4 Seasonal summer average temperatures for the Arno River Basin for the A1FI scenario HadCM3

Comparing these values with the winter season (i.e. December, January, February) indicates a winter temperature rise of between 5°C and 6°C. Consequently, the annual means the Tuscany region will face a temperature increase between 6.5 to 7.5°C if the A1FI scenario is realised. The average winter temperatures are shown in Figure 9.5.

View 1 December, January, February mean temperature for 2001
View 2  December, January, February mean temperature for 2099

View 3  Difference between 2001 and 2099 for December, January, February mean temperature

Having these values in mind the assessment of the future precipitation will be essential. Comparing the annual precipitation, shown in the views in Figure 9.6, indicated that for most regions a reduction of the total precipitation of at least 200mm/year could occur. In some regions this reduction is even larger, while in other regions a small increase in precipitation is predicted (i.e. the Umbrian Apennines). These changes are in particular important in the regions of the Tuscan Apennines where several tributaries of the Arno River...
have their origin. Here the annual sum of precipitation may have decreased up 400 mm to 600 mm per year by 2100.

View 1  Annual precipitation for 2001

View 2  Annual precipitation for 2099
This might increase the threat of water scarcity in the future, especially if we are considering increasing evapotranspiration. If the seasonal developments are analysed, especially the summer season, the results show that the average precipitation during the summer months will decrease in the northern part of the region (e.g. Tuscan Apennines), shown in the views in Figure 9.7 and could slightly increase in the southern parts of the area of examination (e.g. the Umbrian mountains), while the changes in the coastal areas are smaller than in the other areas.
Focusing on winter it can be seen that an increase of up to 100 mm per month can occur but mainly in the western coastal regions and southern parts (i.e. the Umbrian mountains). This is shown in the three views in Figure 9.8. The central regions and the eastern coast remain unchanged or will face a slight decrease of precipitation in winter.
View 1  Sum of the December, January, February precipitation in the Arno catchment for 2001

View 2  Sum of the December, January, February precipitation in the Arno catchment for 2099
9.4.2 The temperature and precipitation prognoses for A2

Focusing on the A2 scenario the increase of the temperature is lower than for the A1FI scenario but still high if one considers the IPCC range for the global mean temperature (1.4 °C to 5.8°C). Considering the annual means this amounts to less than 6°C for the whole Arno River basin. The regional differences are smaller than 0.5°C. The views in Figure 9.9 show the seasonal summer monthly average temperature for the months of June, July and August temperatures for the Arno River basin using the A2 scenario HadCM3.
View 1  June, July, August mean temperature for 2001

View 2  June, July, August mean temperature for 2099
Comparing the annual and seasonal predicted temperatures; in summer the differences are larger than in winter. During the summer season a 9°C to 10°C increase is predicted in some regions. This is shown in Figure 9.9. For the winter season the differences ranges between a 3.5 °C to 4.5°C increase. This is shown in Figure 9.10. In winter the smallest temperature increase will be observed at the coast between La Spezia and Livorno. Figure 9.11 shows the change in the mean annual precipitation for the A2 climate change scenario for the Arno River Basin.
**View 1**  
Average seasonal winter (December, January, February) temperatures for the Arno catchment for 2001

**View 2**  
Average seasonal winter (December, January, February) temperatures for the Arno catchment for 2099
**View 3**  
**Difference between the average seasonal winter (December, January, February) temperatures for the Arno catchment for 2001 and 2099**

*Figure 9.10 Average seasonal winter (December, January, February) temperatures for the Arno catchment for the A2 scenario HadCM3*

**View 1**  
**Annual precipitation for 2001**
Comparing the annual differences to the A1FI scenario the number of regions where there is a large decrease is slightly less. The same is true for the summer and winter season. This is illustrated by Figures 9.12 to 9.13. The decreases in summer precipitation occur mainly in the highlands (i.e. the Apennines and south-west) in a similar manner to the A1F1 scenario.
View 1  Seasonal sum of precipitation for the summer season (June, July, August) for 2001

View 2  Seasonal sum of precipitation for the summer season (June, July, August) for 2099
View 3  

Difference in seasonal sum of precipitation for the summer season (June, July, August) between 2001 and 2099

*Figure 9.12  Seasonal sum of precipitation for the summer season (June, July, August) for the A2 scenario HadCM3*

In summer there is also an increase in precipitation in the Umbrian mountains and in the winter at the coast between La Spezia and Piombino. This is shown in Figure 9.13.

View 1  

Seasonal sum of precipitation in the Arno catchment for the winter season (December, January, February) for 2001
View 2  Seasonal sum of precipitation in the Arno catchment for the winter season (December, January, February) for 2099

View 3  Difference between seasonal sum of precipitation in the Arno catchment for the winter season (December, January, February) between 2001 and 2099

Figure 9.13 Seasonal sum of precipitation in the Arno catchment for the winter season the A2 scenario HadCM3
9.5 Assessment of the results and future planning requirements

The following statements can be made regarding the climate change impacts for the Tuscany region:

- Summers and winters will become hotter at the end of the twenty-first century;
- The summer seasons will be hotter and drier.

These hotter and drier summers increase the possibility of heat waves considerably. This may have a serious impact on agricultural activities, e.g. viticulture and could also result in competing interests for water resources, e.g. power plant cooling/irrigation. The slightly wetter winters in some regions will not compensate for this effect, since evapotranspiration will increase too. This implies that the flood risk will decrease, although intense rain events will be more likely in the future.

Regarding planning issues; it will be the responsibility of administrative bodies to develop strategies suitable to cope with the reduced water availability. Other strategies could involve developing new building codes to cope with the extreme summer temperatures. The current assessment of flood probabilities is mainly based on the calculation of return periods and their associated flood levels, which implies static climate. Such assumptions are at odds with widely respected climate change scenarios.

Estimates for design flood values could be too small (approx. 5% to 20% difference) if dependence (e.g. autocorrelations, long term dependence) in the data is neglected. An example is shown in Figure 9.14 below illustrating this point for the River Grosse Vils/Vilsbiburg, Germany. Based on a bootstrap and model selection strategy that reconstructed internal features in the data, uncertainties in the return level estimates can be assessed systematically. Therefore a more reliable basis for design flood values can be provided. The interpretation is as follows: in 95% of 1 in 100 year return period estimates the expected 1 in 100 year return period will not exceed the 95% confidence limit.
River runoff in Europe exhibits increasing, stationary and decreasing long term trends. Furthermore standard methods applied in extreme value assessment are often not suitable since they are based on the assumption that extremes are independently and equally distributed. Potentially neither assumption may be applicable. These assumptions are often made by decision makers, since for the calculation of design flood values they often add a safety factor to take account of uncertainties. However, in conducting regional assessments each gauge should be analysed separately for non-stationarity. It is recommended that improvements in the approach to the assessment of flood return periods should be made that consider both new technologies and also regional climate change scenarios, although the latter might be uncertain, particularly with respect to regional precipitation development (References: 17 and 66).

However, progress has recently been made to constrain uncertainties, by applying non-stationary extreme value statistics and by an approach allowing provision of confidence levels for return-level estimates (Reference:80). Nevertheless some of the results show that several design flood values for river and sea dikes might be too low, since their calculation is based on the assumption of stationarity in the statistics.

The question still remains, how can decision makers respond to climate change and how they can act responsibly under uncertainty? Small spatial scale climate change scenarios become more uncertain the smaller the grid resolution used. This implies that strategies for adaptation on a small scale of a few hundred metres cannot be provided by climate research. However, all the information needed for future adaptation is available at a regional level, if the assumptions are considered correct. Another critical point is that
decision makers often have an insufficient understanding what climate change implies for their specific region and how researchers calculate scenarios. Furthermore, local stakeholders often cannot translate scientific information into concrete action, although they specifically demand exactly this information. Thus a close cooperation of scientists and stakeholders is essential in anticipatory planning and adaptation measures.
10 Implementation of the draft ARMONIA methodology at a national level in England and Wales

10.1 Introduction

As well as piloting the draft ARMONIA methodology in the Tuscany Region of Italy the draft ARMONIA methodology has also been piloted in England and Wales using readily available data sets. This allowed the methodology to be tested at a national scale as well as a regional scale. Data on the following natural hazards were available:

- Floods;
- Seismic activity;
- Landslides.

The risk indices were developed using the population data from the 2001 census.

10.2 Natural hazard data

10.2.1 Flood hazard

The flood hazard data available for England and Wales comprises two flood extent layers for the 1 in 100 and 1 in 1000 year floods. These were combined to produce a flood hazard map with the following classes:

- **Class 1** - Land flooded by the 1 in 100 year flood
- **Class 2** - Land flooded by the 1 in 1000 year but not the 1 in 100 year flood.
- **Class 3** - Land flooded by neither of the above events.

The flood hazard map for England and Wales takes a very basic approach to flood hazard, neglecting intensity/probability relationships and only providing a very broad classification scheme. For instance, land in the Class 1 area may suffer flood return periods intra-annually right up to one per century. Figure 10.1 shows the flood mapping that was available to the project team.

Ideally the flood hazard for England and Wales would be mapped on depth grid basis for each return period at a relatively high resolution (e.g. a 1 km x 1 km grid). However, data of this detail is not available for England and Wales. One of the issues with the draft ARMONIA methodology is the lack of guidance related to the production of risk mapping at a national scale. The poor resolution of hazard data that is often available for EU countries at a national scale can decrease the accuracy and usefulness of the risk metrics generated.
Note: Large scale area in the box shows the flood extent in the upper reaches of the River Thames

Figure 10.1 Flood extent data for England and Wales
10.2.2 Seismic hazards

Earthquake hazard data for England and Wales was taken from the Global Seismic Hazard Assessment Program (GSHAP) (Reference:53). This global dataset uses the peak ground acceleration with a 10% probability of exceedance over 50 years. The data from England and Wales was cropped from the global map and classed into five hazard zones based on equal interval within the data range of the England and Wales. The seismic hazard scales applied in England and Wales are shown in Figure 10.2.

Figure 10.2 Seismic hazard classes for England and Wales based on a peak ground acceleration with a 10% probability of exceedance over 50 years
10.2.3 Landslide hazard

Landslide hazard data was taken from Reference 54. The map, shown in Figure 10.3, is based upon the number of landslides which have been recorded per km² which are classed into five categories. The resolution of the map is low. The assumption has been made in compiling the map that areas which have suffered numerous landslides in the past will continue to do so in the future.

Figure 10.3 Landslide hazard classes for England and Wales based on the number of landslides
10.3 Receptors

In the case study for England and Wales people have been used as the sole receptors with regards to the hazards. The draft ARMONIA methodology provides indices for alternative receptors such as buildings and roads. However, as discussed in Chapter 3 the format of the data that is required to assess the risk to these receptors is often specific to the data that is available in Italy. A comprehensive geo-referenced national property data set is available for England and Wales. This data set provides the following information:

- National grid reference of the property;
- Type of property – some 50 different types of residential and commercial property are specified;
- Average ground floor area of each type of property;
- Estimated value of the property.

Despite this comprehensive property data set being available it is not possible to employ the draft ARMONIA methodology in England and Wales as metadata on the following are not available in the national property data set:

- Number of floors;
- Age of construction;
- Type of construction.

This illustrates one of the constraints of the draft ARMONIA methodology when assessing a risk index for properties in countries other than Italy.

In order to assess the risk indices for data from the 2001 UK census was used to produce human vulnerability indices in England and Wales. The census data is available at very high resolution. The basic unit at which census data is compiled in the UK is known as an Output Area (OA) and consists of a minimum of 40 resident households and 100 resident persons. The recommended size of an Output Area is generally 125 households. In total there are some 175,000 Output Areas in England and Wales.

10.4 Assessment of the human consequence index

Using the draft ARMONIA methodology the human vulnerability is based upon the proportion of young and old people (i.e. those under 5 and over 65 years of age in each of the Output Areas). This value is normalised between 0 and 1. The human vulnerability index estimated using the draft ARMONIA methodology for England and Wales is shown in Figure 10.4.
This value of the human vulnerability index is then multiplied by the population density of the Output Area and classed into four integer values ranging from 1 to 4. The draft ARMONIA methodology does not explicitly state how the normalised values are to be categorised. Two approaches have been investigated:

(i) **Equal interval approach**

This method divides data up on an equal interval approach. Depending on the distribution of the data it is possible to have a distribution of integers as follows:
• Class 1  80% of the data;
• Class 2  10% of the data;
• Class 3  3% of the data;
• Class 4  2% of the data.

This equal interval approach often results in a very uneven number of classes. Figure 10.5 shows a map of the equal interval approach for England and Wales. This illustrates that owing to the skewness of the distribution almost all the output areas are classified as having a consequence index of 1 i.e. a low consequence. This clearly illustrates that using this approach to the mapping of indices is of little use to decision makers.

(ii) Division by quartile

An alternative method is to divide the dataset by quartiles. This method divides the data so that each class has an equal number of data in it. Figure 10.6 shows a map of the human consequence index when the data set is divided by quartiles. This provides a much more useful map for decision makers than Figure 10.5 as it clearly shows the areas of England and Wales where the consequences of a natural hazard are greatest.

Note: FPV is the consequence index for people

Figure 10.5  Consequence index for people calculated using equal interval divisions
10.5 The estimation of the risk index for people

The human consequence indices for each Output Area and the hazard scores were multiplied together to produce risk maps for each of the various hazard maps available for the UK. As detailed in Section 10.4 the skewness of the dataset meant that displaying the risk using equal intervals would not yield useful results. As a consequence the indicators used in the risk maps for people were derived use quartile divisions. The following Figures for England and Wales are shown in the report:

- Figure 10.7 shows the flood risk indicators for people;
- Figure 10.8 shows the seismic risk indicators for people;
- Figure 10.9 shows the landslide risk indicators for people.

It is important to note that the maps only indicate a relative degree of risk between the census areas Output Areas. It is also important to note that a seismic risk indicator value of 0.8 cannot be directly compared with a flood risk indicator of 0.8.
Figure 10.7 Flood risk indicators for people in England and Wales

Figure 10.8 Seismic risk indicators for people in England and Wales
Figure 10.10 shows the draft ARMONIA methodology applied at a local level for the city of Manchester in England to produce risk indices for people for three natural hazards. It should be noted that the seismic and landslide hazard maps were only available at a very coarse resolution. Figure 10.10 illustrates the key steps in producing risk to people indices using the draft ARMONIA methodology. These are as follows:

(i) Production of hazard maps
(ii) Production of consequence maps where consequence = vulnerability x exposure. In the draft ARMONIA methodology the vulnerability is based on the number of people under five and over 65 years of age;
(iii) Production of risk maps from the combination of the hazard and consequence mapping.

Risk maps have been produced for the following hazards:

- Floods;
- Seismic events;
- Landslides.

The following should be noted:

- The risk indices for each hazard are not directly comparable;
- The scale used to produce the risk indices is not necessarily linear. Hence, if under a future scenario (e.g. climate change or an
increase in exposure caused by a new housing development) the risk index increases from 0.2 to 0.4 this does not necessarily mean that the risk has doubled in quantitative terms such as loss of life or economic damage.

**Hazard, consequence and risk maps for Manchester**

- **Flood hazard**
- **Seismic hazard**
- **Landslide hazard**

**Human consequence = People vulnerability x Exposure**

**Human risk = Hazard x Consequence**

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**Figure 10.10** Risk indicators for people for three natural hazards for Manchester in England
10.6 Comparison of the draft ARMONIA methodology with other risk related metrics available for England and Wales

There have been a variety of risk related metrics and projects, mainly related to flooding that have been mapped for all or part of England and Wales. These include the following:

- Social Flood Vulnerability Index (SFVI);
- Foresight project.

This section contrasts the above approaches with the draft ARMONIA methodology.

10.6.1 Social flood vulnerability index (SFVI)

The background to the Social Flood Vulnerability Index (SFVI) is detailed in Chapter 3 of this report. The SFVI provides a more accurate description of vulnerability than the draft ARMONIA methodology in that it takes into account numerous other socio-economic variables other than just age. The SFVI has also considered the skewness of the data sets and makes allowances for these in contrast to the draft ARMONIA methodology. A map of the SFVI for England and Wales is shown in Figure 10.11.

![Figure 10.11 Social Flood Vulnerability Index (SFVI) for England and Wales](image-url)
Figures 10.12 and 10.13 show the vulnerability index for people produced by the draft ARMONIA methodology and the Social Flood Vulnerability Index (SFVI) for the Greater London area in the UK. The people vulnerability produced by the draft ARMONIA methodology is purely based on the proportion of people under five years or age and over 65 years of age. The SFVI as explained in Chapter 3 takes account of a whole range of socio-economic variables including:

- **Unemployment** as a percentage of all economically active people over the age of 16;
- **Overcrowding** - Households with more than one person per room as a percentage of the household;
- **Non-car ownership** – Households with no car as a percentage of all the households;
- **Single parents** – Single parents as a proportion of all residents;
- **The long term sick** – Residents suffering from limiting long-term illness as a percentage of all residents;
- **The elderly** – Residents aged 75 or over.

The people vulnerability produced using the draft ARMONIA methodology in Figure 10.12 shows that most of the people in Greater London have on average a low or very low vulnerability to natural hazards. However, it is interesting to note that the SFVI shown in Figure 10.13 shows that most areas of Greater London fall into the average, high or very high categories when it comes to assess people’s vulnerability to natural hazards. The discrepancy is because the SFVI takes into account other socio-economic factors other than purely age that research has shown are important in assessing people’s vulnerability to natural hazards. This illustrates a shortcoming in the draft ARMONIA methodology.
Figure 10.12 ARMONIA people vulnerability for London

Figure 10.13 Social Flood Vulnerability Index (SFVI) for London
10.6.2 Foresight project

The aim of the Foresight project was “to produce a challenging and long-term (30 to 100 years) vision for the future of flood and coastal defence in the whole of the UK that takes account of the many uncertainties, is robust, and can be used as a basis to inform policy and its delivery” (Reference:48). As part of the Foresight project a variety of risk maps were produced. Figure 10.14 shows a map at a 10 km x 10 km grid resolution showing the flood risk to people in England and Wales in 2002.

The Foresight map has two important differences from the ARMONIA risk maps. Firstly, in that it is resolved at equal spatial units. This makes interpretation simpler since densely populated areas which may be quite small and difficult to pick out on a map of this size are averaged over larger grid squares. This approach is suited to small scale mapping where general trends are required.
10.7 Conclusions

The following conclusions have been reached concerning pilot testing of the draft ARMONIA methodology in England and Wales:

- Flooding is the dominant natural hazard in the UK. As a consequence hazard, vulnerability and risk mapping for floods are more developed than for other hazards. The draft ARMONIA methodology is based on a method that is related to assessing the risk generated by seismic hazards that is not necessarily applicable to England and Wales;
- The seismic hazard map for England and Wales gives the erroneous impression that high hazard areas exist in the UK. On a global scale seismic hazard in the UK is low and flood hazard demands far greater resources;
- The vulnerability index for people produced by the draft ARMONIA methodology does not necessarily accurately reflect the true vulnerability of people to natural hazards when compared with other social vulnerability indicators such as the Social Flood Vulnerability Index (SFVI);
- Decision makers in the UK tend to be interested in risk to natural hazards being defined in terms of direct economic damage and/or loss of life. It is not clear how the risk indices produced by the draft ARMONIA methodology will assist decision makers and planners in either planning new developments or mitigating current and future risks from natural hazards.
11 Recommended improvements to the consequence indices used in the draft ARMONIA methodology

This chapter details improvements that could be made to the consequence indices used in the draft ARMONIA methodology. The chapter has been structured as follows:

- Improvements to the consequence index for people;
- Improvements to the consequence indices for buildings;
- Improvements to the consequence indices for pipelines.

The chapter also details the issues relating to using indices for assessing risk.

11.1 Improvements to the consequence index for people

The ARMONIA consequence index for people is based upon age alone i.e. the percentage of people under five and over 65 years of age. This index has the advantage that the data from which it is constructed is available for most census datasets within the European Union.

It is important to note that age is not the only variable that characterises a population's vulnerability to natural hazards. There have been numerous other studies that have developed social vulnerability indices for natural hazards. Two notable social vulnerability indices that have been developed are:

- The Social Vulnerability Index (SoVI) to environmental hazards used in some states in the USA (Reference:30);
- The Social Flood Vulnerability Index (SFVI) in the UK (Reference:87).

These are briefly discussed below.

11.1.1 Social Vulnerability Index (SoVI)

The SoVI measures the vulnerability of a population via the following factors:

- Personal wealth;
- Age;
- Density of the built environment;
- Single sector economic dependency;
- Housing stock and tenancy;
- Ethnicity;
- Occupation;
Infrastructure dependence.

The index is a composite additive index and no assumptions are made concerning the relative importance of each variable. Scaling is used to make positive values indicate higher vulnerability and negative values decrease vulnerability. This method is described in more details in Reference (30).

11.1.2 Social Flood Vulnerability Index (SFVI)

The Social Flood Vulnerability Index (SFVI) has been developed by the Flood Hazard Research Centre at Middlesex University in the UK for assessing the vulnerability of the people to floods in England and Wales. The index takes account the following:

- **Unemployment** as a percentage of all economically active people over the age of 16;
- **Overcrowding** - Households with more than one person per room as a percentage of the household;
- **Non-car ownership** – Households with no car as a percentage of all the households;
- **Single parents** – Single parents as a proportion of all residents;
- **The long term sick** – Residents suffering from limiting long-term illness as a percentage of all residents;
- **The elderly** – Residents aged 75 or over.

It is interesting to note that the above percentages were transformed in order to minimise the skewness within the distributions.

The ARMONIA consequence index for people could be improved by including a number of other variables that are readily available in census data throughout Europe. Table 11.1 provides a list of readily available socio-economic data that is collected as part of censuses in 15 different countries throughout Europe.
Variables related to people

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Note: A single variable in this table can represent multiple variables. Aus: Austria, Blr: Belarus, Bul: Bulgaria, Cz: Czech Republic, Fra: France, Ger: Germany, Gre: Greece, Hun: Hungary, Pol: Poland, Por: Portugal, Rom: Romania, Slv: Slovenia, Spa: Spain, UK: United Kingdom

Table 11.1 Readily available census data in Europe (Reference:43)
The table indicates that as well as age the following variables are collated for many European countries:

- Educational attainment;
- Employment status;
- Provision of water/hot water to the place of residence;
- Availability of toilet at the place of residence;
- Availability of bathing facilities at the place of residence.

Research has indicated that the vulnerability of people to natural hazards is directly correlated with not only their age but also their socio-economic status. The following improved vulnerability indicator is suggested:

\[ P_{vi} = \text{Pop}(<5 >65) + \text{EdStatus} + \text{EmployStatus} + \frac{(\text{Water} + \text{Toilet} + \text{Bathing})}{3} \]

Where:

- \( P_{vi} \) is the people vulnerability for a particular area;
- \( \text{Pop}(<5 >65) \) is the percentage of people less than 5 and greater than 65 years of age;
- \( \text{EdStatus} \) is the educational status of the people in the area;
- \( \text{EmployStatus} \) is the percentage of people unemployed in the area;
- \( \text{Water} \) is the percentage of houses without running water in the area;
- \( \text{Toilet} \) is the percentage of houses without an indoor toilet in the area;
- \( \text{Bathing} \) is the percentage of houses without an indoor bath in the area.

It should be noted that this revised vulnerability index could be used in a flexible manner i.e. if one variable such as EdStatus was not available then this could be left out of the equation and the vulnerability index could be modified. It should also be noted that some of the distributions may need to be transformed to minimise the skewness of the distributions.

It is also recommended that the exposure for a particular area is defined as the total population (Poptot) within a census area not the population density of the area.

The consequence index is produced using the following equation:

\[ \text{FFPv} = \text{Poptot}.P_{vi} \]

In the case of lava flows from volcanoes it is stated in the draft ARMONIA methodology that "population exposure should not be considered" owing to the fact that evacuation of the population is possible if the velocity of the lava flow is low (Reference:13). However, this is not the case. With respect to long term planning, to assess the effectiveness of mitigation measures for natural hazards the exposure of the total population should always be considered.
whether evacuation is possible or not. It could also be argued that evacuation is possible with respect to flood hazards provided enough warning time is provided to people. However, achieving an appropriate response of a group of people to a warning is difficult. It is thus recommended that the exposure of the population is considered with respect to lava flows from volcanoes.

### 11.2 Improvements to the consequence indices for buildings

The consequence indices for buildings have been developed from indices used to estimate the risk from seismic hazards in Italy. The vulnerability indices for buildings require the following data to be available:

- Construction type;
- Age;
- Height of the building;
- Maintenance level;
- Density of buildings.

These data are specific to the building database available in Italy and it is unlikely that all these metadata will be available throughout Europe.

There are several other shortcomings with the draft ARMONIA methodology for assessing building vulnerability. These are as follows:

- Various indicators of buildings vulnerability such as building height and age are weighted equally in the formulation of the vulnerability index. No justification for this equal weighting is made;
- No justification is given for any of the other weightings that are used in the equations;
- The building size is not accounted for. For example, a city centre census area may have three tower blocks, which in a severe seismic event are likely to suffer far more extensive damage in cost terms than three farmhouses in a rural census area. However, the methodology only identifies that three exposed elements exist in the census areas and it is possible that the method could produce the same vulnerability index for the tower blocks as for the farmhouses.

An inconsistency in the building vulnerability index for flooding and landslides has also been noted. The building vulnerability for landslide and flood hazards is calculated from the following equation:

\[ B_{vi} = B_{mr} + B_{hr} \]

Where:
Bmr is the number of different types of masonry buildings.

\[ Bhr = \frac{(2BnG + 3BnH)}{Bn} \]

Where:
- \( BnG \) is the number of buildings with up to two floors;
- \( BnH \) is the number of buildings with over two floors.

The \( Bhr \) index indicates that the taller a building is the more vulnerable it is to flooding. This is not the case. In general the taller the building is the less damage that will be incurred during a flood as a result of the fact that the majority of the contents are more likely to be above the level of the floodwater. The key parameter that affects a buildings vulnerability to flooding is its floor area and the level of this floor area above the ground. It is recommended that this indicator is either taken out of the vulnerability index or modified. A suggestion for a simple modification would be as follows:

\[ Bhr = \frac{BnG}{Bn} \]

Where:

- \( BnG \) is the number of buildings with no more than two floors within a particular area;
- \( Bn \) is the total number of buildings within a particular area.

Ideally a vulnerability index for flooding would be related to ground floor area of the building as follows:

\[ Bhr = \frac{\text{FloorAtot}}{\text{FloorAGrdt}} \]

Where:
- \( \text{FloorAGrdt} \) is the total area of the ground floor of buildings in an area;
- \( \text{FloorAtot} \) is the total floor area of all the buildings in a particular area.

Ideally the following dataset is required to assess the vulnerability of buildings to the natural hazards that have been considered in ARMONIA, these are:

- Location of the building;
- Type of building (e.g. residential, commercial or industrial);
- Construction type (e.g. wood, concrete, brick);
- Ground floor area;
- Age;
- Height of the building;
- Maintenance level.
In many EU countries a geo-referenced property data set containing the above parameters is unlikely to be available.

In relation to seismic hazards there is a vulnerability index Bct that takes account of the vulnerability of a building in relation to whether it is isolated or in close proximity to other buildings (i.e. “aggregated”). Bct is calculated in the draft ARMONIA methodology using the following equation:

\[ Bct = \frac{2Bct_i + 2Bcta}{Bn} \]

Where:

- Bct is a factor related to the building density ranked into four classes with scores given from 1 to 4
- Bcti is the number of isolated building
- Bcta is the number of buildings that close together or “aggregated”.

The equation for Bct is incorrect as an equal weighting is given to both the isolated and “aggregated” buildings. Hence using the equation above the value of Bct will always yield a value of one. We have made the assumption that aggregated buildings are more vulnerable than isolated ones. In our application of the Bct index we have revised the equation as follows:

\[ Bct = \frac{2Bct_i + 3Bcta}{Bn} \]

The above revised Bct index equation weights aggregated buildings more than isolated ones. Hence, census areas with a high proportion of apartment blocks will produce a higher vulnerability index than census areas that only have isolated buildings in them.

### 11.3 Improvements to the consequence indices for pipelines

There are numerous issues related to the estimation of the consequence index for linear networks. These are as follows:

- No guidance is given in the methodology as to what constitutes the various categories of network for both road and other linear infrastructure such as power lines, gas pipelines and water supply distribution systems;
- The index uses the size of the linear infrastructure as a proxy for its vulnerability. For example, a network in a poor state of repair may be considerably more vulnerable than one that is regularly maintained. This is not taken into account in the draft ARMONIA methodology;
• The smallest areal unit at which the linear network exposure index is mapped is a census area. As a consequence the linear network features are converted into an areal representation and lose their geographical location within the census area. This aggregation of the linear consequence by census area is required in order to integrate multiple the various indices which are weighted by stakeholders.

11.4 The use of indices

This section describes some of the issues of using indices as a proxy indicator for natural hazard, vulnerability and risk mapping, including the following:

• Weighting of indicators used in indices;
• Validation of indices;
• Indicators as a proxy measure of reality;
• Data decay;
• Normalisation of data to produce indices;
• Transformation of data.

11.4.1 What is an index

It is important that the use and limitations of indices in risk mapping is fully understood by the end user. There is no mention in the draft ARMONIA methodology of the limitations and “usefulness” of the indices. An index may be defined as “a composite representation of numerical measurement manipulated in some manner to give a single value” (Reference:85). A classical definition of an index number is “a statistical value that is modified and its variations signify a change of magnitude, but are not subject to accurate measurement that would not be easily observed and has the influence to affect the values” (Reference:40).

Indices are generally constructed by summing or multiplying several indicators related to the item of interest. Indicators in an index will have different units such as dollars, kilometres, degrees and population per square km². Various methods are used, such as scaling, to create “unit-less” variables as is the case in the draft ARMONIA methodology. For example, a linear method of scaling is used for the Hurricane Disaster Risk Index (Reference:33) and the Earthquake Disaster Risk Index (Reference:32).

Data also can be standardised and made unit-less by using Z-scores and then summing the values. This is a method used for the Social Flood Vulnerability Index (Reference:87) discussed in Section 10.6.1. A “Z-score” is a dimensionless quantity derived by subtracting the population mean from an individual score and then dividing the difference by the population standard deviation. Numbers that are standardised into percentages or indices may be less useful to emergency managers because of the loss of raw numbers that are
useful during the planning phase (Reference:67). This is the case in the draft ARMONIA methodology.

11.4.2 Issues related to the use of indices in natural hazard and risk mapping

There are a number of potential problems that are related to the use of indices for risk and hazard mapping. These include:

- Subjectivity;
- Bias;
- Weighting;
- Methods to combine variables mathematically;
- Selection of indicators and data sources.

These issues are discussed below.

Issues related to weighting of the indicators in an index

In the draft ARMONIA methodology weighting techniques have been incorporated into the index values in order to identify the varying levels of importance of each indicator. For example, in the age indicator for buildings (Bar) used in the ARMONIA building vulnerability index various ages of building are given different weighting factors. There is no explanation as to how these weighting factors were derived. These weightings also differ between volcanic and seismic hazards.

The use of weighting factors is important as issues of bias may emerge when determining the level of importance for each indicator. There are two approaches that can be applied to the weighting of indices. These are:

(i) A subjective approach that is based on expert opinion.
(ii) An approach that is more objective and mathematical in nature, for example analysis of historical records where available).

It is important to note that introducing subjectivity into a study does not necessarily reflect a lack of scientific construction as personal interpretations can develop from many years of field experience during which the product benefits most from a lack of objectivity. Even the act of deciding what to measure and what mathematical procedures to use introduces some level of subjectivity into any study (Reference:85). The issue with the draft ARMONIA methodology is that there is no background given as to how the weighting factors were derived and whether they are applicable to countries in Europe other than Italy.
Issues of validation

A considerable shortcoming of using composite indices, such as those used in the draft ARMONIA methodology, is that there is no simple way to get scientific validation of a particular index (Reference:34). The absence of validation is a major concern. The indices developed in ARMONIA appear to rely on empirical data that is far from perfect. These indices have been developed for one natural hazard (i.e. seismic events) in Italy.

It is often assumed by the “end user” of the indices that because the numbers have been derived using some basic statistical procedure that the overall results of the index is valid and reliable (Reference:85). This is not necessarily the case. It would appear that little validation of the draft ARMONIA methodology has been carried out.

There are some methods that can be used to help validate indices. Qualitative techniques such as conducting in-depth surveys or case studies could be performed to assess the reliability of data (Reference:76). In practice the only way that any sort of metrics related to the risk management could be validated would be to continually test them after major events and then refine them accordingly. However, this would take a considerable amount of time (Reference:85). There are no recommendations in the draft ARMONIA methodology as to how validation of the indices could be achieved.

Indicators as proxy measures of reality

Indices are quantitative, subjective measures, acting as proxies for the concept under examination (Reference:27). As indices are proxy measures, they also do not represent the true nature of a hazard or vulnerability. Cobb and Rixford (Reference:28) state that “every indicator is a flawed representative of a complex set of events”. Indices are unit-less, and the arithmetic is considered to be “odd” because in most cases the values do not represent anything outside of the context in which the situation is being compared. Contextual representation means an index number measuring the magnitude of a hazard, vulnerability or consequence is often not on a linear scale, as a score of 5 on an index does not represent twice the vulnerability or the consequence compared to score of 10 or vice versa. This is a key point that is not pointed out in the draft ARMONIA methodology and is important that the end users are made aware of this.

Data sources, data selection and data availability

There are other methodological questions that should be asked when working with indices and more specifically indices that deal with hazards and vulnerability. These include:

(i) Source of the data
(ii) Selection of indicators
These are discussed below.

(i) Source of the data

In many instances vulnerability will be defined through the availability of datasets rather than because the data truly represents vulnerability (Reference:67). This is certainly the case with the draft ARMONIA methodology where it would appear the vulnerability indices have been selected based on the data sets that are available in Italy. No mention is made of how the vulnerability indices could be constructed in other EU countries, where data sets may differ to those available in Italy.

(ii) Selection of indicators

Another issue is related to the process of selecting indicators. Selection of indicators is usually based on either:

(i) A theoretical approach and an understanding of the relationship of indicators.
(ii) An understanding of statistical relationships (Reference:1).

The theoretical approach is more comprehensive in nature. Using this technique one would decide what factors encapsulate the item measured without regard to data availability (Reference:85). The second approach is to examine what data is available, and then select indicators based on data availability, as would appear to be the case in the draft ARMONIA methodology. Data availability would appear to be a major limitation on producing vulnerability and hazard indices (Reference:85).

Data decay

An important issue with population datasets is data decay; any census or survey dataset becomes less accurate with the passage of time (Reference:67). Data decay also applies to buildings as structures age, renovations occur, buildings are demolished, technology changes and building codes are updated (Reference:35).

The dynamic nature of vulnerability also makes it particularly difficult to quantify. Vulnerability has a time-space dimension that fluctuates according to the type of hazard (Reference:16). More specifically, the vulnerability of populations varies according to time of day, day of the week and season of the year (Reference:32).

Spatial extent over which indices are normalised

The various indices that are used in the draft ARMONIA methodology are normalised using the following equation:
\[
\text{IndexVal} = \frac{\text{ActualVal} - \text{MinVal}}{\text{MaxVal} - \text{MinVal}}
\]

Where:

IndexVal is the value of the index
MinVal is the minimum value of the variable
MaxVal is the maximum value of the variable

The above equation produces an index that is between 1 and 0. No guidance is given in the draft ARMONIA methodology as to what spatial area the variables should be normalised over. It is important that the limitations of normalisation of data are pointed out to the user as part of the methodology.

Figure 11.1 provides a diagrammatic representation of the spatial issues related to normalising indices. This Figure shows indices estimated at a census area level for three different spatial scales: local; regional and national. Owing to the spatial effects on the normalisation process the following should be noted:

- The score after normalisation is not comparable across the three different spatial scales;
- At a local scale when the score is normalised one census area is given a high score and two census areas are given medium-low scores. However, if the same normalisation process is carried out at a national level all these census areas are designated a low score.

**Transformation of data before it is normalised**

There is no mention in the draft ARMONIA methodology of the possibility of transforming the data before it is normalised. This is important because if the data sets are skewed, which is often the case, then the data will need to be transformed. Skewness, in this case, is defined as a measure of the asymmetry of the probability distribution of a variable.

Once the crude percentage of each variable in each census area is determined they should be transformed to minimise skewness within their distributions. There are numerous methods that can be used to transform the distributions. These include:

- Natural log transformation;
- Log to the base ten transformation;
- Square root.

The transformed values should then be standardised to prevent the index from being influenced by any variable that features abnormally high, or low values. Statistical packages can be used to calculate the
standard score automatically otherwise the method of standardisation is given by the following equation:

\[
\text{Standard score} = \frac{\text{Observation} - \text{Average}}{\text{Standard deviation}}
\]

Issues relating to the skewness of data sets are further discussed in Chapter 7.

### 11.4.3 Conclusions relating to the use of indices

The discussion above highlights the issues surrounding the use of any index. The alternative approach to indices is quantitative risk metrics such as expected annual loss of life or cost of damage incurred. Quantitative approaches, although potentially of more use to decision makers, are more difficult to implement since they require consequence versus hazard relationships for each type of exposed element considered.
11.5 General conclusions relating to the draft ARMONIA methodology

This section provides general conclusions relating to the draft ARMONIA methodology:

- The draft ARMONIA methodology does not allow multi-risk maps to be produced. The methodology does allow the consequences of a particular hazard on different receptors (e.g. buildings, people) to be combined to produce a risk index for a particular hazard. However, it is not clear whether such a risk index that combines a number of social, economic and other risk metrics is of use to decision makers;
- There is a high degree of subjectivity regarding the weighting and combining of the vulnerability indices. There is no guidance in the methodology as to how these weightings have been derived and how they affect the risk indicators;
- There is no consideration of uncertainty in the draft ARMONIA methodology;
- There appear to be a variety of shortcomings in the development of the vulnerability and consequence indices, for example:
  - The social vulnerability index only takes into account age and no other readily available socio-economic data such as the health and wealth of the population even though this data is readily available in many European countries;
  - The building vulnerability index does not take the size of the buildings into account so three farm houses in a rural area could have the same vulnerability as three apartment blocks in an urban setting;
  - The building vulnerability index is based on data that may only be readily available in Italy;
  - The building vulnerability for floods is incorrect giving a higher vulnerability to taller buildings which is not the case;
  - The building vulnerability and social vulnerability indices are based on different and inconsistent measures of exposure;
  - One of the vulnerability indices relating to the aggregation of buildings and its effect on seismic vulnerability is incorrect;
  - It is stated in the methodology that for volcanic hazards in the case of lava flows the exposure of the population should not be taken in to account as there will be sufficient time for people to evacuate the area at risk. This is not always necessarily the case;
- No guidance is given in the methodology as to the way in which data should be normalised. The lack of a methodology here and information on how to transform the data can lead to misleading results;
- No guidance is given as to what areal extent the indices should be normalised over (e.g. national, regional or local level) and how this normalisation affects the results;
As a result of the above bullet point the risk indices will not be comparable at different spatial scales;

No advice is given in the methodology as to how skewed distributions should be transformed;

Stakeholders are required to provide a weighting factor to different consequence indices for different receptors (e.g. people, buildings). This can lead to different sets of stakeholders producing very different values of risk indicators, giving possibly misleading results;

A number of different social and economic consequence indices are combined. Further research and consultation is required with stakeholders to assess the validity and usefulness of the results;

It would appear that little research has been done as to how different consequence indices can be combined and what the risk indices actually tell a decision maker. It is not clear if a decision maker is told anything by the draft ARMONIA methodology that is useful or that is not already obvious from existing hazard and exposure mapping.
12 An alternative simplified methodology for multi-hazard and multi-risk mapping

This chapter details an alternative simplified methodology to the draft ARMONIA methodology that is not reliant on specific data, but could be used to produce multi-hazard and multi-risk maps. This methodology could provide a higher degree of flexibility than the draft ARMONIA methodology.

This methodology requires the following steps to be undertaken:

(i) Identification and prioritisation of hazards.
(ii) Identification of vulnerability.
(iii) Identification of receptors (i.e. exposed elements).
(iv) Identification of secondary hazard risk consideration sites and key environmental resource sites.

12.1 Identification and prioritisation of hazards

12.1.1 Identification of hazards

The first step in developing a harmonised risk map for an area is to establish the following:

(i) The natural hazards (e.g. forest fires, floods, earthquakes, landslides) and secondary hazards (e.g. spills of toxic chemicals) that may occur in the area of interest;

(ii) Establish how to prioritise the natural hazards.

It can be useful to develop a “hazard history” for an area to assess the types of hazards that have occurred historically. A checklist for hazard identification may be as shown in Table 12.1.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Occurrence (yes or no)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landslide</td>
<td></td>
</tr>
<tr>
<td>Earthquake</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td></td>
</tr>
<tr>
<td>Forest fire</td>
<td></td>
</tr>
<tr>
<td>Volcano</td>
<td></td>
</tr>
<tr>
<td>Temperature extremes</td>
<td></td>
</tr>
<tr>
<td>High winds</td>
<td></td>
</tr>
</tbody>
</table>

Table 12.1 Example of a checklist for hazard identification

12.1.2 Data acquisition

The data required to represent the different hazards will come from a number of different organisations. The organisations responsible for
collecting the relevant data will vary from country to country within the European Union. An example of the data and sources of data acquisition are given in Table 12.2.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Attributes</th>
<th>Possible source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landslide</td>
<td>Type of landslide, area affected</td>
<td>Geological, soil or national organisation</td>
</tr>
<tr>
<td>Earthquake</td>
<td>Intensity, area affected</td>
<td>National geological organisation</td>
</tr>
<tr>
<td>Flood</td>
<td>Extent of flooding</td>
<td>Water or river basin management organisation</td>
</tr>
<tr>
<td>Forest fire</td>
<td>Area burnt, land use</td>
<td>Land use management organisation, or forestry management institution</td>
</tr>
<tr>
<td>Volcano</td>
<td>Type of volcanic hazard (e.g. lava flow, pyroclastic fall) and extent of the hazard</td>
<td>Vulcanology institute</td>
</tr>
<tr>
<td>Temperature extremes</td>
<td>Maximum temperature, area affected</td>
<td>Meteorological office</td>
</tr>
<tr>
<td>High winds</td>
<td>Maximum wind speed, area affected</td>
<td>Meteorological office</td>
</tr>
</tbody>
</table>

Table 12.2  Example of data acquisition for natural hazards

12.2 Hazard frequency of occurrence

The occurrence interval of a hazard is important to assess the relative frequency of each natural hazard. It gives an indicator of the relative importance of each of the natural hazards. For example if in a particular area flooding occurred 15 times over the previous 104 years then the annual probability of a flood occurring could be argued to be 0.144 or 14.4%. The frequency of occurrence of a particular natural hazard may be obtained from a modelling exercise. For example in the case of flood the 1 in 100 (1% annual probability) and 1 in 1,000 year probability (0.01% annual probability) are often modelled. Table 12.3 indicates how the hazard frequency could be computed using a record of historical natural hazards.
<table>
<thead>
<tr>
<th>Hazard</th>
<th>Number of events</th>
<th>Years in record</th>
<th>Recurrence interval (years)</th>
<th>Hazard frequency (annual probability %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landslide</td>
<td>22</td>
<td>102</td>
<td>4.6</td>
<td>21.6%</td>
</tr>
<tr>
<td>Earthquake</td>
<td>14</td>
<td>215</td>
<td>15.4</td>
<td>6.5%</td>
</tr>
<tr>
<td>Flood</td>
<td>16</td>
<td>150</td>
<td>9.4</td>
<td>10.7%</td>
</tr>
<tr>
<td>Forest fire</td>
<td>5</td>
<td>92</td>
<td>18.4</td>
<td>5.4%</td>
</tr>
<tr>
<td>Volcano</td>
<td>1</td>
<td>101</td>
<td>101.0</td>
<td>1.0%</td>
</tr>
<tr>
<td>Temperature extremes</td>
<td>5</td>
<td>120</td>
<td>24.0</td>
<td>4.2%</td>
</tr>
<tr>
<td>High winds</td>
<td>9</td>
<td>120</td>
<td>13.3</td>
<td>7.5%</td>
</tr>
</tbody>
</table>

Note: In some cases design event frequencies will be available from models studies or from other calculations.

Table 12.3  Example of hazard frequency

A qualitative scoring system should then be developed for the frequency of hazard for a particular area. An example of a qualitative scoring system for hazard frequency could be as shown in Table 12.4 or Table 12.5 which indicates a possible method that could be used to “score” the frequency of floods.

<table>
<thead>
<tr>
<th>Frequency of hazard occurrence in terms of annual probability (%)</th>
<th>Qualitative score</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5%</td>
<td>1</td>
</tr>
<tr>
<td>5% to 10%</td>
<td>2</td>
</tr>
<tr>
<td>10% to 15%</td>
<td>3</td>
</tr>
<tr>
<td>15% to 20%</td>
<td>4</td>
</tr>
<tr>
<td>&gt;20%</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 12.4  Example of a qualitative scoring system for natural hazard frequency based on annual probability

<table>
<thead>
<tr>
<th>Flood hazard areas</th>
<th>Qualitative score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within “active” floodplain</td>
<td>5</td>
</tr>
<tr>
<td>Within 1 in 100 year flood extent</td>
<td>4</td>
</tr>
<tr>
<td>Within 1 in 500 year flood extent</td>
<td>3</td>
</tr>
<tr>
<td>Within 1 in 1,000 year flood extent</td>
<td>2</td>
</tr>
<tr>
<td>Remainder of area</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: The active floodplain is where the velocity could be defined as being greater than 0.5 m/s.

Table 12.5  Example of a qualitative scoring system based for floods

12.2.1 Potential damage magnitude for each hazard

The “potential damage magnitude” of the hazard needs to be identified for each area. A scoring system would need to be produced relating a particular hazard with the potential damage. This “potential damage magnitude” score could range from 1 to 5. For example a 1
in 1,000 year event may be classified as having a damage potential score of 5 whereas a more frequent event such as 1 in 1 year flood or earthquake may be considered to have a damage potential of only 1.

### 12.2.2 Establishing the relative importance of each hazard

The relative importance of each hazard for a particular spatial area (e.g. a 1 km x 1 km grid) could be assessed by combining the frequency score for the hazard with the potential damage magnitude score to get a total score as follows:

Total score for each hazard = Frequency score x Potential damage magnitude score

This scoring system is illustrated in Table 12.6.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Frequency score</th>
<th>Potential damage magnitude score</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landslide</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Earthquake</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Flood</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Forest fire</td>
<td>3</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Volcano</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Temperature extremes</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>High winds</td>
<td>5</td>
<td>3</td>
<td>15</td>
</tr>
</tbody>
</table>

**Total hazard score** 64

Note: The maximum possible in the above case is 125 and the minimum score is 7

The relative importance of natural hazards can then be mapped. The spatial resolution at which the combined multi-natural hazards are mapped is dependent on the data that there is available. Figures 12.1 and 12.2 provide an example of how the individual multi-hazard score maps can be combined to produce a multi-hazard map. Such an exercise would be undertaken using a Geographical Information System (GIS). The scores for the natural hazards could then be classified as follows:

- 7 to 25 Low;
- >25 to 50 Medium – low;
- >50 to 75 Medium;
- >75 to 100 Medium – high;
- >100 to 125 High.
Figure 12.1 Process of combining individual hazard score maps to produce a multi-hazard score map

Figure 12.2 Combined multi-hazard map score map
12.3 Identification of vulnerability

In order to map the risk posed by natural hazards the vulnerability of the receptors needs to be estimated and mapped. The two most useful ways of mapping vulnerability or consequences are in terms of:

- Social or societal vulnerability to natural hazards;
- Economic.

12.3.1 Estimation of social vulnerability to natural hazards

The social vulnerability of a population to natural hazards is affected by a number of factors including:

- **Age**
  The elderly are less mobile and more susceptible to disease.

- **Vehicle ownership**
  Households that do not own vehicles may not be able to readily evacuate an area that is at risk.

- **Financial deprivation factors**
  Financial indicators such as unemployment, level of income have a significant effect on people’s vulnerability to natural disasters.

- **Single parent families**
  This indicates special child care considerations may be required.

- **Ethnic minorities**
  This indicates potential language or cultural considerations that may increase the vulnerability of that portion of the population to natural disasters.

The above information can often be obtained from national census data. A Social Vulnerability Index could be developed which would be a function of the above factors. This index could be range from a score of 1 to 5, with 1 indicating a population in a certain area had low social vulnerability to natural and 5 indicating a very high social vulnerability to flooding. A simple example of how the social vulnerability could be mapped is shown in Figure 12.3. The Social Vulnerability Index could be adapted depending on the availability of data in a particular country or region.
12.3.2 Estimation of vulnerability to natural hazards in terms of economic damage

There are a variety of methods available to estimate the economic damage to properties resulting from natural hazards. However, many of these methods are very data intensive and require damage functions related to specific types of buildings. A simple method of carrying out a qualitative assessment of economic vulnerability would be to conduct a general inventory of businesses and households and indicate their level of economic vulnerability to each hazard. This would involve producing a scoring system for each area.

A map of “critical facilities” could also be produced. This would include:

- Schools;
- Hospitals and nursing homes;
- Fire and rescue services;
- Police and army installations;
- Utilities (e.g. water, gas and electricity);
- Communications;
- Transportation;
- Government buildings.
A simple example of a map indicating different types of properties is shown in Figure 12.4.

![Map example](image)

**Figure 12.4 Example of mapping different types of properties**

### 12.4 Identification of secondary hazard risk consideration sites and key environmental resource sites

#### 12.4.1 Identification of secondary hazard risks

The purpose of this analysis would be to identify locations where there is potential for secondary environmental impacts from natural hazards. Secondary impacts occur when natural hazard events lead to a secondary hazard occurring such as a toxic release or a hazardous spill. Key sites where hazardous or toxic materials exist (e.g. chemical plants, solid waste facilities, hazardous substance disposal sites) would be identified.

#### 12.4.2 Identification of the vulnerability of environmentally sensitive sites secondary hazard risks

The proximity of environmentally sensitive locations to the location of secondary risk sites to determine the overall risks from these facilities
should be assessed. This will allow the environmental vulnerability to be estimated.

12.5 Production of multi-hazard risk maps

Multi-hazard risk maps would be produced by overlaying the combined natural hazard map with the social vulnerability, economic damage and environmental vulnerability maps. Simple examples of societal and economic multi-hazard risk maps are shown in Figures 12.5 and 12.6.

Figure 12.5 Map showing societal risks to natural hazards

Figure 12.6 Map showing economic risks to natural hazards
13 Conclusions and recommendations

The draft ARMONIA methodology was applied in the Arno River basin, and in England and Wales as a means to validate and confirm the methods developed as part of the project. A number of gaps and limitations in the draft ARMONIA methodology were identified. Improvements to the draft methodology have been suggested.

The following represents the main conclusions and recommendations that have resulted from the case study:

- The draft ARMONIA methodology needs to be revised and validated in local areas where quantifiable risk metrics such as economic damage and loss of life are available for a number of different hazards. There are a number of case studies at a local level in Europe where this could be carried out. It would be a good test of the ARMONIA risk indices to compare them with such case studies;
- Alternative multiple risk mapping methods that are not as data specific as the draft ARMONIA methodology need to be investigated further;
- More guidance is required relating to the stakeholders’ weighting of the consequences indices in the draft ARMONIA methodology. Many decision makers place the reduction of loss of life as their highest priority with respect to natural risk mitigation. The question as to whether consequence indices for people can be merged with consequence indices for other receptors such as building and linear infrastructure to provide an overall risk index needs to be further investigated;
- Many decision makers require risk metrics in terms of economic damage and or loss of life in order to plan sustainable risk mitigation measures. More work is required on fragility/vulnerability curves for a number of receptors and hazards to allow these risk metrics to be quantified;
- There needs to be greater research into what the end users of risk maps actually require. Although spatial planners in many European countries only appear to require hazard maps, other decision makers, responsible for implementing mitigation measures, need to know specific information in the form of quantifiable risk metrics.
14 References


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