

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



# The Internet of Things for Natural Risk Management (Inte.Ri.M.)

*Riccardo Beltramo, Paolo Cantore, Enrica Vesce,  
Sergio Margarita and Paola De Bernardi*

## Abstract

This chapter deals with the development of a management system, which integrates the use of IoT in natural risk detection, revention, and management with economic evaluation of each stage. In the introductory part, recent data are presented that document the importance that natural disasters have for the environment and for the Italian economy. Section 2 presents the Inte.Ri.M. project—the Internet of Things for Natural Risk Management—its purpose, activity plan, and bodies involved. Technical aspects are treated in Section 3 with the choice of hardware and software components and the solutions for collecting and transmitting data. Section 4 is about the economic aspects considering the stages of prevention, intervention, and restoration and the relation between the intensity of human activity and environment to define a range of situations. These scenarios call for different economic methodologies useful to estimate economic implications of each stage in the short, medium, and long term. Section 5 describes the structure of the Inte.Ri.M. management system and the foreseen functionalities. In the conclusion, the critical points are discussed, and the steps for the transposition of the work carried out on the territory are outlined, according to the provisions of the work program.

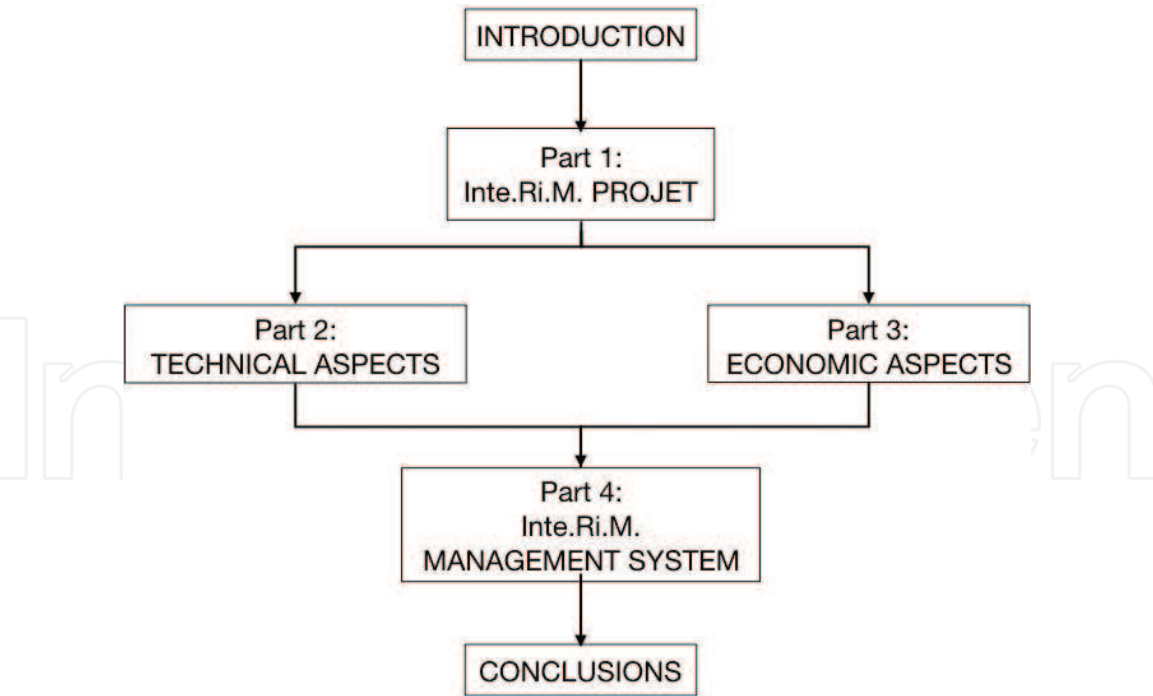
**Keywords:** risk management, disaster, economic impact, sensor, forecast, IoT

## 1. Introduction

The structure of the chapter is described in **Figure 1**.

Evaluation and management of natural risks are relevant topics that have been brought to the fore by the recent earthquakes in Italy. The consequences of these phenomena make clear that it is mandatory to evaluate the risk and correctly manage information and emergency interventions. Securing the territory is on the top of the agenda of our government, and Piedmont region has recently adopted a plan to finance, with over 60 million euros, land protection and hydrogeological risk prevention measures [1].

Piedmont, a region in the north-west of Italy, located at the western edge of the Po Valley, is occupied for about 49% of its territory by the mountain ranges of the Alps and the Apennines, which delimit it on three sides like an arch. The region is statistically affected by alluvial events with average occurrences of an event every 18 months or so. In the alpine sector, special nivo-meteorological conditions can cause avalanches.



**Figure 1.**  
*The structure of the chapter.*

The regional territory is also subject to earthquakes: the tectonic context and the active geodynamic regimes lead the region to be the site of seismic activity, generally modest in terms of energy, but notable as a frequency. Floods, fires, landslides, and avalanches can be less catastrophic compared to earthquakes, but they create damages as well, due to their frequency. Natural causes and an improper use of the territory are at the base of this kind of events. Management deficiencies cause **economic** losses in these contexts [2].

The effects of these phenomena influence human activities in the short and medium-long term; they cause real natural disasters whose damages are measured in victims and economic losses, in the short term, to the ecosystem and to human, civil, and productive settlements, in the medium-long term. The restoration of the initial conditions can take decades.

Although the attention devoted to forecasting and managing the effects of these phenomena has increased over time, and investments in parallel, the achievements recorded in the field of prevention have been few, and they show that the spaces for improvements exist and are wide. Monitoring networks are used where phenomena have occurred in the past or where there are significant threats of danger. As a result, large areas of territory are not monitored, while the availability of significant and updated data is the basis for any preventive action. The consequence of this attitude is that the interventions take place after natural disasters occur, while a preventive view, made up of infrastructural interventions, would allow to counter huge damages to the population and to the structures and to better organise the management of emergencies.

## 2. Inte.Ri.M. project

Based on this, the Inte.Ri.M. project—the Internet of Things for Natural Risk Management—has been launched in 2017, with an interdisciplinary approach, by a research group of economists, mathematicians, computer engineers, and experts in management systems of the University of Turin, linked to the Research Centre on

Natural Risks in Mountain and Hilly Environments of the same university and with the support of Piedmont region.

The choice of the acronym Inte.Ri.M. expresses the sense of provisional nature, which, in the specific case, can be associated to the dynamic balance of the elements of nature. Therefore, nothing is immutable, everything is temporary, and sometimes, the provisional nature is expressed in a brutal manner, with tragic consequences for humans.

The general objective of the project is the evaluation and management of natural disaster risks in a systemic and integrated way, in which technical and economic variables are measured to prevent and assess, with a holistic approach, the natural risks in ecosystem services.

The ultimate goal of the project is the realisation of a computerised integrated system for the evaluation of costs and benefits in some natural risk situations. The methodology that has been put in place is able to compare the costs of prevention, including the costs of the detection system, analysis and reporting, and an estimate cost to contain damage, with the benefits deriving precisely from the damage avoided (in the case study).

The specific objectives of the project, which correspond to the same number of work packages (WP), are as follows:

1. Identification of macro natural disaster risks in mountain ecosystem (WP1).
2. Consideration to disasters, whose impact is localised and circumscribed (WP2).
3. Focus on specific natural disaster risks: avalanches and landslides in Piedmont region (WP3).
4. Implementing technical tools and economic assessment approaches to prevent and manage natural disaster risks (WP4).
5. Application and integration of prevention and management system outputs on real-time dashboard with IoT tools to support disaster risk reduction decision-making processes (WP5).
6. Testing and applicability of the integrated key risk indicators selected from the dashboard in a pilot case (WP6).
7. Performance dissemination through communication and raise awareness of the institutions, businesses, and population interested in risk prevention (WP7).

Time sheet and deliverables are reported in **Figure 2**.

Currently, WP1 has been concluded and has led to the selection of sites to be monitored. WP2 and WP5 are in progress. Therefore, in the parts related to the technical aspects (Part 2) and to the economic aspects (Part 3), the analysis carried out to define the specifications of the integrated system is presented.

The identification of macro natural disaster risks in mountain ecosystem (WP1) has recorded an increment of natural disasters, in frequency and intensity. Evidence indicates that exposure of persons and assets to risk in all countries has increased and vulnerability has decreased, thus generating new risks and a steady rise in disaster-related losses, with a significant economic, social, health, cultural, and environmental impact in the short, medium, and long term. In this scenario,

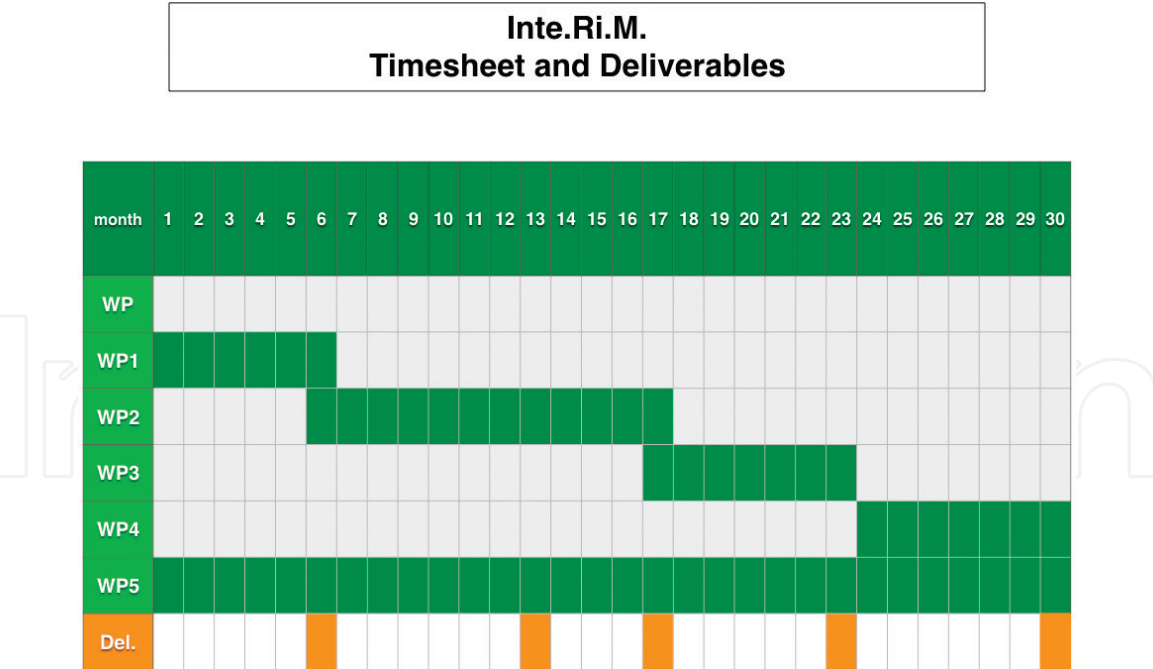


Figure 2.  
Timesheet and deliverables.

mountain ecosystems, which furnish a large group of goods and services to humanity, for people that live in mountains or outside [3], like source of ecological and food security, are deeply affected by natural disaster [4].

It is widely accepted that mountain ecosystems must be protected but is neglected by the fact that they act also as buffer against natural hazardous. The measurement of full costs of losses and degradation of these ecosystem services are difficult to assess, but there is a sense of urgency to implement an economic tracking system to monitor all disaster risk reduction costs for mitigation, preparedness, and emergency response.

A correct evaluation of ecosystem services gives helpful information to estimate costs and benefits of decisions, to define future scenarios, and to recognise and avoid unexpected consequences [5].

The value of ecosystem services can be linked to the direct use (e.g., wood) or indirect use (value of specific ecological functions), or to the particular item relevance for other goods or values, or finally, the value may simply be intrinsic (e.g., existence value or cultural value). The capacity to prevent and respond to a disaster is especially important in mountains area, where remoteness and difficulty of access are often features of communities that, during disasters, are cut off from the outside world more often and for a longer time than lowland areas. For this reason, it emerges urgently the need to manage disaster risk with an effective integration among technical tools and economic approaches to measure the activities of prevention (ex ante risk management), rehabilitation, and recovery (ex post risk management) [6].

Environmental data are at the base of natural disaster prevention. The state of the art for landslide monitoring uses inclinometers, extensometers, and piezometer sensors. For avalanche monitoring, the most common solutions are ultrasound sensors, Doppler radars, and optic sensors. Floods and earthquakes require not just sensors; indeed, the most important prevision tools are software using mathematical algorithms based on time series. We will focus on avalanches and landslides in Piedmont region. The regional agencies of environmental protection of Piedmont (Arpa Piemonte) provide open data about river and snow levels, landslide areas, and other meteorological information.

Inte.Ri.M uses the data already available, integrating them with those measured by the WSN Scatol8®. Scatol8® is a WSN developed in the University of Turin.



Many sensors are included in the platform, that is, wind direction and speed, snow level, liquid flow, rain level, air pressure, solar and ultraviolet radiation, noise, vibration, soil moisture, and many others. Scatol8® platform is based on open source hardware and software not only for cost saving but also in the view of knowledge sharing. Several experiences have been made in environmental monitoring. We built WSN for data acquisition in mountain huts, parks, mine, and other kinds of areas.

Our interdisciplinary proposal aims to mix our technical and economic skills to assess how much preventing disasters with WSN can cost and make to save money at the same time. The use of open data that are already available is useful in the starting stage of the study and will reduce costs. At the same time, open source WSNs are suitable for detecting data, saving cost in comparison with proprietary solutions.

We consider economic and environmental indicators at the same time. Starting from the literature review, we choose the environmental variable relevant for the project scopes. We select the most suitable evaluation methods for the economic analysis of the ecosystem services (direct and indirect) that we integrate with the economic valuation of the human activities managed in the observed areas. The intensity of a measured variable or the result of statistical elaborations can assume different sense in the phase of sensing, data analysis, and communication with the stakeholders. Smartphone, tablet, and other devices are useful for the warning and the management steps of emergencies. They can also collect data from people to the emergency area. Assessing the economic impacts of disasters is a very recent field of study. The methodologies adopted to enable a transparent and coherent economic assessment of disaster risk management are based, first of all, on the post-event losses. The impact assessments estimate the economic and social impacts of past disasters. Storing such information in a database is a precondition for estimating future disaster impact. Moreover, we use the cost-benefit analysis (CBA) integrated with complementary tools as, for example, cost-effectiveness and multicriteria analysis (MCA) and robust decision-making approaches (RDMA). This holistic methodology is effective in relation to reliable input data availability (e.g., past disaster losses, indirect losses, and macroeconomic impacts), among which those from private business sector and public finance are important for achieving good-quality economic impact analysis. Approaches need to address the different layers of risk (from intensive to extensive risk), underlying risk drivers, as well as be tailored to mountain local contexts. Addressing these underlying risk drivers will reduce disaster risk, lessen the impacts of climate change, and consequently, maintain the sustainability of development (UNISDR, 2015). In parallel, attention will be paid to the need of communication among various actors involved in natural disaster management, through new technologies like the IoT and cloud computing.

### **3. Technical aspects**

#### **3.1 How technologies can contribute to disaster prevention and critical events notification**

Disasters are caused by nature and/or by human activities, and they can impact on security, agriculture, industry, health, and natural environment. Technologies can have a key role in disaster prevention and management. While some tools, as for example, some environmental sensors, have been on the market since the first half of the twentieth century; in the last 10 years, the opportunity to connect devices through the Internet has created many new opportunities. People can use recent technologies for real-time analytics, remote or in-site monitoring, data analysis,

early warning notification, victim localisation, and data aggregation. Research institutes are the organisations that commonly collect data and try to build some models useful for events forecasting. Those institutes can build their own data acquisition systems, and they can use data collected by others, for example, weather forecast by military or a mix of both. The diffusion of open data databases that people can consult for free on the Internet can help to have more data, but, at the same time, it is important to investigate about how those data were collected and how accurate are them.

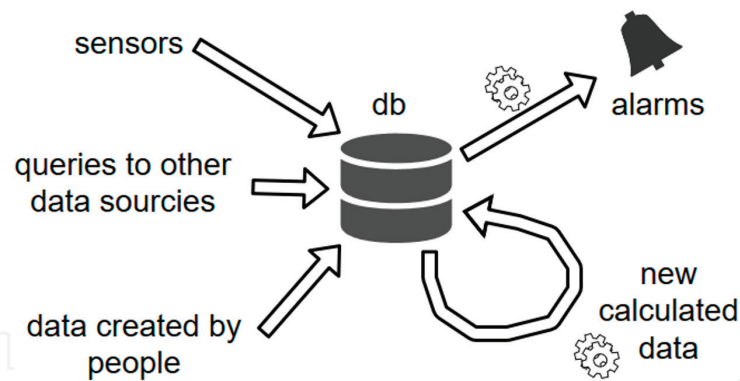
Useful raw data can be collected not just from sensor networks but also thanks to IoT devices [7]. If we search information about disaster prevention and IoT, we can find that there is a lot of confusion in the use of the word IoT; unfortunately, this is true also in scientific papers. The biggest confusion is between Internet of Things and sensor networks. There are many definitions of IoT, and we refer to the one made by the Institute of Electric and Electronic Engineers. The document “Towards a definition of the Internet of Things (IoT)” [8] revision 1 (2015) tries to define the concept in 86 pages. We can find that the main concepts, taken from Section 5.3, are the following:

- **Interconnection of Things:** The first feature of IoT is derived from the name that describes it. It is a system that deals with the interconnection of “Things”. The word “Thing” refers to any physical object that is relevant from a user or application perspective.
- **Connection of Things to the Internet:** From the name IoT, we can also learn that the “Things” are connected to the Internet. Accordingly, from the name we can deduce that the system is not an Intranet or Extranet of Things.
- **Sensing/actuation capability:** There is the involvement of sensors/actuators in the IoT system. The sensors/actuators are connected to the “Things” and perform the sensing and actuation, which bring the smartness of the “Things”.
- **Embedded intelligence:** Smart and dynamic objects, with emergent behaviour, embed intelligence and knowledge functions as tools and become an (external) extension to the human body and mind.
- **Interoperable communication capability:** The IoT system has a communication capability based on standard and interoperable communication protocols.

The first point is important: the physical object itself must be relevant from a user or in the application perspective. For example, a temperature sensor that sends data to a remote dashboard is not an IoT device. On the other hand, a fridge that sense that the milk is ended and it informs as with a push notification or an alarm clock that changes the alarm time according to the traffic information are examples of IoT devices.

**Figure 3** shows how data can be collected and used. Data sources can be sensors, other databases, or people notifications. In the last case, people can contribute in many ways, for example, using a mobile application to notify something.

Once raw data are acquired, the business logic can notify alarms or create new data, for example, forecasts, combining trends, and different data sources. The intensity of a measured variable or the result of some statistical elaborations can assume different sense in the phase of sensing, data analysis, and communication to the stakeholders.



**Figure 3.**  
 Data input and output.

### 3.2 Environmental risk and sensors and forecasting technique examples

Environmental data are at the base of natural disaster prevention. In this section, we will explore what are some of the best sensor-based solutions currently on the market that allow to predict or to early warning disasters.

#### 3.2.1 Landslides

The state of the art for landslide monitoring uses inclinometers, extensometers, and acceleration and piezometer sensors. Before using sensors, it is important to have an inventory with the zones of interest. This can be done to detect landslide that already happened with high-resolution aerial images [9] or LiDAR data. These data must be aggregated to the information that researchers can obtain from city registers, people interviews, other researcher's databases, etc. Once the areas of interest are defined, it is possible to use sensors for advance warning, for event warning, or for both the scopes together.

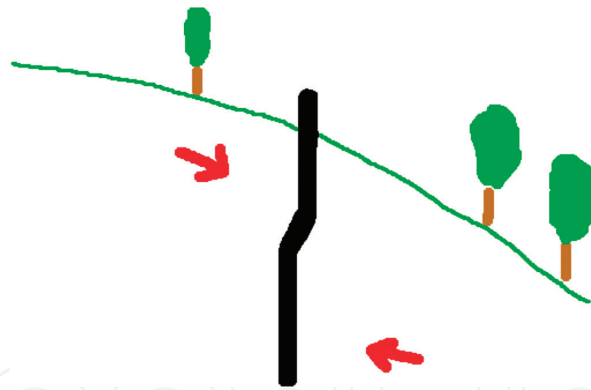
Inclinometer (see **Figure 4**) and extensometer can be used for advance warning, detecting the small changes in the distance between two points. The most common idea [10–13] for landslide monitoring during the event is to put a lot of nodes on the area of interest; in this way, the signal can be forwarded to the neighbour nodes before the sending nodes probably die [10-13].

#### 3.2.2 Avalanches

Compared to other natural disasters, the risk of avalanches is more to be controlled by humans. Many studies correlate the temperature changes, the type of the snow, and the probability that an avalanche occurs. Humans can also create new controlled avalanches to avoid a disaster, for example, they can trigger some small avalanches before too much snow accumulates on the mountains over a part of a ski resort or a street. In any case, human's understanding of the dynamic response of the snowpack to avalanche control explosives is rather limited [14].

The historical and present weather conditions can be used to forecast the snow conditions in the future. In Europe, the model COSMO (<http://www.cosmo-model.org/>) is an example of a project developed to create an atmospheric forecasting model. Ref. [15] uses this model in conjunction with a snow cover model to forecast avalanche activity; particularly, they concentrate on wet-snow instability. The WSL Institute for Snow and Avalanche Research SLF creates a repository that includes the snow cover model that they used and other similar ones (<https://models.slf.ch/>).





**Figure 4.**  
*Inclinometer probes allow to detect ground movements under the soil.*

If the historic trend of environmental parameter such as temperature and snow level is really important to discover the avalanche's probability, in situ test made by people can be also quite important to discover how much the layers of snow are discontinuous.

For avalanche monitoring, the most common sensor solutions are **ultrasound sensors**, **Doppler radars**, and **optic sensors** [16]. Other solutions include **cameras** and image recognition, LiDAR, or the use of **geophone** built for earthquake monitoring [17]. These seismic sensors have two roles: monitoring the activity of the avalanche and studying the dynamics of the avalanche. It is interesting to notice that every avalanche does not only produce a seismic signal but also some low frequency infrasonic acoustic waves (below 20 Hz). Remote infrasound solutions can be used for monitoring also when the visibility is low [18].

Using geophones, it is important to discriminate signals due to the avalanche from other noises. The analysis in the time-frequency domain allows to distinguish different sources, for example, helicopters or airplanes that generate signals on some specific harmonic frequencies [19]. It is also interesting to notice that diverse kinds of avalanche; for example, loose snow and slab ones have their typical signal characteristics. Detecting precursor signal with geophones is very difficult but these instruments allow not just to detect avalanches but also to study the dynamic of the snow inside the avalanche.

Another interesting aspect of snow to be monitored is the snow flow. The snow can be moved by the wind, and in this way, it can influence the avalanche danger, it can block some roads or the access to some buildings, and it can cause other problems. Lehning and others, in the article *Snow drift: acoustic sensors for avalanche warning and research*, compare many kinds of sensor for snow flow; in particular, they concentrate their analysis on the acoustics sensors. Their findings are that, at the present, it is not possible to measure the mass of the flux of snow with high accuracy [20]. A significant reduction of false detection in infrasonic measure can be obtained using machine learning classification techniques compared to the use of a threshold [16].

One problem of snow monitoring is also that, in all the previous cases, you can only monitor a specific area, but the snow condition can be quite different in another place not far from the installed sensors.

New technologies have an important role not just in avalanche detection but also for localising the victims. Common instruments like the ARTVA allow to find people under the avalanche. New tools like wearable sensors are currently not so diffused, but in future, they will probably help the rescue operations, giving information about the health status of the victims under the snow [21].

### 3.2.3 Floods

The risk of flood disaster increased in the last years because people build more buildings on floodplains, and the area covered by cement has increased. To make actions against flood effective, it is important to forecast it further in advance as possible. Usually people working in the emergency response staff are notified before common people. This happen because early previsions are more subject to false alarm [22]. The predictability can change a lot depending on the historical data and the place. For example, Webster et al. in their article demonstrate that it was possible to predict the 2010 floods in Pakistan 6–8 days in advance using a multi-year analysis and a hydrological model to mitigate the impact anticipating actions [23]. Rain sensors alone cannot forecast floods; the most important prevision tools are software using mathematical algorithms based upon time series. The data for the analysis can be a mix among rain gauge measures and satellite information. Prediction models useful for short-range prediction can differ from the ones that are best for long-term forecasts [24]. It is interesting to notice that simulate flood disaster in cities must also take into account the sewer capacity [25].

Other types of events to be forecasted for safety reasons are the wave run-up and the wave overtopping. The project HIDRALERTA [26] developed for the safeguard of the Portugal coasts is an interesting case because it is a tool for evaluating the risk, taking a decision, and eventually alerting the involved stakeholders. The explained methodology is composed by four parts and can be applied to different geographic area with different data sources:

- The wave characterisation: This step can be accomplished with some spectral or mid slope wave models. These predictive models need the sea to be monitored and, being too much complex, can be simplified using some matrix with some pre-run different models for multiple conditions. The use of machine learning techniques for predicting values can also help.
- A neural network determines if the wave will overtop the barrier or not.
- Risk level calculation for the overtopping values. Risk maps are produced taking into account the thresholds for the overlapping, the probability for the event to occur, and the consequences.
- The warning and alarm system.

### 3.2.4 Earthquakes

As for floods, also for earthquakes, the most important prevision tools are software using mathematical algorithms based upon time series. Earthquakes can have a bigger impact if they affect some human structures like a dike or a nuclear power plant. Herle and others [27] simulate many dangerous events for calculating the risk of a dike failure. In their simulation, they use a protocol called message queue telemetry transport (MQTT) that is a lightweight IoT transmission protocol. We can find an interesting approach in the article by Zambrano et al. [28]. They build a system for early detecting and notifying earthquakes using people smartphones' accelerometers. The work is a notable example of a project that can be developed almost without having new costs and using existing devices for a new scope. Munib ur Rehman and others in their article analyse how ICT and wireless sensor

networks can contribute to detect earthquakes early. They used three main different approaches correlating three events with the possibility of an earthquake. Detecting abnormal animals' movement can help to early prevent calamity, and also variation in groundwater pressure gives information about the possibility of earthquakes. Another precursor is the concentration of radon on the ground that changes because of the breakings of rocks below the surface.

Sensors can give an important contribution also after a disaster; for example, they can monitor pollutants and contaminants including radioactive scenarios after an earthquake has damaged an industrial area.

### *3.2.5 Debris flows*

Another dangerous process that can occur during strong rainfalls is the debris flow. Compared to landslides, the debris flows are more difficult to study because these events can occur in a very short time, and using aerial photographs, it is hard to find traces of previous events [29]. An approach for forecasting debris flows can be the creation of a map with the alluvial fan using LiDAR data and photograph and keeping trace of the event occurrences. Because this event can be considered as the union of landslides and water floods, sensors can help to detect strong waterfall and notify early warning. Example of sensors for this application is ultrasonic or radar gauges, ground vibration sensors, video cameras, avalanche pendulums, photocells, and trip wires [30].

### *3.2.6 Fire*

It is very hard to forecast a fire. It can be caused directly by humans or by some objects like trains or electrical lines. If we want to limit fire consequences, it is important to detect the fire as soon as possible. A possible approach is to use IP cameras to detect the smoke at its beginning using some detection algorithms [31, 32, 33]. Another approach is to use geostationary satellites and image processing [34].

Fire can be early detected even before the smoke presence using gas sensor as demonstrated by Gutmacher et al. [35] in the article "Gas Sensor Technologies for Fire Detection". In their experiment, the fire was detected by gas sensors 4 minutes before one optic smoke sensor detected it. This approach can be used mostly in closed areas, for example, offices and houses. In the same context, also heat detectors can provide early warning of fire incidents.

An interesting experiment in outdoor context [36] uses the wireless sensor network transmission signal strength indicator variance between two nodes to detect the fire. The idea is that the changes in the vegetation water content level due to the fire influence the wireless signal.

## **3.3 Other scenarios and solutions**

Human activities can have an appreciable impact on natural disaster activities can have as a consequence relevant natural disasters, for example, the Chernobyl nuclear disaster that happened during some scheduled test. Also, in the Seveso disaster, people working in the company had many responsibilities [37]. Apart from human dangerous behaviours and errors, when an organisation is conducting an environmentally risky activity, it is important to continuously monitor the relevant processes.

Some very diffused technologies can help during disasters: smartphone, tablet, and other devices are useful for the alert and the management steps of emergencies. They can also collect data from people in the emergency area, for example,

the device can share the position of an injured person using the GPS. Also, social network like Twitter and Facebook can help to collect data from people in the zone of the emergency.

Lapante and others in the article “Could the Internet of Things Be Used to Enhance Student Nurses’ Experiences in a Disaster Simulation?” [38] illustrate the simulation of a street accident with many people injured. Nurses and patients in the place are connected and can share information about the patients, thanks to some wearable sensors and the use of RFID for patient recognition. If their approach is not realistic because people are not usually equipped with a RFID system for recognition, an interesting approach is the one of Libelium Meshlium. This product, which is currently on the market, allows to count people in a space looking for the Bluetooth and Wi-Fi signal of their mobile phones. This approach cannot assure to count the total amount of persons, but it is easy, and it is applicable in real word and not just in simulations.

### 3.4 Possible issues in data communication

Many technologies are useful for collecting data from the sensor nodes in a network. **Table 1** shows some of the currently used communication technologies. In the most common scenario, the Internet network is used to transmit data to a remote server. It is important to underline that different protocols can operate together: for example, we can have one protocol for data collection among the nodes of a wireless sensor network (WSN) and another one from one collector node in the WSN and the Internet.

The data communication is easier if we collect data for doing forecast but is more critical if we need to transmit information in real time during the disaster. The main problems in transmitting data in such conditions are the availability of power supply for the nodes and of the data network for transmitting the data packets.

Many research reports (e.g., [39]) discuss the importance of redundancy. It is possible to use some battery to assure that the node will transmit data also if there is no external power, but the most critical point happens if the data network is absent. For example, if the cellular base transceiver station of our operator is not available, it becomes important to use the one of another operator. All the mobile phones permit to make emergency call independently from the operator and the credit, but this is not the same for other services like sharing the position.

In some applications, for example, avalanche monitoring, we can put many radios to have more chances that almost one radio will successfully transmit. The adoption of a mesh network, where a packet can take many paths to reach its destination, also helps.

The importance of having a working system during the disaster depends on the specific application. For example, at that time, information needed for prevention can be less useful with respect to data useful to localise injured people overwhelmed during an earthquake. The network services can be unavailable not just because the radios are physically broken but also because there are too many requests: for example, many people trying to call with their mobile phones just after the disaster can saturate the cell.

Before proceeding with the installation of the monitoring network prototype, it is considered useful to test the performance of the network in a mountain environment. For this reason, the site of the Angelo Mosso Institute of the University of Turin has been chosen. It hosts groups of international researchers working in various scientific areas. The objective of this phase is the verification of the energy performance of the remote sensing network in relation to the frequency of data transmission [40].



Name	Network topology	Average ranges	Average Tx power	Scenario
ZigBee (s2/s2pro)	Mesh	20 m/3.2 km	3.1 mW/63 mW	Many nodes, node routing needed
3G/4G	ptp (from users view)	Typical carrier ranges 30 km	2 W	Direct communication to a remote server thought the Internet. No LAN available
xBee 802.15.4 (s1/s1 pro)	Fully connected star	120 m/3.2 km	10 mW	Low power, not many nodes
xBee s5 868/900	Star	500 m–12 km	315 mW	Have to collect data in open spaces. Do not need packet routing
Lora	Typically star (mesh supported)	5–15 km	100 mW	Need to transmit small amount of data covering distances in Km order. Need a WAN gateway in the same technology as the nodes
Sigfox	Star	30 km	300 mW	Direct communication to a remote server thought Internet, less expensive than 3G. Only few access points available
Satellite	ptp	36,000 km	2–5 W	There are no other ways to connect. For example, you are in the sea or in a desert
Wi-Fi	Typically star	50 m	100 mW	Can use an already built Wi-Fi network. Do not need packet routing
Bluetooth	star	50 m	10 mW	Need to interface with a Bluetooth device

**Table 1.**  
*Technologies suitable for data transmission in disaster scenario.*

4. Economic aspects

The economic part of the Inte.Ri.M project aims at selecting correct methodologies to evaluate and to allow the comparison among costs of prevention and the damages from the disasters that can be avoided. In order to achieve this ambitious goal, an overall strategy is defined, and three parts are identified. The first is about the different scenario to analyse, depending of the type of territory that disaster may affect, and the second is related to the different methodologies used for evaluation. The third part is focused on the actual possibility to compare the costs and benefits of disaster prevention.

4.1 Territory and disasters

According to the area that disasters affect, it is possible to identify different situations. Inte.Ri.M. project has focused its attention on mountain ecosystem (Piedmont region) and above all on specific natural disaster: avalanches and land-slides, with circumscribed and localised impact. As seen, the same reasoning can be



extended to other geophysical (like earthquakes and forest fires) and hydrological disasters [41].

For the purposes of ongoing research, two classification parameters have been identified: the *type of territory* affected by the disaster and the time taken to recover from the consequences. Both are important for economic evaluations.

The first, it is fundamental to choose the correct variables to be considered. It is very different to destroy an urban area from a completely uninhabited area. Thus, as a sample area, two different types were chosen, always in a mountain environment: a highly natural area and an urbanised area.

In **Figure 5**, the presence of the ecosystem services (ESS) or economic components can be noticed, depending on the type of area taken into consideration.

The second, it is useful to evaluate the “time axis” that sets the economic reasoning. **Table 2** shows the various recovery times for different disaster and for type of area.

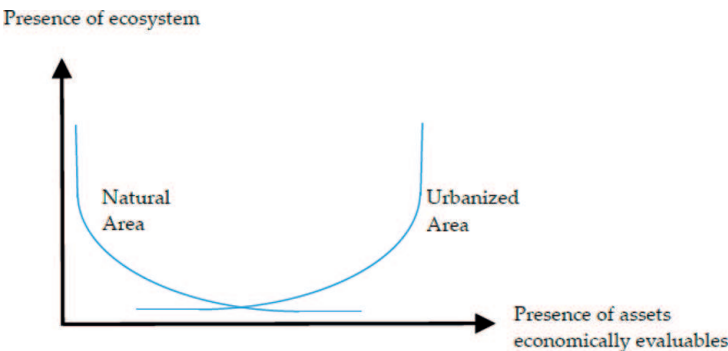
This subdivision based on the time horizons allows, within the economic assessment, to make a more correct comparison with the benefits of the avoided damage. To consider that the comparisons must be homogeneous also from the temporal point of view with the benefits that derive from the systems that disasters are going to disturb. In the case of ecosystems, as well as in traditional economic systems, the perspective is that of the medium/long term (Ministero dell’ambiente e della tutela del territorio e del mare, 2009).

First of all, we identified what are the information concerning natural disasters to be taken into consideration. After that, we proceed to build a scheme useful for economic evaluation.

To achieve this, it is necessary to hypothesise which valuation objects would have been damaged and, on the basis of this, verify which tools are available to give an economic value. Ecosystems played an important role in this process. Even if they can be classified into natural, semi-natural, and artificial [42], for the natural territories, the presence of natural ecosystems was particularly assumed, and therefore, we have taken into consideration the damage only to this system. Therefore, the urbanised areas are not considered as artificial ecosystems (urban ecosystem), and other methodologies are used to calculate damages on people, infrastructure, and industrial plants.

#### 4.2 Disaster on highly natural area: the value of ecosystem service (ESS)

When it was agreed that economy and ecology had to go in tandem (cfr “ecological economy”) against a background of unsustainable growth in the resources use, common language has been sought. The first step to solve this challenge is to refer to a common functional unit: the ecosystem (Ministero dell’ambiente e della tutela del



**Figure 5.**  
*Presence of ecosystem or assets economically evaluable.*

	Short term	Medium term	Long term
Natural area	Earthquakes, avalanches	Landslides	Landslides
Urbanised area		Landslides, avalanches	Earthquakes, landslides, avalanches

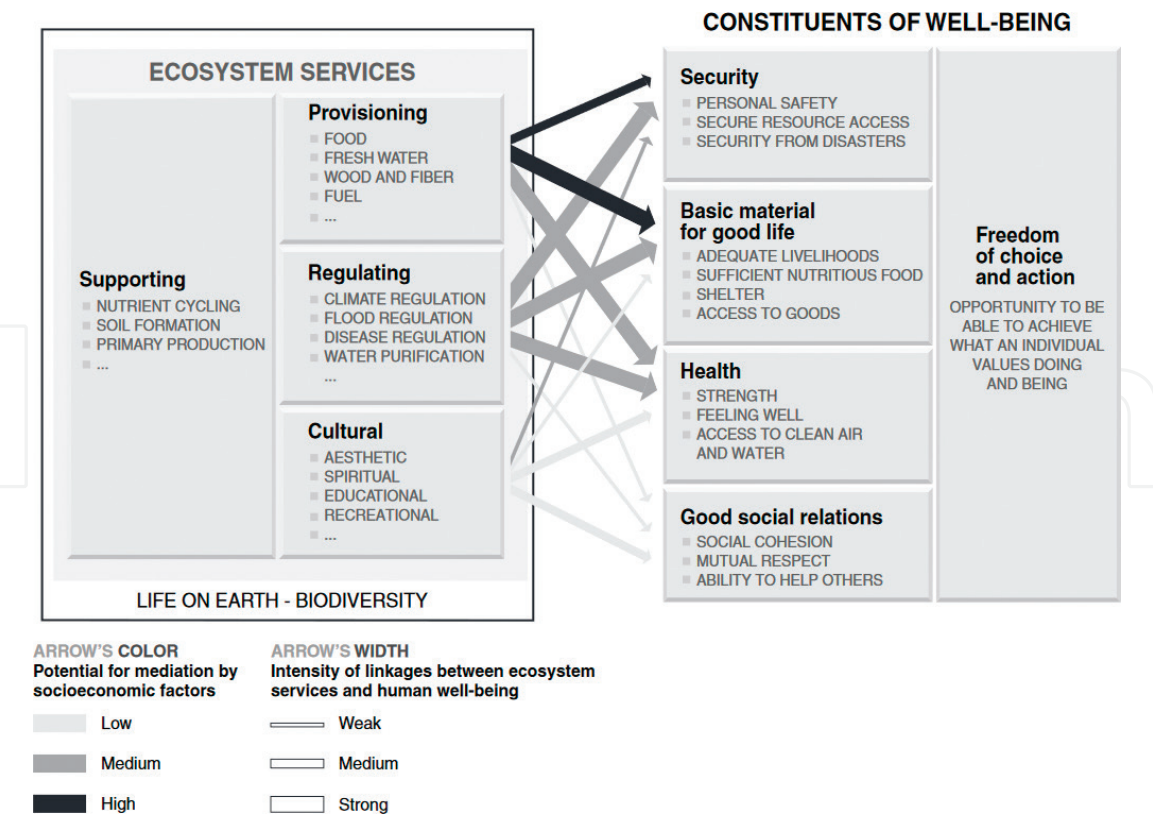
**Table 2.**  
*Time axis for disasters and areas of different types.*

territorio e del mare, 2009). Because it is very difficult to evaluate an ecosystem for the multiple relationships inside, we value ESS to human well-being [43].

This aspect gives us a chance on developing a different logical argument. In fact, rarely, the discussion on an area’s value is focused on ESS: normally all attention is on the role that plays on local economies. Areas have to be recognised for the service they provide: mitigation of climate change and natural disasters, disease control, maintenance of water quality, and cultural services, including recreation, maintenance of historical or iconic landscapes, and protection of sacred natural sites [44].

ESSs are defined by the Millennium Ecosystem Assessment as “the benefits people obtain from ecosystems” [3]. Fisher and Turner [45] added that “ecosystems services are the aspects of ecosystems utilised (actively or passively) to produce human well-being”. The MA developed and claimed a very important concept: the well-being of society is strictly linked to services provided by nature. **Figure 6**, by MA [3], shows this relation.

The measurement of losses’ full costs and degradation of these ESSs are difficult to assess, but there is a sense of urgency to implement an economic tracking system to monitor all disaster risk reduction costs for mitigation, preparedness, and emergency response. A correct evaluation of ESS gives helpful information to estimate costs and benefits of decisions, to define future scenarios and to recognise and avoid unexpected consequences [5]. The value of ESS can be linked to the direct use (e.g., wood) or indirect use (value of specific ecological functions) or to the particular item relevance for other goods or values, or, finally, the value may simply be intrinsic (e.g., existence value or cultural value). To narrow the field and make a good comparison, the first step is to draw from the studies that have circumscribed key ESS of the different biomes on Earth [3]. The starting point is the ecosystems present in the investigated areas. The logical path is that of analysing the identification of the services offered, to move on to quantification and valorisation [46]. In this case, we consider ESS in alpine environments (mountains and forests), which mainly serve areas with high naturalness but also urbanised areas, always in a mountain environment. For the *identification* step, it is important to start from ESS definition. If ESSs are useful for human well-being, the supply of and demand for ESS have to be determined [47]. In order to define which type of ESS the territory can supply, the reviews cited by Haida et al. [48] have reported that most investigated are regulating services (mainly carbon sequestration) followed by provisioning services (such as the supply of fresh water and food) and cultural services (largely recreation and tourism). From the demand side, an analysis of inhabitants, touristic flows, and activities must be conducted (on bibliographic basis). The steps of *quantification* and *evaluation* show the main difficulties to arrive at a concrete and usable result. Starting from Costanza’s study, in one of the most famous ecological economists, where dozens of scientific papers on economic evaluation of ESS [43] are summarised [43] and produce a “summary of average global value of annual ecosystem services”, many other researches have tried to get into the specifics of this complex assessment.



**Figure 6.**  
*Ecosystem services and human well-being.*

Despite all the progresses made in this field, it is difficult to assess environmental assets, especially when it is necessary to attribute value to the benefits they generate. Even if the monetary evaluation of environmental goods without a market can be more or less correct, it provides a starting point for hypothesising policies and strategies. In order to focus attention and attribute a monetary value to environmental goods and, in this case, to ESS, the willingness to pay (WtP) and total economic value (VET) are often used. Also, in his review reports, WTP of individuals for ESS is the first method used [43]. In this case, it is emphasised that it is not a matter of attributing a value to a real exchange but only to make comparisons and establish strategies. Monetary value can be used as an indicator to encourage development policies.

Instead, as in the case of PES (payment for ecosystem services) [46], governments and private enterprises have started to pay for ESS [44]. Other authors have stated that its price does not represent the good real value but only one way to facilitate comparison with actions that have a market [49].

For quantification and attribution of value in the development of the project, reference was made to the data sheets deriving from Making Good Natura (LIFE+11 ENV/IT/000168) [5]: within it is possible to find indications for the evaluation of different ESSs.

### 4.3 Disaster on urbanised area: the value of life, infrastructures, and plant

In this part, the urbanised area is taken into consideration, but “urbanised like” can be in mountain territory, the focus of the Inte.RI.M. project. The urban situation is easier to assess but only apparently. It is true that there are methods for evaluating human lives and economic activities, but for these too, there are aspects of uncertainty as well as those predicted for ESS.

In order to monetise the value of a *human life* in disasters, we often refer to VOSL (value of statistic life) and DALY (disability-adjusted life year) [50].

For a “complete and detailed assessment of the exposure of ‘economic activities’ to natural disaster”, Marin et al. study [51] refers to literature that recommends the use of different proxies depending on type of disaster. For flood, an interesting study carried out on an Italian case exploits the overlap between risk maps and residential areas. Starting from this information and using databases on real-estate values and reconstruction costs, it is possible to arrive to a damage assessment “ex ante” in case of floods useful for strategic reasoning [52]. For landslides, another Italian case is chosen. The interesting aspect of this research is that “Four types of assets are combined in the weighted assets map: (1) physical (buildings, cultural buildings and transportation networks), (2) social (population), (3) economic (land value), and (4) environmental (land cover and protected areas)” [53]. The joint evaluation of these variables on a concrete level allows us to arrive at a hypothesis that is not too far from reality.

#### 4.4 Balanced scorecard

For monitoring and managing economic aspects of the project, we use different methods and tools that belong to the manager’s toolbox, for example, cost-benefit analysis and multivariate analysis (in this work, we will focus on the former). But rather than using these raw mathematical, statistical, or financial tools alone, we integrate them in a wider framework, balanced scorecard, whose strengths are very useful for the Inte.Ri.M. project.

Balanced scorecard is a business framework used for tracking, planning, and managing an organisation’s strategy. The knowledge of balanced scorecard was introduced by Robert S. Kaplan and David P. Norton in 1992 [54] and spread thanks to their book in 1996 [55]. The many criticisms the framework received are not discussed in this work.

Many benefits come from balanced scorecard. Among all, the framework allows:

- Transforming strategic objectives in operational objectives
- Defining priorities of development projects and actions
- Measuring and checking organisation’s path towards defined targets
- Improving competencies in building and implementing strategies
- Spreading knowledge of the strategy in the whole organisation

Balanced scorecard is based on four “perspectives”: financial, customer, internal business processes, learning, and growth. For each one, relevant topics are objectives, measures, targets, and initiatives, which must be defined, described, or computed as a preliminary step in strategy definition.

Mainly used in business, balanced scorecard is also used in the public sector, that is, government and non-profit organisations. In these cases, perspectives may be reordered differently or adapted to this different context. Specific benefits for government or non-profit organisations arise from strategy maps, a sort of add-on for balanced scorecard [56]. Strategy maps emphasise cause and effect relationships among perspectives and linked objectives but specifically take into account human capital and other variables belonging to the field of knowledge economy that



usually financial accounting does not consider. This is the most important reason why we decide to use the balanced scorecard with strategy maps. In the Inte.Ri.M. project, each type of area has a distinct balanced scorecard.

#### **4.5 Cost-benefit analysis and cost-effectiveness analysis**

It is in this framework that we integrate classical management tools like cost-benefit analysis [57, 58], for comparing prevention costs with the damages from the disasters that can be avoided. One of the preliminary activities required to perform cost-benefit analysis is to measure all cost and benefit elements and to convert them in some unit of monetary measurement. Then, traditional indicators like net present value or internal return rate are computed.

In many applications of the analysis, especially in the public sector, problems arise because elements are present that analyst or policymaker cannot or does not want to convert in a monetary measurement, that is, human lives, healthcare quality, or beauty of a landscape. For an example about environmental resources, close to our research interest, see [59]. For this reason, besides cost-benefit analysis, we also use cost-effectiveness analysis. Although typically employed in health applications, the Inte.Ri.M. project can benefit from this technique as it allows to compare alternatives based on their cost and a measure of effectiveness that is quantified but not monetised, for example, the number of lives saved instead of a monetary value of lives. Given the impossibility to compare costs expressed in monetary units and benefits expressed in another unit of measurement, cost-effectiveness analysis proceeds through the construction of cost-effectiveness indexes that allow to compare the various alternatives.

Although the researcher's toolbox is very rich, some problems still need to be investigated. One of the most critical variables in the Inte.Ri.M. project is recovery time. Recovery time is neither a cost nor a benefit element, but it is essential to define the time window costs, and benefits are spanned over. Recovery time is difficult to estimate and is likely to increase. To make matters worse, an increase in recovery time induces changes in amount and allocation in time of monetary values. This dependence on an exogenous variable requires to reconsider the financial model and may impact considerably on results and on sensitivity analysis, one of the final steps of cost-benefit analysis.

### **5. Conclusions**

The chapter outlined the state of the art of Inte.Ri.M. project. The on-site activity will provide answers to the question marks determined by the specific operational conditions established by the mountain environment.

The project will be able to generate benefits that potentially will have an impact in terms of creating value for the area. Beneficial effects are identified on two levels:

- A broad level: regarding the method of analysis development that integrates economic and technical evaluations. This output is designed to be made replicable in as many areas as possible.
- The restricted level (identified as “pilot case”) that through the project will make use of hard data for risk management in the phases of prevention, intervention, and recovery is capable of enhancing the data relating to the analysis of costs and benefits.



The project development is planned at two levels (national and international). Each stage foresees a growing extension (qualitative and quantitative) of Inte.Ri.M. system through applications that imply an increasing complexity, in terms of technical, economic, and management issues to cope with and in number and variety of partners to involve. The needs of time and funding grow, therefore, consistently. The output of our project and actions planned to increase interest and promote cooperation, jointly with the research team's propensity to act internationally, could make international level directly accessible.

IntechOpen

IntechOpen

### **Author details**

Riccardo Beltramo\*, Paolo Cantore, Enrica Vesce, Sergio Margarita  
and Paola De Bernardi  
University of Turin, Turin, Italy

\*Address all correspondence to: [riccardo.beltramo@unito.it](mailto:riccardo.beltramo@unito.it)

### **IntechOpen**

© 2018 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

## References

- [1] Piemonte Region, Piemonte Informa [Online]. 2017. Available from: <http://www.regione.piemonte.it/pinforma/ambiente/1695-oltre-60-milioni-per-la-difesa-del-suolo-e-contro-il-dissesto-idrogeologico.html>. [Accessed: 20-7-2018]
- [2] Arpa, Piemonte Region, Rischio Naturali [Online]. 2018. Available from: <http://relazione.ambiente.piemonte.it/2018/it/territorio/fattori/rischi-naturali>. [Accessed: 20-7-2018]
- [3] Millenium Ecosystem Assessment. Ecosystem and Human Well-Being. Washington, DC: Island Press; 2005
- [4] Nibanupudi HK, Shaw R. Mountain Hazards and Disaster Risk Reduction. Japan: Springer; 2014
- [5] Schirpke U, Scolozzi R, De Marco C. Modello dimostrativo di valutazione qualitativa e quantitativa dei servizi ecosistemici nei siti pilota. Parte1: Metodi di valutazione, Bolzano. 2014;1:3-5
- [6] Zimmermann M, Keiler M. International frameworks for disaster risk reduction: Useful guidance for sustainable mountain development? Mountain Research and Development. 2015;35(2):195-202
- [7] Gaire R, Sriharsha C, Puthal D, Wijaya H, Kim J, Keshari P, et al. Internet of things (IoT) and cloud computing enabled disaster management. In: Integration of Cyber-Physical Systems, Cloud, and Internet of Things. New York, United States: Cornell University Library; 2018
- [8] IEEE. Towards a Definition of the Internet of Things (IoT) [Online]. 2015. Available from: <https://iot.ieee.org/definition.html>
- [9] Yan Q, Li H, Jing L, Ge W, Ding H, Tang Y, Kongwen Z. Research on Automatic Detection of Seismic Landslides Information. IEEE International Geoscience and Remote Sensing Symposium (IGARSS). Beijing, China: IEEE; 10-15 July 2016
- [10] Mishra PK, S. K. Shukla Dutta S, S. K. Chauha Prasad GM. Detection of Landslide Using Wireless Sensor Networks. IEEE; 2011
- [11] Supekar PR, Takayama S. Characteristics evaluation of sensing network in wireless landslide surveillance system. In: Proceedings of the SICE Annual Conference; Tsukuba, Japan. 2016
- [12] Khoa VV, Kazuya O, Shigeru T. Collaboration of host system and local sensing node network system. In: Proceedings of the SICE Annual Conference; Tsukuba. 2016
- [13] Vera JE, Mora SF, Cervantes RA. IEEE Biennial Congress of Argentina (ARGENCON). Design and testing of a network of sensors on land surfaces to prevent landslides. Buenos Aires Argentina; 2016
- [14] Hans-Peter M, Schweizer J, Birkeland K. Some recent advances in snow and avalanche science. Cold Regions Science and Technology. 2011;119-121
- [15] Bellairea S, Herwijnen AV, Mitterer C, Schweizer J. On forecasting wet-snow avalanche activity using simulated snow cover. Cold Regions Science and Technology; 2017:2838
- [16] Thüning T, Schoch M, Herwijnen AV, Schweizer J. Robust snow avalanche detection using supervised machine learning. Cold Regions Science and Technology. 2015:60-66
- [17] van Herwijnen JSA. Monitoring avalanche activity using a seismic

- sensor. *Cold Regions Science and Technology*. 2011:165-176
- [18] Scott E, Hayward C, Kubichek R, Hamann J, Pierre J, Comey B. Single and Multiple Sensor Identification of Avalanche-generated. *Cold Regions Science and Technology*. 2007 pp. 159-170
- [19] Herwijnen AV, Turner J, Schweizer J. Listening to Snow—Avalanche Detection Using a Seismic Sensor Array. Squaw Valley, CA: International Snow Science Workshop; 2010
- [20] Lehning M, Naaim F, Naaim M, Brabec B, Doorschot J, Durand Y, et al. Snow drift: Acoustic sensors for avalanche warning and research. *Natural Hazards and Earth System Sciences*. 2002:121-128
- [21] Michahelles F, Matter P, Schmidt A, Schiele B. Applying Wearable Sensors to Avalanche Rescue: First Experiences with a Novel Avalanche Beacon. *Computers and Graphics*. Pergamon New York: 2003;27(6)
- [22] Stephens E, Cloke H. Improving flood forecasts for better flood. *The Geographical Journal*. 2014:310-316
- [23] Webster PJ, Toma VE, Kim H. Were the 2010 Pakistan floods predictable? *Geophysical Research Letters*. 2011:1-5
- [24] Wu L, Seo D-J, Demargne J, Brown JD, Cong S, Schaake J. Generation of ensemble precipitation forecast from single-valued quantitative. *Journal of Hydrology*. 2011:281-298
- [25] Lee C-S, Ho H-Y, Lee KT, Wang Y-C, Guo W-D, Chen DY-C, et al. Assessment of sewer flooding model based on ensemble quantitative precipitation forecast. *Journal of Hydrology*. 2013:101-113
- [26] Sabino A, Poseiro P, Rodrigues A, Reis MT, Fortes CJ, Reis R, et al. Coastal risk forecast system. *Journal of Geographical Systems*. 2018;20:159-184
- [27] Herle RBJBS. Smart sensor-based geospatial architecture for dike monitoring. In: *IOP Conf. Series: Earth and Environmental Science*; Saint Mary; 2016
- [28] Zambrano AM, Perez I, Palau C, Esteve M. Distributed sensor system for earthquake early. *IEEE Latin America Transactions*. 2015;13:291-2998
- [29] Margottini C, Canuti P, Sassa K, et al. *Landslide Science and Practice: Volume 1: Landslide Inventory and Susceptibility and Hazard Zoning*. Springer, Verlag Berlin Heidelberg; 2013
- [30] Arattano M, Marchi L. L. Systems and sensors for debris-flow monitoring and warning. *Sensors*. 2008:2436-2452
- [31] Millan-Garcia L, Sanchez-Perez G, Nakano M, Toscano-Medina K, Perez-Meana H, Rojas-Cardenas L. An early fire detection algorithm using IP cameras. *Sensors*. 2012:5670-5686
- [32] Kanwal K, Liaquat A, Mughal M, Abbasi AR, Aamir M. Towards development of a low-cost early fire detection system using wireless sensor network and machine vision. *Wireless Personal Communications*. 2017:475-489
- [33] Qureshi WS, Ekpanyapong M, Dailey MN, Rinsurongkawong S, Malenichev A, Krasotkina O. QuickBlaze: Early fire detection using a combined video processing approach. *Fire Technology*. 2016:1293-1317
- [34] Koltunov A, Ustin SL, Quayle B, Schwind B, Ambrosia VG, Li W. The development and first validation of the GOES early fire detection (GOES-EFD) algorithm. *Remote Sensing of Environment*. 2016:436-453
- [35] Gutmacher D, Hoefer U, Wöllenstein J. Gas sensor technologies

for fire detection. *Sensors and Actuators B: Chemical*. **2012**:40-45

[36] Qiang C. A forest early fire detection algorithm. *Sensors & Transducers*. 2014:73-79

[37] Centemeri L. Retour à Seveso: La complexité morale et politique du dommage à l'environnement. *Annales. Histoire, Sciences Sociales*. 2011:213-240

[38] Laplante NL, NL PA, Laplante PA, Voas JM. Could the internet of things be used to enhance student nurses' experiences in a disaster simulation? *Online Journal of Nursing Informatics*. 2018

[39] Islam RU, Andersson K, Hossain MS. Heterogeneous wireless sensor networks using CoAP and SMS to predict natural disasters. In: 2017 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS); Atlanta, GA; 2017

[40] Istituto Angelo Mosso. Università degli studi di Torino [Online]. Available from: <https://www.unito.it/ateneo/strutture-e-sedi/sedi/piano-di-sviluppo-edilizio/progetti-di-edilizia-universitaria/istituto>. [Consultato il giorno: 23-07-2018]

[41] Debarati G-S, Philippe H, Regina B. Annual Disaster Statistical Review 2015: The Numbers and Trends. Brussels, Belgium: Université catholique de Louvain; 2016

[42] Lawton JH. What do species do in ecosystems? *Oikos*. 1994;**71**(3):367-374

[43] Costanza R, d'Arge R, de Groot R, Faber S, Grasso M, Hannon B, et al. The value of the world's ecosystem services and natural capital. *Nature*. 1997;**387**:253-260

[44] Dudley N, Higgins-Zogib L, MacKinnon K, Sandwith T, Stolton

S. National Parks with benefits: How protecting the planet's biodiversity also provide ecosystem service. *Solutions for a Sustainable and Desiderable Future*. 2011;**2**(6):87-95

[45] Fischer B, Turner RK. Ecosystem services: Classification for valuation. *Biological Conservation*. 2008;**141**:1167-1169

[46] Ministero dell'ambiente e della tutela del territorio e del mare. Definizione del metodo per la classificazione e la quantificazione dei servizi ecosistemici in Italia; 2009

[47] Grêt-Regamey A, Brunner SH, Kienast F. Mountain ecosystem services: Who cares? *International Mountain Research and Development*. International Mountain Society; 2012;**32**:S23-S34

[48] Haida C, Rüdiger J, Tappeiner U. Ecosystem services in mountain regions: Experts' perceptions. *Regional Environmental Change*. 2016;**(16)**:1989-2004

[49] Massimo De Marchi RS. RS. La valutazione economica dei servizi ecosistemici e del paesaggio nel Parco Naturale Adamello Brenta. *Valutazione Ambientale*. 2012:54-60

[50] Casucci S, Liberatore P. Una valutazione economica dei danni causati dai disastri naturali [Online]. 2012. Available from: <http://www.irpi.cnr.it/outreach/una-valutazione-economica-dei-danni-causati-dai-disastri-naturali/>

[51] Marin G, Modica M. Socio-economic exposure to natural disasters. *Environmental Impact Assessment Review*. Elsevier Science. 2017;**64**:57-66

[52] Sterlacchini S, Zazzeri M, Genovese E, Modica M, Zoboli R. Flood Damage in Italy: Towards an Assessment Model of Reconstruction Costs. Vienna: EGU General Assembly; 2016;**11**

[53] Pellicani R, Westen CJV, Spilotro G. Assessing landslide exposure in areas with limited. *Landslides*. 2014;**11**:463-480

[54] Kaplan RS, Norton DP. The balanced scorecard—Measures that drive performance. *Harvard Business Review*. 1992;**70**(1):70-79

[55] Kaplan RS, Norton DP. *The Balanced Scorecard: Translating Strategy into Action*. Harvard, United States, Boston: Harvard Business School Press; 1996

[56] Kaplan RS, Norton DP. *Strategy Maps: Converting Intangible Assets into Tangible Outcomes*. Harvard, United States: Harvard Business School Press; 2004

[57] Amartya S. In: Adler MD, Posner EA, editors. *The Discipline of Cost-Benefit Analysis, Cost-Benefit Analysis. Legal, Economic, and Philosophical Perspective*. Chicago, United States: The University of Chicago Press; 2001

[58] Layard R, Glaister S. *Cost-Benefit Analysis*. Cambridge, United Kingdom: Cambridge University Press; 1994

[59] Dasgupta P, Mäler K-G. The environment: Environment and emerging development issues. In: Layard R, Glaister S, editors. *Cost-Benefit Analysis*. Cambridge, United Kingdom: Cambridge University Press; 1994