The cartography in seismic hazard assessment and communication: the case study of the 2012 Po Plain earthquakes (northern Italy)

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Abstract
In this article, the use of cartography and geographical information system are discussed within hazard and risk communication approaches. It aims to examine the seismic risk cartography related to the area struck by the 2012 seismic sequence in the Po Plain which was related to the activity of buried Apennines faulted folds. It has consisted of seven M>5 quakes from 20th May to 3rd June 2012 and more than 2500 aftershocks of lower magnitude during almost one year. The most relevant geological effect caused by the two stronger earthquakes (ML = 5.9 and ML = 5.8) was the 10-15 cm uplift of the epicentral area. Moreover several hundreds of earthquake-induced environmental effects (EEE) were detected (soil liquefaction phenomena, ground ruptures, sand boils, etc.). By the comparison of the location of the EEE with the Geomorphological Map of the Po Plain, it appeared that they were aligned and concentrated along the courses of abandoned riverbeds mainly characterized by the presence of superficial sandy texture highlighting the importance the geomorphological maps for seismic hazard assessment. As concerns macroseismic intensity maps, an intensity field that integrates the ESI scale, which considers the EEE and the MCS intensity evaluations, based on the pattern of buildings damage, represents a better tool for characterizing the 2012 event in the framework of the seismic-hazard assessment of the Po Plain.

In spite of the unpredictability of earthquakes the population has given credit to various groundless alarms on the basis of gas emission, bubbling water and ground fractures. Therefore the Emilia-Romagna Region established a group of experts that throughout a dedicated website communicates correct information on particular geological phenomena that are observed and usually misunderstood by the population. The role of communication is essential in order to enhance awareness on seismic hazard and environmental effects comprehension among civil society.

Keywords
Cartography, earthquake-induced environmental effects, seismic hazard assessment, rumors, communication, Po Plain, northern Italy.

Introduction

Communication on seismic hazard is essential to protect people and infrastructure from devastating disasters due to extreme events and to develop a social risk preparedness culture. Whereas the predisposing factors and the impact of earthquakes have a spatial dimension, the cartographic representation is a relevant tool for seismic hazard assessment and communication, potentially able to reach a different and widened public. In this contribution, the use of cartography and geographical information system are discussed within hazard and risk communication approaches. Despite cartographic information allow to visualize and to synthesize the complexity of variables related to seismic hazard, in general, their interpretations and the knowledge exchange between scientific community and civil population still remain often difficult. This paper aims to trace the evolution and development of seismic risk cartography related to the area struck by the 2012 seismic swarm in the Po Plain (Fig.1) that caused 27 deaths, over 400 persons injured, the evacuation of 14,000 people and considerable damages to the cultural heritage and to the regional economic activities.

Fig. 1 – Epicentral area of the 2012 earthquakes in the Po Plain (northern Italy)

The geological consequences of the 2012 Po Plain earthquakes

The 2012 Po Plain earthquakes have been analyzed from various viewpoints (seismological, seismotectonic, geomorphological, historical etc.) as shown by many articles and among them,worthy of note is Anzidei et al. (2012).

In detail, on May 20, 2012, at 4:03 local time (2:03 UTC), a large part of the Po Plain between the cities of Ferrara, Modena and Mantova was struck by a damaging earthquake (ML 5.9). The epicenter was located in the province of Modena, approximately 30 km west of Ferrara. The 29th May 2012 (ML = 5.8) a second shock hit the area, 12 km west of the first epicenter. Moreover this seismic swarm has consisted of another five M>5 quakes till to 3/06/2012 and more than 2500 aftershocks of lower magnitude during almost one year. The earthquake sequence was caused by the thrust front activity of buried Apennines folds (known as Ferrara Folds) formed by three N-verging arcs covered by Po Plain Plio-quaternary sediments (Pieri and Groppi, 1981). The most external structures, the active Ferrara and Mirandola thrusts and folds were responsible (Bignami et al. 2012, Salvi et al. 2012). The near acceleration recording station (MRN) was situated at Mirandola, at distance of 17 km to the epicenter of the May 20th earthquake and of 2 km to the epicenter of the May 29th earthquake. Besides the collapse of various unreinforced industrial and civil buildings and old masonry monuments, due to their high vulnerability, the two events caused several geological and geomorphological effects over large areas in the region.

In detail, the most relevant geological effect caused by the two stronger earthquakes was the 10-15 cm of uplift of the epicentral area, detected by the InSAR interferometry, corresponding to the the most external structures of Ferrara Folds (Salvi et al., 2012).

At a detailed scale several hundreds of earthquake-induced environmental effects (EEE), mainly of the geological/geomorphological type, scattered all over the epicentral area, were detected (Fig. 2). They mainly consisted of liquefaction phenomena, ground ruptures and sand boils. Some artificial canals showed uplifting, bulging and cracks of the bottom and fractures and soil slips on the banks. Also hydrogeological anomalies, such as strong water-table fluctuations, emission of hot water and sand from ground cracks and water wells, have been recorded.

Di Manna et al. (2012) reports that more than 500 ground effects were recognized, spread over an area of about 700 km, whereas, according to the Emergeo Working Group (2013), more than 1000 environmental effects, spread over an area of about 1200 km2 were detected. The different number of EEE is due to the use of aerial photography on a wider area (Emergeo Working Group, 2013) and to the method of EEE counting (single or cluster of EEE).

Fig.2. Examples of earthquake-induced environmental effects (EEE) in the epicentral area: ground ruptures, sand emission from water well, bottom canal showing uplifting and cracks, sand boils due to liquefaction.

Immediately after the earthquake of May 20th 2012 a field survey was conducted by researchers coming from all over Italy through the natural and built environment for capturing as quickly as possible EEE and ascertaining damage to buildings and infrastructures.
On the base of the data and information collected by Di Manna et al. (2012) and Ninfo et al. (2012) during the field surveys the following notes on the EEE can be done: a) the liquefaction begins immediately after a strong earthquake and with a considerable amount of water; b) the deposition of the sediments on the ground is very rapid; c) the water coming out from fractures, warm in some cases, gave rise to jets also 1,50 m high; d) about 80% of the effects were induced by the May 20th main shock (M = 5.9), while 20% of the effects were triggered by the May 29th main quake (M = 5.8); e) many liquefactions related to the 20th May 2012 shock were reactivated by the 29th May 2012 event; f) the epicentral distance from the farthest liquefaction phenomena was about 25 km; g) the sediments were brought to the surface by the uplifting of the more superficial water table; h) the sediments were brought to the surface in correspondence of ground fractures or wells and were mainly sand coming from the first meters of the subsoil; i) the material ejected reached in many cases a thickness of more than 30 cm and, inside some buildings, from pavement cracks it uplifted up to 1 m; l) the rising of the water table has been detected, as well as witnesses, by automatic monitoring in several wells.

Material and Methods

a) The coseismic effects inventory and seismic hazard cartography

Despite the several database implemented for a better understanding of the scenarios observed by surveys of several Italian Universities and research centers, such as Istituto Nazionale di Geofisica e Vulcanologia (INGV), Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Geological Service of the Emilia Romagna Region, an EEE homogeneous overview merging the different contributions is still missing. A doctoral research was focused in building up, within a GIS environment, a homogeneous and integrated database inventory of the earthquake-induced environmental effects, based on linked descriptive sheets, in order to have a more holistic overview of the EEE distribution in the area (Lanfredi Sofia, in progress). Hence, it is presented how cartographic representations can became a helpful instrument to visualize and communicate seismic hazard to widen public; in particular how the seismic hazard cartography at local scale has evolved during the last two years after the earthquake experience.

Geological, geomorphological, geochemical and geophysical features of the epicentral area were analyzed by researchers to identify the seismogenic structures, to study the effects on the environment with the goal to better understand earthquakes and to provide new knowledge for civil protection, population and local stakeholders as policy makers. Sharing preliminary data among scientists, informing people and media about the causes and effects of the earthquake in a short time was crucial, first of all in relation to the environmental effect recognition.

The raw environmental effects data were derived from different investigating techniques: field and aerial surveys, internet crowd sourcing and personal communication through interviews. Beside differences in relieve counts and recognition by various researcher teams the heterogeneity on field surveys procedures, data acquisition tools and in data analysis methods applied brought to different databases (e.g. Emergeo, 2012; ISPRA, 2014).

In Lanfredi Sofia (in progress), the acquired data have been structured in reports and maps illustrating the spatial distribution of the EEE and their correlation with the triggering causes and predisposing factors.

By overlaying a variety of thematic layers of the study area and related to the geology, geomorphology and water table it was possible to better understand the subsoil of the area. Geoprocessing tools within GIS allowed to merge all different coseismic effects in one single layers and trough the description discriminate all the points into different phenomena in five categories: liquefaction, ground cracks, slope instability, terrain elevation changes, and others. A series of 250 sheets, directly linked to the location of EEE spatial distribution (i.e. street, city, and/or geographical coordinates) has been created in order to communicate information through exhaustive descriptions of the different types of effects with the associated cartography and photographic documentation (Fig.3) . The final aims is the inventory publishing with an open source mapping interface.

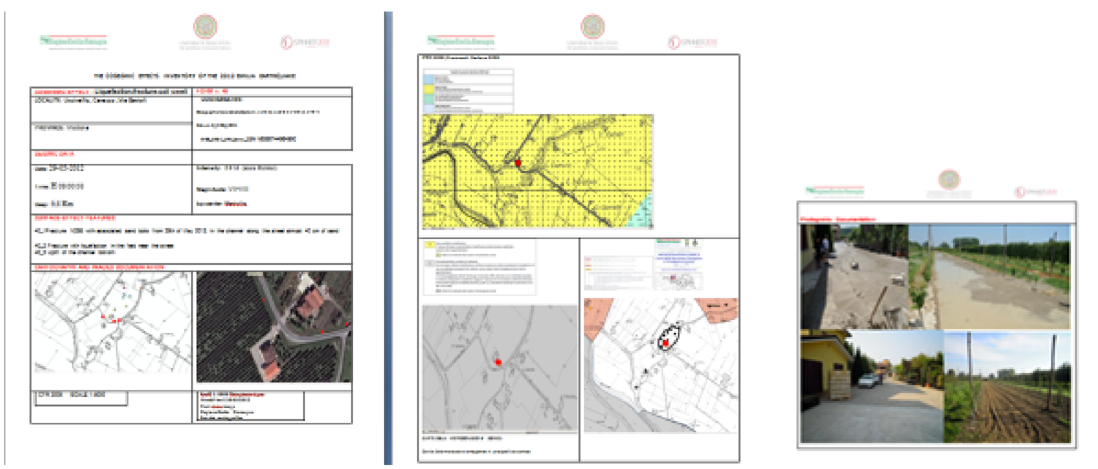

Fig. 3 Example of Data Sheet for earthquake-induced environmental effects (EEE) inventory. The data sheets contain information on the EEE typology, the epicenters location, the EEE coordinates, a brief description of the phenomena, subsets of seismic risk cartography and EEE images taken different periods.

b) Seismic hazard cartography

Since after the first EEE collection, by the comparison of their location with the Geomorphological Map of the Po Plain (Castiglioni et al., 1997) did appear clearly that the coseismic effects were aligned and concentrated along the courses of abandoned riverbeds (at ground level or as levees) and on crevasse splay mainly characterized by the presence of superficial sandy texture (Fig. 4). This aspect highlights the importance and the role of the geomorphological maps for seismic hazard assessment of alluvial plain areas.

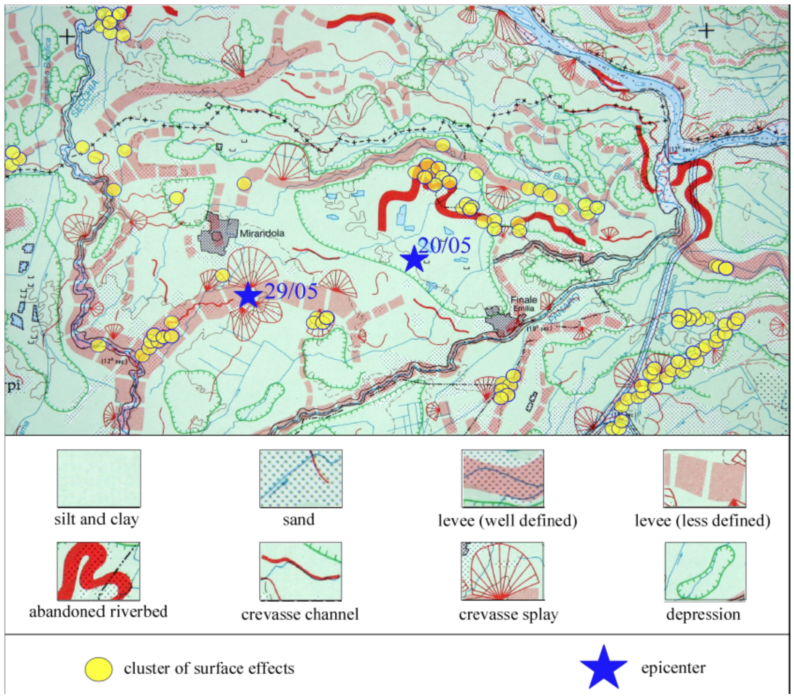

Fig. 4. Location of the EEE on the Geomorphological Map of the Po Plain (Bertolini and Fioroni, 2012)

Concerning macroseismic intensity maps, generally implemented at small scale, a macroseismic intensity field based on the ESI scale (Guerrieri & Vittori, 2007), which considers the characteristics and size of EEE, was depicted by Di Manna et al., 2012 (Fig. 5). Comparing the ESI local intensity values with the macroseismic intensity evaluations map (MCS, Galli *et al.*, 2012), based on the pattern of buildings damage, it is clear that the epicentral intensity evaluations are comparable and EEE can be a better tool for local intensity assessment, as they are independent of the type of construction, but are governed directly by the geological/geomorphological site conditions. For these reasons, a macroseismic intensity field that integrates ESI and MCS intensity evaluations represents a better tool for characterizing the 2012 event in the framework of the seismic-hazard assessment. The above mentioned aspects have been also recently highlighted in the article of De Martini et al. (2014).

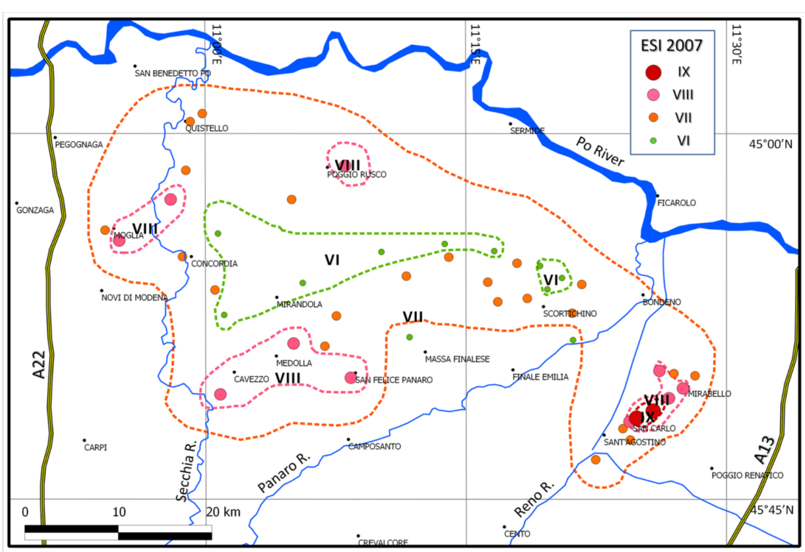

Fig. 5 . ESI local intensities (based on the characteristics of the surveyed ground effects) and inferred isoseismals (Di Manna et al., 2012).

The 2012 earthquakes experience has enhanced the details in the seismic hazard mapping of the municipalities located in the epicentral area. In fact, the seismic hazard cartography edited by the Regione Emilia Romagna for the local administration have been developed through the implementation of large scale maps also including the EEE and the stratigraphy of the subsoil (Regione Emilia Romagna, 2013). For instance, taking in account the territory of the municipality of Cavezzo (epicenter site of the 29th May 2012, ML = 5.8, quake), by the comparison of the medium scale (1:25,000 scale) seismic susceptibility map for assessing seismic hazard implemented by Provincia di Modena, (2009)(Fig.6) and the large scale (1:10,000) Seismic Microzonation map implemented by Regione Emilia Romagna (2013)(Fig. 7) it can be seen as the areas susceptible of liquefaction are more detailed and they were defined by the location of EEE and the interpolation of the stratigraphic layers.
Visualizing land natural hazards and uncertainties through cartographic information, allow to explain and to synthesize the complexity of variables of natural hazard events. Natural disasters such as earthquakes have spatial dimensions and impacts, for instance cartographic representations and GIS constitute a powerful tool for understanding scientific contents and to reach a differentiate and widened public.

Fig. 6 Sketch of a medium-scale (1:25,000 scale) seismic susceptibility maps of Cavezzo Municipality (Province of Modena, 2009). Dark color: area prone to seismic amplification for lithological characteristics and potential liquefaction; Light color: area prone to seismic amplification for lithological characteristics and potential ground collapse

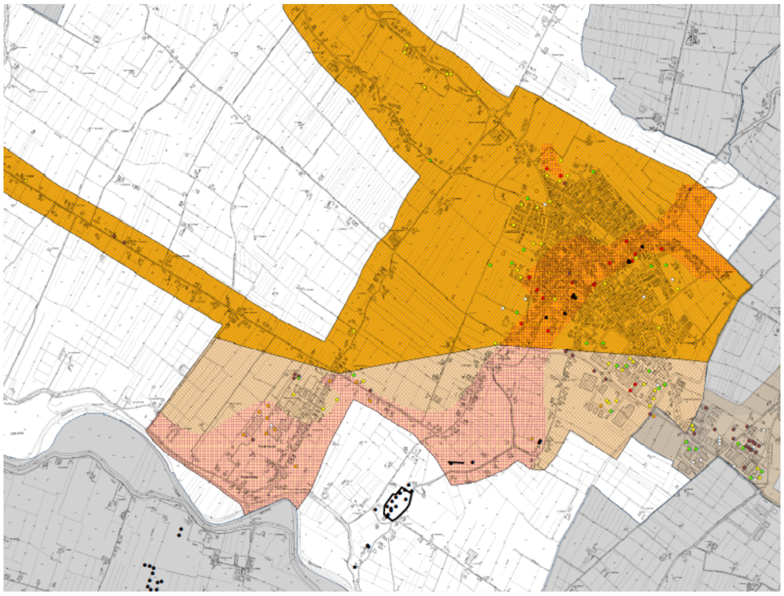

Fig.7 Sketch of the Seismic Microzonation map of Cavezzo municipality (Regione Emilia Romagna, 2013). Dark orange: Substrate at depths <120 m. Sediments prone to liquefaction in the first 10 m from ground level. Light orange: Substrate at depths <120 m. Sediments prone to liquefaction between 10 and 20 m from ground level. Pink: Substrate at depths > 120 m. Sediments prone to liquefaction in the first 10 m from ground level. Light pink: Substrate at depths> 120 m. Sediments prone to liquefaction between 10 and 20 m from ground level. Points: layers prone to liquefaction at different depths. Grey: area out of the municipality; White: area in the municipality not investigated.

c) A website for the correct communication of particular geological phenomena

The most important and delicate problem following the 2012 Emilia seismic sequence has concerned earthquake prediction. Although experts have repeatedly stressed in all possible ways the unforeseeable nature of earthquakes, the population has given credit to various groundless alarms which were spread around. The tragic experiences of the earthquake-struck population, have induced some people in the epicentral area and its surroundings to pay particular attention to particular geological phenomena occurring in their own territory, wrongly linking them to premonitory signs of earthquakes (Bertacchini et al., 2014).

For example, in mid-February 2013, in the Ferrara plain, a jet of methane and hot water gushing out from the soil aroused concern among local inhabitants since it was interpreted as a precursory sign of a seismic event. Actually, this vent was coming from a poorly sealed old methane well and the alert ceased. A similar phenomenon, accompanied by gurgling of water and gas took place in May 2013 in Mantua province. In this case, it could be explained as the emission of atmospheric gas (mainly nitrogen) due to the rising of the water table. In mid-August 2013, at the outskirts of Ferrara, a ground fracture similar to those occurring in the 2012 seismic sequence, was observed and reported sensationally by the local media. However, this crack was caused entirely by soil settlement. Furthermore, in the epicentral area, many people observed a marked increase - up to 400 cm - of the water table inside phreatic wells, confirmed also by instrumental recording, usually occurring some days before and during the main shocks. In some cases an increase in water temperature was also observed from irrigation wells, but it was later verified that this phenomenon was related to the overheating of water pumps clogged with sand

On 31st May 2014, at the outskirts of Bondeno (Ferrara Province), a sand boil took place in correspondence with a borehole for geotechnical investigations. During drilling operations a gas level was intercepted at a depth of 30 m. The presence of methane pushed the sand upwards, causing the formation of a sand boil coming from the first confined aquifer. When methane was depleted, also the phenomenon ceased to occur (Fig. 8)

Fig. 8. Sand boil which took place on 31/05/2014 at the outskirts of Bondeno (Ferrara Province). Note the similarity with the sand boils in Fig. 2.

On May 2014 the Emilia-Romagna Region established a working group of experts that throughout a dedicated website (Regione Emilia Romagna, 2014) for communicating correct information on the particular geological phenomena that are observed and usually misunderstood by the civilians.

To avoid the spreading of wrong convictions, it appears fundamental to describe and explain, to the media and to general public these particular surface phenomena and locate them in the geological framework.

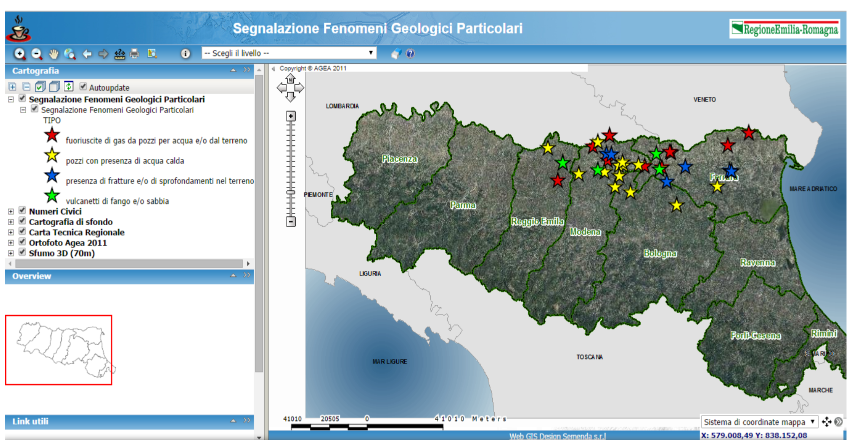

Fig. 9 Website dedicated to the particular geological phenomena
Regione Emilia Romagna (2014)

From May 2012 to April 2015 the population forwarded to the Region 38 alerts, located in the epicentral area the May 2012 earthquakes. As stated before, these particular geological phenomena concern: outflow of gas from wells trough water or from the soil (10) occurrence of sand boils (5), presence of fractures or sinking into the ground (6), wells with the presence of hot water (17). Phenomena of this type have always been observed, as they are related to the geological context of Emilia Romagna Region. It should however be noted that the frequency with which the phenomena have been reported in areas affected by the earthquakes is certainly much increased since May 2012.

The role of communication is essential in order to enhance awareness on seismic hazard and environmental effects comprehension among civil society.

Conclusion

Considering the cartography in seismic hazard assessment and communication priority should be focused on the seismic spatial environment; important parameters are the definition of the study area affected by the hazard , the nature of the information on refers to the objective or scope and characteristic of the seismic hazard analysis based on the information and the authority of different information sources. Cartographic thematic design imply graphic semiological considerations in order to represent and transfer the correct size and spatial distribution of the physical and hazards variables (Gaspar-Escribano, 2011). The correct understanding of the seismological message will depend on the design of this cartography.

According to Gahegan (2000) cartography representation may take over others, given that vision is the dominant sense. For this reason may also bring out stronger effective responses than other representations. Cartographic visualization serves a variety of map use goals vary significantly in terms of which purpose is emphasized. As referred by Maceachren (et al., 1997), taking into account different audiences, data types, and interaction levels, map use goals fall into four categories: exploration, analysis, synthesis, and presentation. The improvement of this understanding must, therefore, attempt cartography from the perspective of visual communication and pay special attention to map design. Provide accurate maps implied cartographic procedures that in the GIS environment let to acquire, store, and analyze heterogeneous collected data. From different sources: satellite images, topographic maps, GPS point, spatial features are elaborated in sets of vector (point , line polygon) or raster format layers each of which are georeferenced spatial information associated to a cartographic representation layout.

This perspective of cartography as a communication medium is well recognize in the literature (Dent, 1972; MacEachren, 1995; Slocum et al., 2005), since Bertin (1967) first elaborate the template for graphic semiology. In order to elaborate visually engaging and easily readable maps, cartographic principles design such as an appropriate symbolization, choice of color, balance between thematic layers and base map, or maximum numbers of classes have to be followed; this parameter are implemented in a cartographic information system: the offered colors, base maps, and layer combinations are in accordance with these rules and ensure cartographically high quality maps. Land analysis and information system are fundamental for the definition of priorities and recommendations necessary to reduce territories vulnerability and to enhance sustainable land management

In spite of the unpredictability of earthquakes the population has given credit to various groundless alarms on the basis of gas emission, bubbling water and ground fractures (Bertacchini et al, 2014). The Emilia-Romagna Region enable a working group of experts that throughout a dedicated website communicate correct information on particular geological phenomena that are observed and usually misunderstood by the civilians. To avoid the spreading of wrong convictions on particular surface phenomena, it appears fundamental to describe and explain to the general public, the particular phenomena and locate them in the geological framework. The divulgation of scientific information and knowledge is essential to enhance understanding in seismic hazard and environmental effects comprehension among civil society (RER). Cartographic representations assume a central function in the communication of natural hazard and risks, facilitating the interpretation of phenomena and environmental variables such as the risk that the population would be difficult to understand.

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