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CYCLE XXVIII

*AN INTEGRATED STUDY OF COSEISMIC SURFACE EFFECTS  
OF THE 2012 EMILIA EARTHQUAKE:  
CATALOGUE, SUSCEPTIBILITY ASSESSMENT AND ANALYSIS  
OF SEISMIC RISK AWARENESS*

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## *Abstract*

The social and economic impacts caused by the seismic sequence in the Po Plain on May 2012 were locally increased by the widespread occurrence of Coseismic Surface Effects (CSE). In the framework of the Spinner Project (2013), focused on the CSE related to the 2012 earthquakes, this thesis has proposed an interdisciplinary approach of investigation which, by considering the key role of geosciences for seismic risk assessment and for seismic risk communication, it has identified CSE catalogues, CSE susceptibility mapping and analysis of risk perception as fundamental tools for enabling and enhancing social seismic-risk awareness.

The study area extends around 1400 km<sup>2</sup> and corresponds to the epicentral area of the Emilia earthquakes located between the province of Modena and Ferrara.

This thesis is structured in three main sections, according to the main objectives of the research:

1. The first section is dedicated to the catalogue of CSE induced by the strongest quakes of May 20th and 29th 2012. A comprehensive georeferenced CSE catalogue has been created by merging and homogenizing different databases that included information collected by various teams of researchers. The catalogue counting 1910 CSE, completed by 200 descriptive datasheets has been published online to guarantee a access general public access.
2. The second section is dedicated to CSE susceptibility mapping at regional scale. This task has been carried out by using bivariate and multivariate geostatistical data-driven methods, such as Information Value, Weight of Evidence and Logistic Regression. These methods, based on CSE catalogue as supporting evidence and on several predisposing factors maps such as geomorphological features, subsurface lithology and groundwater depth, were applied in a comparative way to map zones prone to CSE in the study area. The satisfactory results, that have been quantitatively validated, allow the consideration of the approach adopted as an innovative methodological contribution to this field of study, that is generally based, in geoenvironmental practice, on deterministic assessments which rely on costly and often unavailable local in-site tests.
3. The third section is dedicated to risk awareness analysis with special emphasis on the role of seismic cartography as a tool for risk communication. A study on risk perception was carried out through an online questionnaire distributed within the Emilia population, through dissemination on

the municipalities official websites and in collaboration with educational institutions (secondary and high schools). The questionnaire was compiled from answers provided by 468 individuals. Results and correlations between variables, statistically tested with Pearson's chi-square statistic and Cramer's V coefficient in SPSS, Excel and R software, have indicated that gender, nationality, school location, residence were significant variables, conditioning risk perception and that, overall, a weakness in seismic risk knowledge among the Emilian community exists. Nevertheless, the feedback outlined expressed the usefulness of seismic cartography for risk understanding. Moreover, the population after the earthquake experience also became more conscious of importance of geoscientific knowledge requiring to be more aware about seismic risk. The study addressed an additional issue in the domain of seismic information strategies: the terminology used in newspaper during the emergency period of the 2012 events.

Altogether, the three sections of this doctoral research indicate possible tools and strategies to convey, on a collective level, scientific information on seismic risk and correlated CSE, in order to enhance risk awareness, preparedness and local resilience among communities.

## ***Riassunto***

Le ripercussioni socio-economiche causate dai sismi Emiliani nel maggio del 2012 sono state amplificate dall'occorrenza degli effetti cosismici di superficie (ECS), che si sono manifestati in seguito alle scosse di maggior magnitudo (5.9 e 5.8 rispettivamente il 20 e 29 maggio 2012). La limitata consapevolezza sismica tra la popolazione emiliana è attribuibile ad una pluralità di cause, che in questo studio hanno portato a riconsiderare la stretta relazione tra conoscenze scientifiche e percezione sismica, riconoscendo alle geoscienze un ruolo fondamentale nei processi di valutazione e comunicazione del rischio. La presente tesi si inserisce nel progetto Spinner (2013), volto ad approfondire gli studi sugli ECS indotti dalla sequenza del 2012. Lo studio si articola in tre principali sezioni che analizzano in modo integrato lo studio degli ECS indotti dai sismi emiliani del 2012, ampliando l'interesse scientifico alla comprensione del rischio sismico della Pianura Padana e alla necessità di proporre nuovi approcci e strumenti per una consapevolezza sismica condivisa.

1. La prima parte della tesi è dedicata alla implementazione di un catalogo geo referenziato degli ECS riferiti ai sismi emiliani. Le informazioni di diversi database, realizzati dagli enti di ricerca

che hanno censito direttamente in campo gli ECS, sono state integrate ed omogenizzate in un unico comprensivo catalogo. Il catalogo include 1910 ECS, si correda di 200 schede descrittive ed è stato pubblicato online al fine di garantirne la consultazione pubblica.

2. La seconda parte di questo lavoro si è indirizzata all'analisi e alla mappatura della suscettibilità agli ECS a scala regionale (1:200.000), al fine di discriminare, in una visione sinottica, le aree della pianura modenese e ferrarese maggiormente inclini a questi fenomeni in caso di terremoto. Con questo scopo è stato proposto un approccio metodologico statistico-probabilistico, applicando in modo comparativo, metodi bivariati quali il Valore Informativo e il Weights of Evidence (peso delle evidenze) e la Regressione Logistica, come metodo multivariato. Basati sulla relazione spaziale tra le evidenze di supporto, in questo studio fornite dal catalogo degli ECS realizzato, e le mappe tematiche rappresentative dei fattori predisponenti considerati, questi metodi validati quantitativamente hanno consentito di mappare la suscettibilità agli ECS con soddisfacenti risultati in termini predittivi nell'area di studio. La ricerca presenta un contributo metodologico innovativo poiché, tra le pratiche geo ingegneristiche il rischio di liquefazione (CSE) è valutato localmente con metodi deterministici basati su costose, ed a volte carenti, prove in situ.

3. Nella terza sezione la tesi ha approfondito uno studio di percezione sul rischio sismico tra la cittadinanza emiliana dopo l'esperienza del terremoto del 2012. L'indagine è stata realizzata attraverso la divulgazione online di un questionario, coinvolgendo un campione statistico differenziato di 468 persone. Lo studio ha interessato la popolazione giovanile delle scuole medie di primo e secondo grado e la popolazione, che ha compilando il questionario pubblicato sui siti comunali. L'analisi statistica delle risposte e l'analisi della significatività di relazione tra variabili socio-demografiche e percezione del rischio basata sull'analisi bivariata del chi-quadrato di Pearson e sull'indice V di Cramer calcolate in Excel, SPSS, e R ha dato risultati interessanti per l'indagine; sono infatti emerse correlazioni significative tra alcune variabili demografiche (genere, luogo di residenza, livello di istruzione etc.) e conoscenza o percezione dei rischi. Il questionario ha rilevato come l'esperienza sismica del 2012 abbia contribuito a forgiare una maggiore sensibilità e consapevolezza sismica tra la popolazione emiliana di pianura; ma nello stesso tempo dall'analisi delle risposte dei questionari è emersa una generalizzata conoscenza delle cause e delle dinamiche che sottendono la pericolosità e il rischio sismico nell'area di studio.

La ricerca ha posto in evidenza due importanti aspetti che confermano le ipotesi iniziali di questo studio: l'importanza e l'utilità dello strumento cartografico (cartografia sismica) e dei cataloghi open

source e la necessità espressa dalla popolazione di poter accedere all'informazione scientifica, quale fonte ritenuta autorevole ed attendibile in materia di rischio e pericolosità sismica. La complessità dell'argomento ha richiesto un approccio interdisciplinare. Dall'approfondimento degli ECS indotti dai sismi emiliani del 2012, la riflessione ha allargato lo spettro investigativo alla dimensione conoscitiva e comunicativa della pericolosità e del rischio sismico locale in terra emiliana. In particolare è stata approfondito il linguaggio utilizzato dai quotidiani locali online durante l'emergenza.

Il contributo scientifico di questa tesi di dottorato si concretizza nell'implementazione del catalogo "open source" dedicato agli ECS e nella realizzazione di mappe di suscettibilità agli ECS-liquefazione. Nel complesso, la tesi suggerisce efficaci strumenti informativi di divulgazione scientifica sul rischio sismico e sugli ECS, con la finalità generare consapevolezza sismica e facilitare la costruzione di pratiche sociali resilienti a livello comunitario.

# 1 INTRODUCTION

## 1.1 Context

The present doctoral research has been developed in the framework of the Emilia-Romagna Region Spinner Project (2013) which has financed other three doctoral theses under the common title of: *“Geological surface effects of the 2012 Emilia earthquakes: studies for the improvement of safety and the sustainability of territorial development”*, whose focus was to deepen the knowledge on the coseismic surface effects (CSE) induced by the 2012 Emilia earthquakes. This thesis had as main purpose the CSE cataloguing and dissemination, as well as the CSE susceptibility assessment and mapping within the central southern area of the Emilia Po Plain. The interdisciplinary approach of this study has allowed to critically investigate the geo-governance dynamics linking territory, risk and society in the Emilian context. The doctoral research has included analyses of risk perception and communication, furtherly has explored and suggested strategies devoted to enhancing seismic awareness at community level. The outcomes of this research can be significant for future land-use planning and decision-making at regional and local levels.

## 1.2 Problem definition

The complex nature of hazards and their cascading effects require a comprehensive analysis of the interactions between natural hazards and risks within their geographical and social contexts.

Risk assessment must link rigorous scientific results with the realities of communities potentially affected by these risks (Cutter et.al., 2003). Moreover, the understanding of local hazards and risks by the public is pivotal, which implies wide-ranging risk communication strategies and the support of democratic public involvement in risk management at local level (Alexander, 2000). During the last decades, the facet of risk understanding by the general public and the community involvement in prevention policies and risk mitigation strategies has become paramount in the conceptual framework of international treaties and programs, especially promoted by the United Nations, as shown by the priorities defined in the Sendai Framework for Disaster Risk Reduction (2015-2030), which points out the importance of disasters and risks understanding. As cited in the document (priority 1.) *“risk management should be based on disaster risk understanding, in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment”* (SFDRR, 2015). In this regard, the previous Hyogo Framework for Action 2005-2015 (HFA, 2005) had already underlined the importance of knowledge, innovation and education to build a culture of safety and resilience at all levels.

Risks need to be addressed regularly by means of a high level of knowledge, to provide information for any decision which should to be taken with the community involvement in the optic of sustainable and inclusive land governance. The existing gap between scientists (with a scientific and technical language) and the public should be overcome through effective forms of communication for a common understanding of risk, to enable the process of disaster.

The 2012 earthquakes of the Po Plain led to several socio-economic and cultural impacts, highlighting a general underestimation of local seismic hazard and misinterpretations about CSE manifestations. The lack of a collective seismic culture was related to a combination of factors such as the loss of seismic memory, the wrong conviction that the alluvial sandy soils of the Po Plain may reduce the seismic signal, and the poor developed seismic risk communication among others.

The 2012 seismic sequence has been investigated from different and partial viewpoints (e.g. geological, seismotectonic, historical, social, anthropological).

This study, mainly focused on CSE, embraces an holistic perspective in deepening the 2012 earthquakes. It appears indeed necessary to rethink the current paradigm and propose a new conceptual approach of seismic hazards and CSE communication, in which geosciences should play a significant role, enhancing risk awareness within the population.

The main scope of this work was to improve the integration of existing sectorial investigations overcoming potential shortcomings of the partial standpoints, because a broader approach is needed to fully appreciate the complexity of hazards and their numerous regional impacts (Cutter et al., 1997, 2003, 2010.) The following research questions consent to better guide through the content of this thesis, and delineate the theoretical and conceptual assumptions of the research herein presented:

- Can spatial geographic information (seismic cartography) and open-access catalogues referred to CSE reach a wider and more diversified audience through the visualization of uncertainty and of risks?
- Alternative geostatistical methods are feasible to predict susceptibility to CSE at regional scale?
- Mapping prone areas to CSE occurrences may facilitate the population comprehension of those misunderstood phenomenon during the 2012 events in Emilia Po Plain?

- How has the 2012 earthquakes experience influenced seismic perception, and what level of knowledge about seismic hazard/risk and CSE can be observed within the Emilian population?
- Which type of language did the source of public information (newspapers) use to inform population during the emergency period in 2012?
- Which factors have influenced the erroneous seismic hazard/risk perception in the specific social context of the Emilia-Romagna Region, where community cohesion and other social aspects (social, economic and historical) have encouraged resilient behaviours and valuable disaster recovery strategies?
- Could deeper and widespread knowledge of earth sciences and seismic cartography contribute to social seismic awareness?

### 1.3 Aims and objectives

Based on literature review of publications dedicated to the 2012 Emilia seismic sequence in different scientific domains such as geosciences and anthropology, the public seismic risk understanding has been poorly explored or even neglected.

The main aim of this thesis is to verify the importance of the scientific knowledge and the role of geosciences for the public understanding and awareness of hazards and risks. Under this view, this work indicates new approaches and methods, especially focused on the CSE assessment, from which the use of cartography and public online catalogue have been identified as empowering tools of seismic risk comprehension.

The questions mentioned above (section 1.2) have been developed in specific research objectives, which structured the thesis integrating its different sections. In each chapter, a brief description of the specific objectives and a literature review of the main topic are first presented.

Following the introduction corresponding to chapter 1, in chapter 2 the thesis illustrates the geological and geomorphological context of the study area, whereas chapter 3 focused on the Emilia seismic sequence, describes in detail the CSE occurrences and other anomalous phenomena not directly related to seismic activity, but still generating high levels of alert within communities, due to the apparent similarity with the coseismic effects.

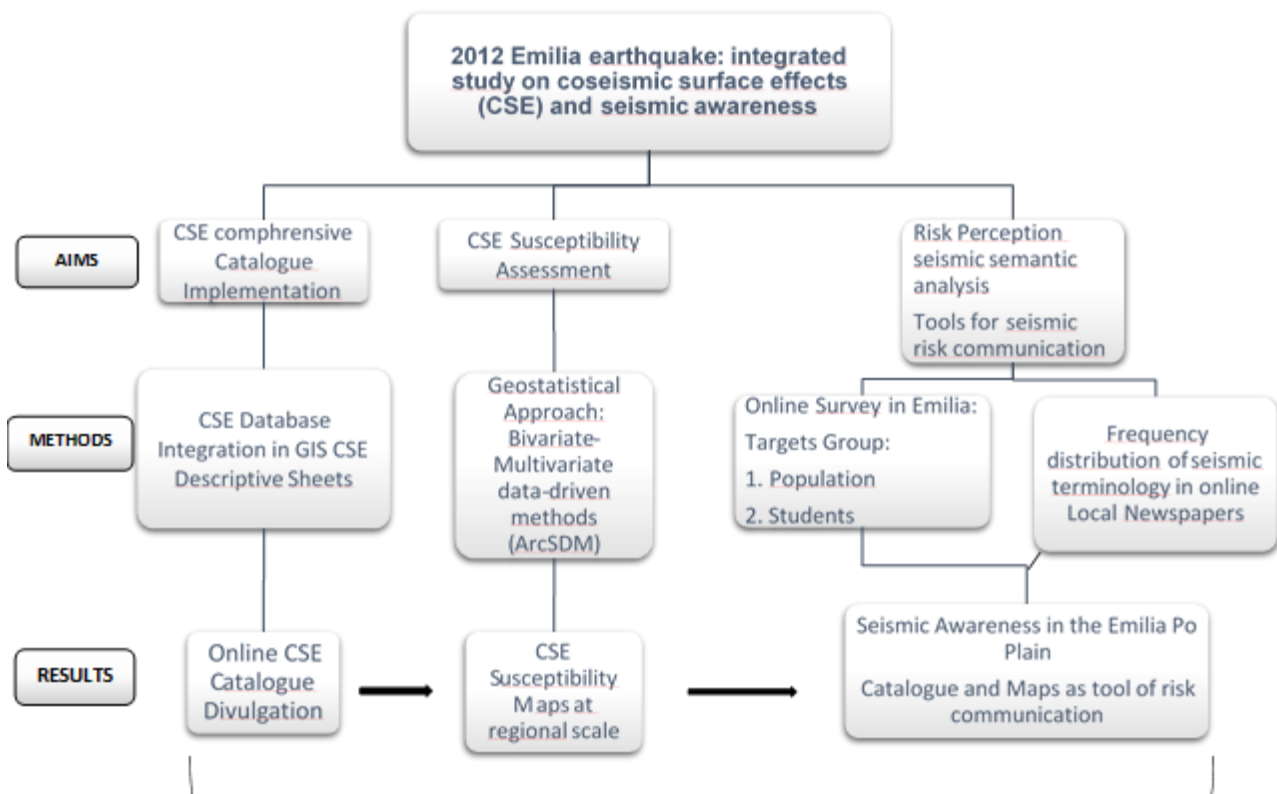
- (i) The first main section, corresponding to chapter 4, has been dedicated to the CSE inventories that have been published and particularly to the description of the catalogue

that has been implemented within this PhD research, particularly focused on the 2012 Emilia seismic sequence.

- (ii) In chapter 5, this investigation has tested three different geostatistical data-driven methods to assess susceptibility to CSE in the target area.
- (iii) Chapter 6 is composed by two main sections. Section 6.2 has investigated the “seismic semantic” of articles published on online local newspapers during the emergency. Section 6.3 has presented the results of a survey carried out via online questionnaire, concerning the degree of public seismic perception of Emilians (represented by two different target groups) in comparison with the real seismic risk of the area defined by the official seismic risk classification. The study has intended to underline the significance of scientific information and the efficacy of cartographic products as tools for local seismic hazard and risk understanding.

Chapter 7 is dedicated to the conclusions of this study.

## 1.4 Work flow



1.4-1 Flowchart showing data and procedures

## 2 GEOLOGICAL-GEOMORPHOLOGICAL SETTING OF THE PO PLAIN

### 2.1 Geographic setting

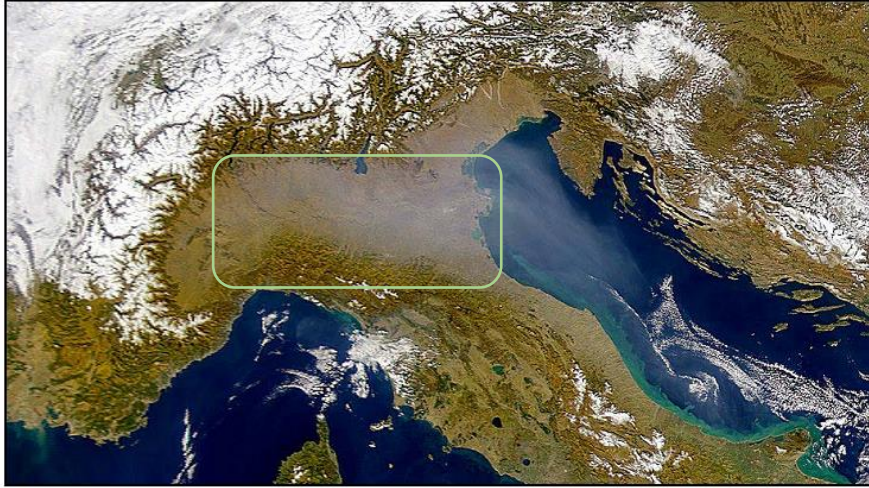
The Po Plain, is the major plain of Italy and among the largest floods plains in Europe. It is comprised mostly within the catchment area of Po River (75,000 km<sup>2</sup>), flowing in West-East direction with a length of 652 km (Marchetti, 2001). The surface area is roughly 46,000 km<sup>2</sup>, equal to 71% of all the plain areas in Italy, and 15% of the nation's territory (Pellegrini M., 1979). The Plain is bounded by the chain of the Alps, and from the findings of the Langhe and Monferrato on the north west and south-west, to the south by the chain of the Apennines and to the east is wet by the northern Adriatic Sea (Figure 2.1.-1). The plain altitude ranges from about 500 m, at the feet of the Alps and the Apennines, to some meters below sea level in the Po delta area and in the Venice area. The boundaries plain/Apennines and plain/Alps are purely morphological; in fact, the geological structures continue buried under the quaternary continental sediments as far as the R. Po (Pieri and Groppi, 1981).

The Po Plain, namely otherwise Po Valley, Plain of the Po, Po River Plain or Padan Plain stretches between the regions of Piedmont, Lombardy, Veneto, Friuli-Venezia Giulia and Emilia Romagna counting around 20 million of inhabitants (<http://www.treccani.it/enciclopedia/pianura-padana>).

Two main geographical areas defined the plain into an upper drier zone, not particularly fertile for agriculture, and a lower one "the low plain" which is a very productive land. Agricultural sector takes a greater importance around the "line" of the *fontanili* (water springs), pools of water that mark the transition from high to low plain supplying water for ditches and irrigation channels.

Depending on the different zones and from the influenced played by the orography of the basin, Po Plain has a mild continental climate and a humid subtropical climate.

Winters are foggy, damp and chilly, with sudden bursts of frost. Average annual temperature is around 5°C on Alps, 5-10°C in medium mountains, 10-15°C in the other zones. Variability of the temperature is also due to lakes mitigation effects. Average rainfall value is 1.200 mm, unevenly distributed both in space and time. About temporal distribution, the maximum rainfall is reached in the spring season.



*Figure 2.1-1 Geographical Setting of the Po Plain. Satellite image showing the geographical configuration of the Po Plain, an enclosed basin surrounded by the Alps to the north and the Apennines to the south. Image courtesy of NASA, available at: <http://eoimages.gsfc.nasa.gov/>.*

The Po Valley is one of the most important industrial and agricultural areas in Italy. Even its economic importance focus on secondary and tertiary sectors: 33% of labors are employed in services and business; 40% of national industry fall in this geographical area. Hydroelectricity is generated from the Po river which is also the main source for irrigated agriculture in the low plain which intensive and high mechanized (UNEP). Historically, the “*Bassa Padana*” was inhabited and farmed earliest, in Etruscan and Roman times, and has been completely devoted to agriculture since the Middle Ages.

The thesis focuses particularly on the southern central Part of the Po Plain, a territory that has been struck by a seismic event in 2012 and that have induced coseismic surface effects.

## 2.2 Geological and seismotectonic setting

The Po Plain comprises the Apennine foreland area and related foredeep of two oppositely verging fold-and-thrust belts: S-verging central-southern Alps to the north, and N-NE-verging northern Apennine to the south (Amorosi et al., 2016). The two belts developed from the convergence between the African and European plates, beginning in the Cretaceous (Carminati and Doglioni, 2012), are still advancing at a rate of 3–8mm/y (Serpelloni et al., 2007). From a general point of view, the Apennine chain is a post-collisional belt; its formation is associated to the complex interactions between the African and European plates (Martini et al., 2001). Compressional deformation results from the westward subduction of the Adriatic lithosphere and from its flexural retreat, causing the formation of compressional fronts migrating towards the E and NE, thus progressively affecting the Adriatic foreland (Figure 2.2-1) (Patacca et al. 1990, Chiarabba et al. 2005, Basili and Barba 2007, Carminati et al. 2010, Cosentino et al. 2010, Molli et al. 2010; Bignami

et al., 2012). The chain consists in thrust plains and folds originated in the Oligocene and has displaced and superposed to structural units belonged to different Mesozoic, Cenozoic domains (See Figure 2.2.-1). This active collision between plates regulated the rate of sedimentation and subsidence, the seismicity of the plain and the setting of the drainage network.

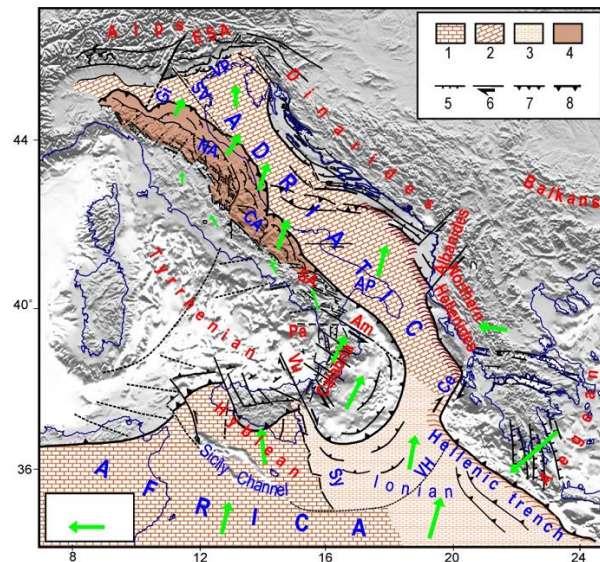


Figure 2.2-1 Tectonic Setting of the Mediterranean Basin. Tectonic setting and blocks kinematics of the central Mediterranean basin compatible with the Holocene deformation field (Mantovani et al, 2011). 1-2) African and Adriatic plates; 3) Ionic plate; 4) external part of the Apennine chain carried by the Adriatic plate; 5, 6, 7) main tectonic compressive features. The blue green arrows show the long term kinematic setting with respect to Eurasia. AM=Southern Apennines, AC= Central Apennines, AS=northern Apennines, ASE=South-eastern Alps, SV=Schio-Vicenza fault system.

The topographic surface of the Po Plain hides these buried tectonic structures below Plio-Quaternary marine and continental deposits. The hidden thrust front of the southern Alps corresponds to a single wide arc extending from Milan to Lake of Garda (Vannoli et al., 2015; Amorosi et al., 2016). While the frontal portion of the northern Apennines is organized in three complex systems of thrust-related folds as displayed in Figure 2.2-2: the Monferrato, the Emilia, and the Ferrara-Romagna Arcs, from west to east respectively (Pieri & Groppi, 1981; Michetti et al, 2012; Ghielmi et al., 2013).

The latter is further subdivided into three relatively minor structures: the Ferrara folds, the Romagna folds and the Adriatic folds. The Ferrara folds («Pieghie Ferraresi») are the most external structures of this arc (Burrato et al, 2003; Carminati et al, 2010). These buried structures deform the sedimentary cover (Scrocca et al, 2007) and at the same time they are related to the deepest thrusts and folds affecting the base (Boccaletti et al, 2011).

The ongoing deformation of the northern Apennine belt can be deduced and proved through: i) historical and regional seismicity, ii) the recent evolution of topography and the drainage network patterns (Burrato et al., 2003; Galadini, 2012); iii) geodetic data indicating the main compressional mechanism (Scomiglio et al. 2012).

In fact, present day, active NE-SW compression along the outer Apennine front and in the Po plain is recorded by GPS data, that show an average horizontal shortening of approximately 1-3 mm/y across the Po basin (Devoti et al., 2011). The geometry and location of the main faults are now well established thanks to extensive seismic reflection surveys performed during the 70's for oil and gas exploration (Ori and Friend, 1984; Pieri and Groppi, 1981) (Figure 2.2.-3).

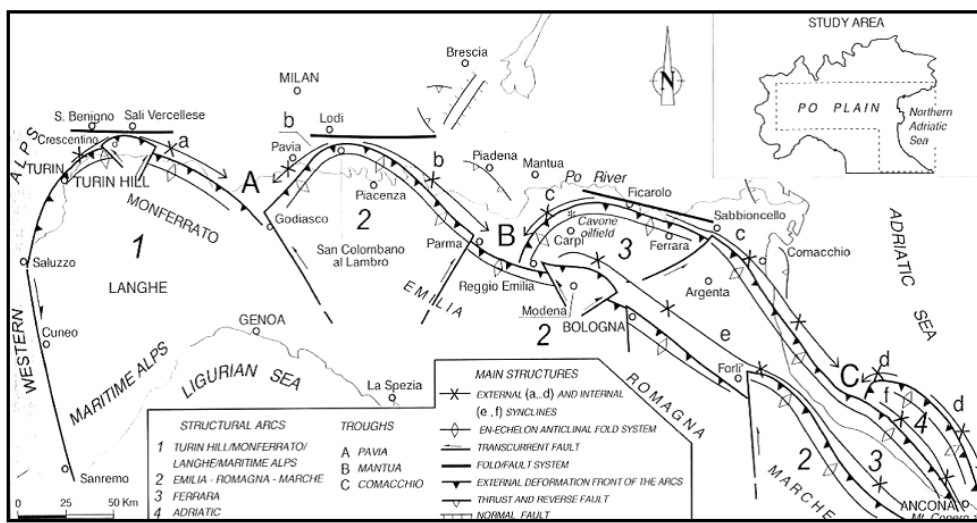


Figure 2.2-2 Structural and Tectonic setting of the Po Plain (Costa, 2003). The causative thrust faults of the two main shocks of the May 2012 Emilia sequence were two segments belonging to the Ferrara Arc in correspondence to the Ferrara and Mirandola fold system (Bignami et al. 2012, Salvi et al. 2012).

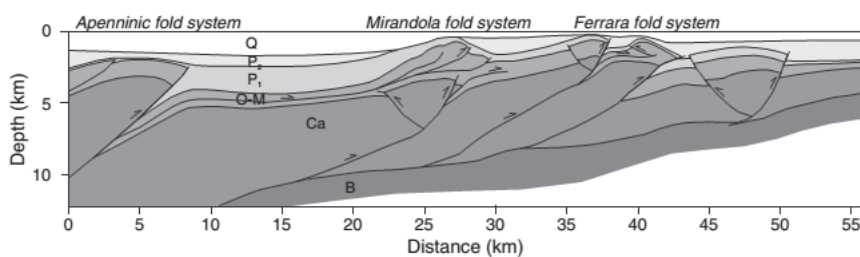


Figure 2.2-3 Geological Section across the Epicentral Area of the 2012 Emilia-Romagna seismic sequence (Galli, 2012).

The general geological-stratigraphic setting of the area is characterized by a subsoil of poorly consolidated fluvial Holocene deposits, progressively younger from west to east. In details, the filling of the basin, concerning the transition from marine to continental sedimentation are the result of tectonic-sedimentary events where value of subsidence (rate of 2/3mm/y), calculated based on the thickness and absolute age of the Pleistocene base (Carminati and Martinelli, 2002;

Vannoli et al., 2014; Amorosi et al., 2016), are higher than the uplift rates along the buried thrusts and related folds (0.53 mm/y for the anticline of Mirandola, that is reduced to 0.16mm/y). The Plio-quaternary sedimentary deposits thickness ranges from several thousand meters to few tens of meters at the top of the buried anticlines (Bigi et al. 1992) as it is in the epicentral area of the 2012 event. This thrust front is covered by a thick (up to 8 km) Pleistocene deposits of fluvial origin accumulated by the Po River and its tributaries (Ghielmi et al., 2013).

The internal structure of the continental succession was influenced by the Middle to Late Pleistocene climate variability characterized by glacial and interglacial periods. Extensive fluvial channel bodies generated during glacial periods were sundered by intervals of laterally continuous overbank facies deposited during the interglacial (Amorosi et al., 2008). Up-section fluvial sands are overlain by Holocene mud-dominated succession with subordinate lenticular fluvial channel bodies. The top fluvial sediments represent the latest phase of the basin fill which began in the Middle Pleistocene. They consist of clay, silt and sand deposited by the Po River system (Boccaletti et al, 2011). This alluvial succession mainly it consists of alternating coarse sediments of channel environment and alluvial plain fine deposits. The former deposits, mainly of braided system type, are generally less than 10 m thick with a fining-upward trend that evolves vertically to floodplain deposits and are recorded at different depths within the alluvial succession (Amorosi et al, 2004). In general, following the scheme of stratigraphic relationships of Dondi et al. (1982) and the geophysical sections of Pieri and Groppi (1981), the sedimentary cover the Po Basin, from bottom to the surface top, consists of the following units:

- Successions of carbonate platform environment sediment during Jurassic-Lower Cretaceous to Middle Eocene, prior to the formation of the Po sedimentary.
- Successions of clastic sandy marl (pre-evaporitic), sediments dating back to Upper Eocene and Upper Miocene, during the formation of the Po basin.
- Messinian clastic sequences sedimentation occurred during the strong sea regression;
- Post-Messinian clastic sequences laid down, during the Pliocene transgression;
- Successions of marine terrigenous characterize the Lower- Middle Pleistocene;
- Succession of continental terrigenous: between the Middle-Upper and Holocene. It is subdivided into a Lower and Upper unit. The Lower unit consists of predominantly fine alluvial deposits with interbedded gravelly and sandy ribbon-like bodies, (paleo-riverbeds); the Upper unit includes, however, the systems of alluvial cone in the area in front of the Apennine and Alpine Chains and the fluvial-deltaic systems along the Po River.

The Pleistocene sequence has been divided into two groups of geological units (Supersynthem), separated by stratigraphic discontinuity surfaces and characterized by deposits of different lithology which allow the sequence stratigraphic interpretation of quaternary deposits and their underground relationship at a regional scale (Molinari & Pizzolo, 2009). From the youngest to the oldest group:

- Emiliano-Romagnolo Supersynthem, equivalent to the Quaternary continental cycle Qc (Ricci Lucchi et al, 1982 in Priore, 2016);
- Quaternario Marino Supersynthem, which falls within the Quaternary Marine cycle (sensu Ricci Lucchi et al, 1982 in Priore, 2016).

The Supersynthem "*Emiliano-Romagnolo*" has been further divided into lower and *upper* "*Sistema Emiliano Romagnolo*", which are separated by a stratigraphic discontinuity identified through in-depth interpretation of seismic profiles provided by 'ENI-AGIP (Emilia-Romagna & ENI-AGIP, 1998).

To conclude this section is important to mention the hydrological aspect of the study area, where it is possible to recognize two overlying aquifer systems. The shallower one is a semiconfined and locally aquifer phreatic comprising interconnected silty-sand lenses of variable thickness up to 6–8 m. It is underlain by an aquiclude of silts and clays, which confine the second, deeper aquifer located at an average depth of 16–18 m b.g.l. (Papathanassiou et al., 2012).

### 2.3 Geomorphological setting

The geomorphological landscape of the Po Plain is the result of the complex Holocene evolution of the Po river network originating from Alps (Northern) and Apennine (southern) catchments, which have contributed to shape the surface of this alluvial plain (Amorosi et al., 2016). Drainage network changes in the study area are the consequence of climatic and tectonic actions forcing also by human influence (Castaldini et al., 2003; Ravazzi, 2003). Indeed, the present morphology of the Po Plain has resulted from the interaction between depositional and erosive dynamics occurred from geological to historical periods after the Würmian glaciation (Marchetti 2002). The thickness of sediments succession reaches 2 - 6 km in the north, in the southern sector of the study area are between 100 m and 8 km (Burrato et al., 2003, 2012).

More in detail, it is possible to identify several quaternary geomorphological units (Marchetti, 2002). The area located between the southern front of the Alps and the Po River is characterized by the presence of a wide low-gradient, south-sloping topographic surface of fluvial-glacial and fluvial origin. The Po Plain at the Alps foothills presents small patches of early to Middle Pleistocene fluvial-glacial deposits («old terrace unit», Marchetti 2002). Moraine deposits of Pleistocene-Holocene age lay near the main alpine valleys outlets (Burrato et al., 2003). The «Plain main level» (Petrucci and Tagliavini, 1969), mostly formed during the last glaciation, when alpine rivers were larger than today (Marchetti, 1990, 1996). Abandoned river paleo-channels were oversized with respect to the present hydrography. Their reduction in discharge, which has occurred at the end of the last glaciation (Marchetti, 1996), influenced the erosion of the upper alluvial plain. The present drainage network flows in valleys deeply incised into the old proglacial sandurs aggradation surface.

South of the Po River the drainage network flows on top of a Holocene aggradation surface, which merges with the active alluvial plain of the axial Po River (Bianchini et al. 2014). Near to the Apennine border this surface presents coalescing alluvial fans of the same age as the «Plain main level», overlain by older fans deposited during previous glacial maximums (Marchetti, 2002). Considering that drainage network paths are sensitive to tectonic deformations, it is possible to suggest a direct relation between the geometry and kinematics of the tectonic setting and the drainage systems (Schumm et al., 2000; Champel et al., 2002). Indeed, the river diversions are clear indicators of the anticline or syncline presence. Deflection of the river around an area undergoing uplift or subsidence will appear as an abrupt shift in the river course coincident with the deformed zone (Holbrook and Schumm, 1999). In addition to the deformation seen in a longitudinal profile,

tectonic activity may also induce lateral shifting of a river (normal to the topographic gradient of the floodplain). Shifting may occur by sudden avulsion or slow migration of a stream toward the lower down-tilt part of the floodplain in relation to the rate of lateral tilt (Peakall et al., 2000).

Nevertheless, geomorphic features are controlled by the interaction of anticline and syncline growth and sedimentation rates. In fact, the thickness of the deposits and the geometry of depositional and erosional surface have led over the time major changes in the variations of the hydrographic networks (Burrato et al.). Another important variable to ponder in the analysis of fluvial drainage variations is the river size in the interaction of geomorphic factors such as depositional and erosional alternations (Bruentt & Schunn, 1983; Guccione et al., 2002, Burrato et al., 2003). The surface uplift has conditioned the northward shift of the Po river and the deviation of Secchia, Panaro and Reno (Castaldini, 1989, Boccaletti et al., 2004; Burrato et al., 2012). Furthermore, to better understand the present landscape of the area and most recent changes in the Po valley, Bondesan et al. (1992) indicated the importance of anthropogenic interventions, as all regimentation waterways works done in historical times. For instance, hydraulic interventions have been implemented to avoid the overflowing of the Reno river which has deviated its path, bringing also alterations on the depositional rates during the time which led to pensile or extinct riverbeds (Castaldini, 1989). The main cartographic reference for the geomorphology of the area, remains the *Geomorphological Map of Po Plain* (Castiglioni et al., 1997) and its explanatory notes (Castiglioni and Pellegrini G.B., 2001), which allow to appreciate the main landforms of the Po Plain (see Figure 2.3-1).

Overall, this research has mainly payed attention to few geomorphological units recognizable on the geomorphological map (Castiglioni et al., 1997a). The landforms considered within this study are: the meanders of alluvial Po plain, the deposits of fluvial levees, the crevasse splays and the paleo-riverbeds, who bear much of the studied area. In this zone, the altimetry variations of the landscape correspond to the levees or to the depressed areas between current and extinct river paths (Castaldini, 1989). The surface deposits of silt and clay are widespread, while sandy deposits are mainly distributed in ribbons and lenses along the; alluvial ridges. Moreover, along the main rivers crossing the area elongated sand deposits are founded.

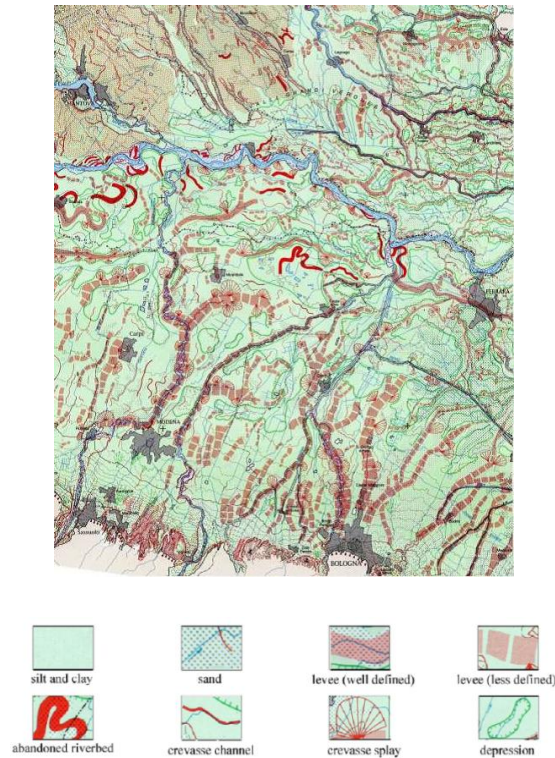


Figure 2.3-1 Section of the Geomorphological Map referring to the central part of the Po Plain (Castiglioni et al., 1997a.)

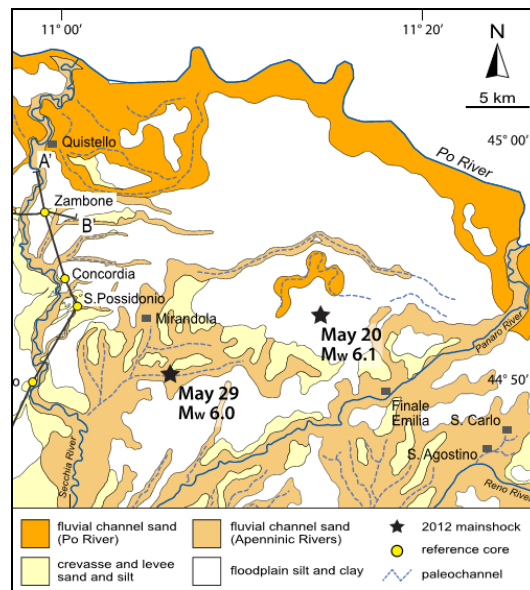


Figure 2.3-2 Surficial geology map of the central Po Plain (modified after Regione Emilia-Romagna, 1999) (Amorosi et al., 2016).

Observing at the map of figure 2.3-2, the paleo riverbed levees of Secchia, Panaro and Reno rivers maintain SSO NNE direction until Finale Emilia, changing subsequently for a W-E direction parallel to the Po river in the northern sector, while those of the Po river show in general a clear O-E direction. (Castaldini, 1989). The alluvial plain has formed during the Quaternary, with the regression towards East of the Adriatic Sea and by the formation of the alluvial fan systems related

to the Alpine and Apennine tributaries. The floodplain stratigraphic sequence, as it is shown in Figure 2.3-3, is typically characterized by thick banks of prevailing sands, interfingering with bodies of clays, silts and sometimes gravelly sands. This area of complex sedimentary arrangement is commonly called "plain of meanders". The alluvial cover is made by fine deposits and grain sizes range from sands to clays from the Po river to as far as Modena. Considering the grain size distribution, the piedmont plain sector presents instead sandy gravelly deposits alternated with finer sediments related to the alluvial fans (crevasse splays).

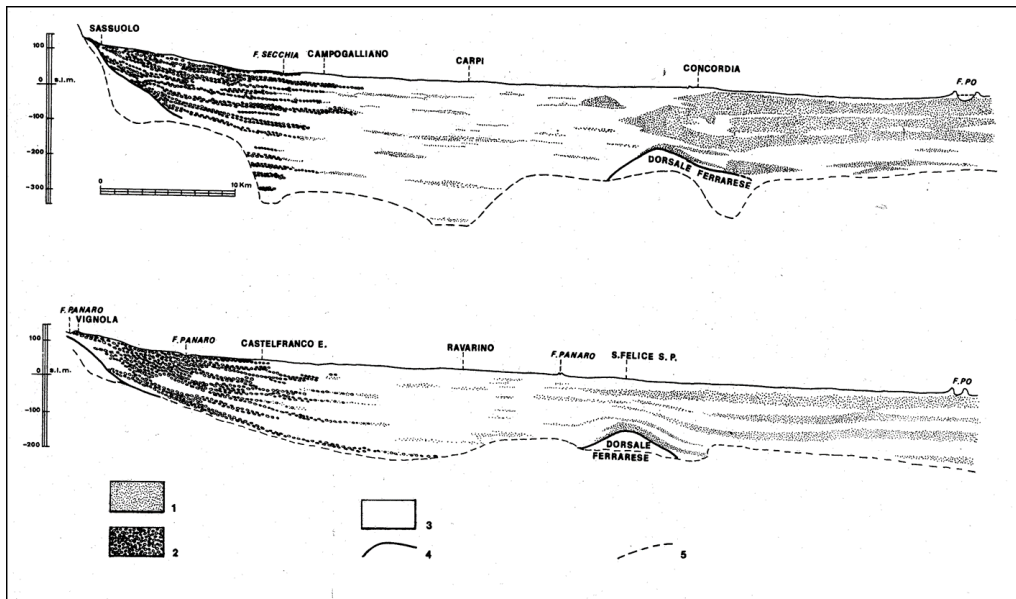


Figure 2.3-3 Geological sections of the shallow deposits in the Modena plain: 1) sands; 2) gravels; 3) clays and silts; 4) limit with marine deposits of the substrate; 5) Limit of the alluvial substrate (Gasperi & Pellegrini, 1981).

Other geomorphological landform is constituted by sediments that characterize levee weakly detected. These flank the river channels with riverbeds typically engraved at an altitude lower than the ground level. They present a generally elongate shape along the axis of the water course and are characterized by a transverse convex profile with a slope of the order of 0.2%. The stratigraphic sequence is constituted by an alternation of fine sand and structured clayey silt; the sandy layers tends to increase upward. Other fluvial forms are the alluvial crevasses (crevasse splays in the geomorphological map of figure 2.3-1). Their border is part of many levees of ancient Apennine streams, as for example at northeast of Finale Emilia and St. Agostino. The Po Plain is mainly characterized by levees (well or less defined in relation to their high). The present main levee of the Panaro river, was active until the end of the nineteenth century, while the one of the Reno river remained active until the mid-eighteenth century. The last with surficial sandy deposits, develops between St. Agostino, Mirabello and Vigarano Mainarda with SW-NE trend, rising 3-4 meters above

the surrounding plain level; the highwater bed and the embankments area are appreciable for long tracts (Castaldini and Raimondi, 1985). This paleo riverbed branches off the present course of the Reno river in the surrounding of St. Agostino, it extends in a SW -NE direction for 10 km and then deviates at 90°. The abandoned bed of the Reno River, is mostly characterized by sand, interbedded by finer layers of clay and silt. In S. Carlo detailed geologic, geotechnical and geophysical surveys were carried out with the aim to reconstruct the geological model of the subsoil (15 to 20 m in depth) (Gruppo di lavoro, 2012, Lai et al, 2012). According to these investigations, the embankment consists of an alternation of sand and silt for a total thickness of about 4 m. Alternations of sandy silt and silty sand extend for another 6 m from ground level. Locally a 4-m thick lens of fine and medium sand, corresponding to the ancient Reno riverbed, is present. Clay and silt deposits with an abundant organic fraction and a constant thickness of 9 to 10 m have been found overlying alternation of sandy silt and silty sand.

The levee corresponding to the paleo river bed of Secchia extends between Mirandola and Bondeno for over 20 km in W-E direction. Whereas sandy texture of lighter color indicates the bank within darker clayey deposits which refer to the ancient riverbed. It is important to mention how in 19<sup>th</sup> century the area up to Bondeno, Finale Emilia, Mirandola was affected by floods of the Po river several times (Castaldini, 1990).



## 3 THE 2012 EMILIA SEISMIC SEQUENCE AND COSEISMIC SURFACE EFFECTS

### 3.1 General definitions and type of CSE

The liquefaction phenomenon has always aroused great scientific and technical interest within the communities of geotechnical engineers and geologists. Significant efforts have been done in devising nomenclature to define the failure response of saturated soils during earthquakes. However, no definition or classification system appears to be entirely satisfactory for all possible failure mechanisms.

One preliminary task of this study was to identify an univocal term for the geological – coseismic surface evidences induced by the 20<sup>th</sup> (Mw 5.9) and 29<sup>th</sup> (Mw 5.8). May quakes on the Po Plain in 2012. In this thesis, the definition of coseismic surface effects and the related acronym of CSE has been chosen. Different nomenclatures such as earthquake environmental effects (EEE), geological surface effects (GSE), coseismic effects, geological earthquake secondary effects, ground effects, liquefaction phenomena *etc.* are found in literature or in inventories, where usually liquefactions are the most frequent and widespread phenomena (e.g. Alessio et al., 2012; Di Manna, 2012; Civico et al. 2015; Guerrieri et al., 2015).

As previous stated, part of the difficulty in understanding liquefaction and CSE is due to the terminology applied to describe the phenomena. Beyond the heterogeneity of definitions, it is significant to recall that geotechnical and earthquake engineering principally direct the attention to evaluate the potential of soil liquefaction. Looking at the etymology, liquefaction comes from the Latin verb *liquefacere*, which means to weaken, to melt, or to dissolve. Casagrande (1936) first presented a qualitative understanding of sand liquefaction and its effects under cyclic loading. Terzaghi and Peck (1948) with the expression "spontaneous liquefaction" described the sudden loss of resistance of loose sands, while Mogami and Kubo (1953) related the specificity of this phenomenon to earthquakes. The strong Seismic events that hit Alaska in March 1964 and later, in June of that year, the Japanese city of Niigata, have significantly contributed to improve the knowledge and the understanding of the liquefaction phenomenon.

Furthermore, Sladen et al. (1985) gave the following specific and widely accepted explanation of soil liquefaction:

*“Liquefaction is a phenomenon wherein a mass of soil loses a large percentage of its shear resistance, when subjected to monotonic, cyclic, or shocking loading, and flows in a manner resembling a liquid until the shear stresses acting on the mass are as low as the reduced shear resistance”.*

As defined by the National Research Council's Committee on Earthquake Engineering (1985), soil liquefaction includes *"all phenomena giving rise to a loss of shearing resistance or the development of excessive strains as a result of transient or repeated disturbance of saturated cohesion less soils."*

Idriss and Boulanger (2008) have described the liquefaction as: *“Loose cohesionless soils tend to contract during cyclic loading, which can transfer normal stress from the soil skeleton to pore water, if the soil is saturated and largely unable to drain during shaking. The result is a reduction in effective confining stress within the soil and an associated loss of strength and stiffness that contributes to deformations of the soil deposit. This loss of strength and stiffness due to increasing pore pressures is called liquefaction”.* Conceptually, liquefaction is the transformation of a granular material from a solid to a liquefied state due to the increased pore-water pressure and reduced effective stress, with the tendency of granular materials to compact when subjected to cyclic shear deformations (Marcuson 1978). In general liquefaction is used to describe a variety of seismic-related phenomena, which befall in saturated cohesion less soils under undrained conditions during static and cyclic loading. If load acts in a short time, as in the case of an earthquake, the tendency of this soil is to densify because the excess pore of pressures cannot be rapidly dissipating and consequently the decrease of effective stresses occurs. When this happens, the soil behaves as a fluid (Martin et al. 1975; Seed and Idriss 1982) (see Figure 3.1-1).

To better explain this phenomenon is useful to refer to the shear resistance  $\tau$  for cohesionless soils, expressed in terms of effective stress by the Mohr-Coulomb's formula:

$$\tau = c' + (\sigma_{v0} - u)\tan\phi' \quad \text{Equation 1}$$

where:

$\tau$  is the soil shear strength, the resistance to rupture in shear (on the failure plane)

$c'$  is the undrained soil cohesion (equals zero for loose sands and normally consolidated clays),

$\sigma_v$  is the total vertical stress,

$u$  is the pore water pressure,

$\phi'$  is the shear strength angle of undrained soil internal friction in terms of effective stress. Better explained, a state of 'soil liquefaction' happen when during an earthquake the effective stress of soil is reduced to essentially zero ( $\sigma_v \cong 0$ ), which corresponds to a complete loss of shear strength. (Seed & Lee, 1966). The saturated sand under seismic conditions, is unable to drainage because the speed of cyclic stress is significantly higher than the speed required for filtration water in pores (measured by the hydraulic conductivity) as expressed in Figure 3.1-2.

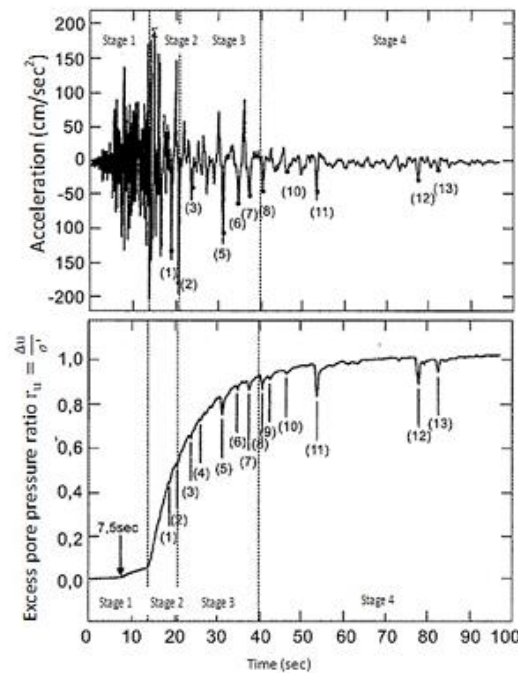


Figure 3.1-1 Acceleration response signal of an earthquake in association to the gradual stress transfer (increase of excess pore pressure ratio  $u$ ) (Monaco, 2014).

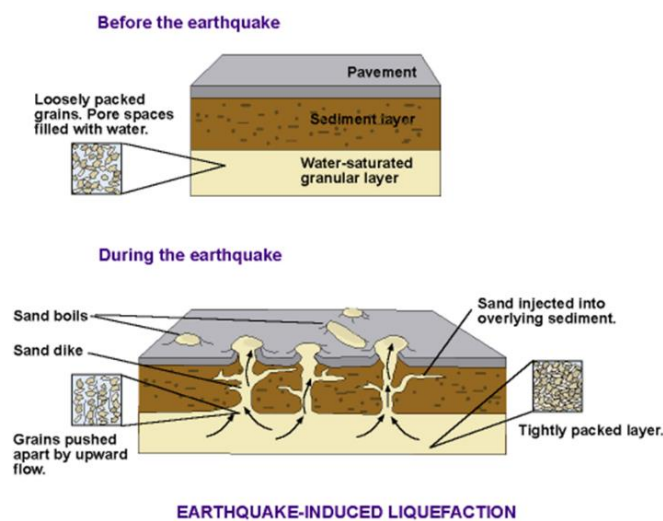


Figure 3.1-2 Liquefaction dynamic. Intergranular contact before and after liquefaction and related surficial manifestation. [http://wap.isu.edu/EnvGeo/EG5\\_earthquakes/eq\\_mod5.htm](http://wap.isu.edu/EnvGeo/EG5_earthquakes/eq_mod5.htm).

As mentioned above, specific type of soils and specific conditions favor the phenomenon investigated. In fact, the occurrence of liquefaction depends on various geological, compositional, and local factors such as: age of soil deposits, depositional environment, hydrological conditions, and prior local seismic history (Youd, 1998, after Youd and Perkins, 1978). Groundwater table depth can be considered a determining parameter to identify potentially liquefiable soils. More in details, relative density, grain size, fines content, grain cementation, current state of stress, and stress history have all strong correlation with the potential of soil liquefaction (Silva et al., 2003; Holzer et al., 2011). Furthermore, abrupt lateral facies changes represent key factors that control the areal extent of seismic liquefaction (Holzer and Bennet, 2007; Alfaro et al., 2010; Moretti and Van Loon, 2014).

As specified in Calabrese et al (2012), the simultaneous presence of the following conditioning favor the occurrence of CSE:

- Degree of saturation equal to 1;
- Presence of uncemented and loose sand ( $D_r < 60\%$ )
- Average diameter of the grains of  $0.02 \text{ mm} < D_{50} < 2 \text{ mm}$ ;
- Sand from fine to medium with content in fine material ( $d < 0.005 \text{ mm}$ ) variable between 0 and 15%;
- Depth to water table  $< 5 \text{ m}$ ;
- Depth of potentially liquefiable deposit within 15-20 meters from ground level;
- Recent deposits (formed from Holocene).

In addition, the liquefaction manifestation is conditioned by seismic triggering parameters:

- Earthquake with  $M_w > 5.5$ ,
- Maximum expected acceleration  $PGA > 0.15 \text{ g}$  (with an estimated return time of 475 years)
- Minimum of shaking event duration of 15-20 sec (Lai et al., 2009).

Earthquake-induced CSE most commonly observed in the following types of soils: fluvial-alluvial deposits, eolian sands and silts, beach sands, reclaimed land, uncompact hydraulic fills.

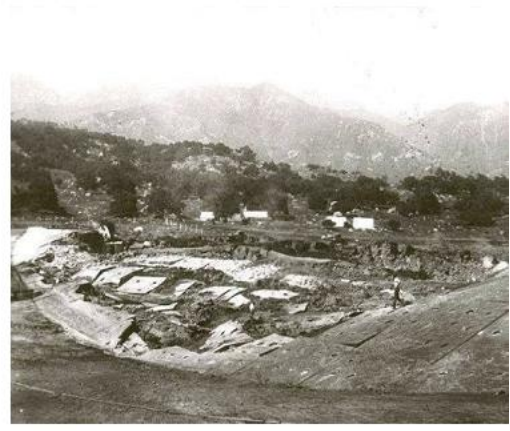
Concerning triggering factors, liquefaction may be originated by either monotonic loading (e.g. single sudden occurrence of a change in stress (examples include an increase in load on an embankment) or by cyclic loading (e.g. repeated change in stress condition which refer for instance wave loading or earthquake shaking). Robertson (1994) proposed a comprehensive classification

system for the liquefaction phenomenon. The latest version of the classification system, data by Robertson and Fear (1996), can be exemplify as follows:

1. **Flow liquefaction:** a phenomenon that occurs when liquefaction is triggered in a soil whose residual strength is lower than that needed to maintain static equilibrium of a slope or footing of a building for instance (i.e. static driving stresses exceed residual strength as in figure 3.1-4). This can occur due to monotonic loading or cyclic loading, and can be sudden and catastrophic. In fact, it can produce extremely large deformations (e.g., flow slides). Cases of flow liquefaction are relatively rare in practice but can cause tremendous damage. Failures caused by flow liquefaction, triggered by cyclic or monotonic shear loading, are often characterized by large and rapid movements, which can produce of disastrous effects. In figure 3.1-3 these kinds of liquefaction have been presented. Generally, loosely packed soil is highly susceptible to flow liquefaction, on the contrary medium dense to dense granular soils are not. When the phenomenon is triggered it develops mud flows where the liquefied materials cover large distances (Robertson et al. 1996).



(a)



(b)

Figure 3.1-3 Damages from flow liquefaction. (a) Alaska Earthquake, 1964, and (b) Santa Barbara Earthquake, 1925. [www.ce.washington.edu](http://www.ce.washington.edu).

2. **Cyclic softening:** is another phenomenon, triggered by cyclic loading, occurring in soil deposits with static shear stresses lower than the soil strength. Cyclic softening used to refer to large deformations befalling during cyclic shear due to pore pressure build-up in soils that would tend to dilate in undrained, monotonic shear. Deformations due to cyclic softening develop incrementally because of static and dynamic stresses that exist during an earthquake. Unlike the previous point, the deformations are stopped at the moment when

sell out the external shear forces applied. Two main engineering terms are in use to define the cyclic softening phenomenon.

- Cyclic liquefaction: the increase neutral overpressure is sufficient to break the effective stress agent;
- Cyclic mobility: the increase neutral overpressure is not able to lead to annulment the effective agent effort. They develop in each case important deformations.

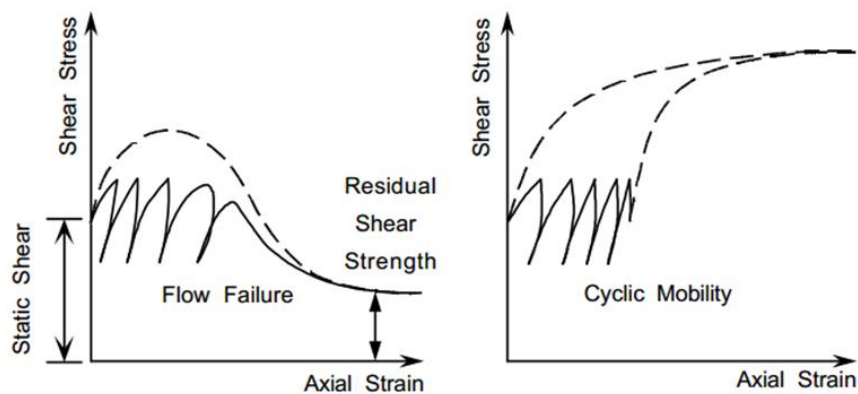


Figure 3.1-4 Flow Liquefaction (a) ad Cyclic Mobility (b). Flow liquefaction (a) and Cyclic Mobility (b). (Monaco, 2014).

Once the likelihood of soil liquefaction has been identified, an engineering evaluation must focus on the typology and magnitude of ground failures that might result.

The CSE are firstly grouped into two main categories:

- Primary effects, embrace any surface expression of the seismogenic tectonic source, are directly linked to earthquake energy. The dimension of primary effects is given by two parameters: i) Total Surface Rupture Length (SRL) and ii) Maximum Displacement (MD). Their occurrence is commonly associated to a minimum intensity value (VIII), except in case of very shallow earthquakes in volcanic areas. Primary effects are surface faulting, surface tectonic uplift/ subsidence;
- Secondary effects, that consist of a wide range of geological surface phenomena induced by the ground shaking (Hydrological anomalies, liquefaction as sand boils, ground cracks, lateral spread, any ejection of material, Anomalous waves/tsunamis, Slope movements, Trees shaking, Dust clouds, Jumping stones) (Esposito et al. 2015).

The National Council of American Research (Liquefaction of soils During earthquakes, 1985) has compiled a list of types of failure commonly associated the liquefaction of soils during earthquakes:

- Sand boils, which usually result in subsidence and relatively minor damage.
- Flow failures of slopes involving very large down-slope movements of a soil mass.
- Lateral spreads resulting from the lateral displacements of gently sloping ground.
- Ground oscillation where liquefaction of a soil deposit beneath a level site leads to back and forth movements of intact blocks of surface soil.
- Loss of bearing capacity causing foundation failures.
- Buoyant rise of buried structures such as tanks.
- Ground settlement, often associated with some other failure mechanism.
- Failure of retaining walls due to increased lateral loads from liquefied backfill soil or loss of support from liquefied foundation soils.

The following pictures, mainly taken from [www.ce.washington.edu](http://www.ce.washington.edu), allow appreciate and better understand the different types of CSE manifestations:



*Figure 3.1-5 Example of Sand boils. Sand boils that erupted during the 2011, Christchurch earthquake.*



*Figure 3.1-6 Example of flow failure of slopes. Flow failures of slopes involving very large down-slope movements of a soil mass. Turnagain (1964) Alaska.*



Figure 3.1-7 Example of Lateral Spreading. Lateral spreading Sunset Lake trailer park in Tumwater.



Figure 3.1-8 Example of Damage from liquefaction. Kocaeli (1999) Turchia.



Figure 3.1-9 Example of Damage from liquefaction. Niigata earthquake (1964).

Nowadays different scales allow to measure the severity of damage caused by liquefaction. Green et al. (2005) identify the severity of the damage considering the site boundary (liquefiable layer depth and thickness, density liquefiable layer) for the interpretation of cases of paleo-liquefaction. In Van Ballegooy et al. (2012) the scale of severity is defined in relation to the damage caused to houses, infrastructure and territory. Moreover, an important contribution is the ESI scale that is well described in chapter 4.2.2. The ESI scale allows the assessment of local seismic intensity only based on the evidence of CSE, without being influenced by human parameters such as effects on people and the man-made environment as the traditional intensity scales (Porfido et al. 2007). The Italian legislation for the evaluation of coseismic site effects refers to the D.M14/01/2008, also known as NTC 2008 (Technical Standards for Construction), and its development of 02/02/2009. The theme of liquefaction is treated in paragraph 5 of this thesis, where beside the liquefaction

susceptibility assessment methods proposed by this work some explanations concerning Seismic Microzonation evaluations are indicated.

### 3.2 General definitions and type of CSE

In May–June 2012 an energetic seismic sequence struck the northern part of Italy, precisely a wide sector of the Po Plain, within the provinces of Modena, Mantua, Bologna, Rovigo and Ferrara. This area is characterized by high population density, concentration of industrial plants and important architectural heritage of the historical city centers. The 2012 earthquakes have left severe damages to structures and infrastructures were reported in the entire region. Considering few reports, the total damage was estimated in 27 fatalities, hundreds of injured, about 15.000 homeless, 40.000 people evacuated. Furthermore, due to the high concentration of industrial facilities, the economic damage reached the order of 5 billion euros (source: [www.agi.it](http://www.agi.it)). In addition, hundreds of historical buildings from the fifteenth century, including churches, tower bells, castles and fortresses, were severely ruined (Lombardi and Bhattacharya 2014). Extensive damages were also reported on infrastructures, lifelines, on the precast concrete industrial plants, and unreinforced brick masonry houses. The latter occurred in historical part of towns, such as Finale Emilia, San Felice sul Panaro, Mirandola, Cavezzo, Sant'Agostino and Poggio Renatico (Scisciani & Pizzi, 2012; EMERGEO Working group, 2012). The Emilia seismic sequence took place in a relatively low seismic hazard area (Seismic Hazard Map of Italy MPS04 from MPS WorkingGroup (2004). Despite the moderate seismicity of the region, is significant to highlight that for the exposure ad population density the Po Plain is one of the most vulnerable area of Italy. Moreover, from the lithological point of view the thick cover of young, unconsolidated sediments of the Po alluvial plain strongly amplifies the seismic shaking (Bordoni et al., 2012; Margheriti et al., 2000; Marzorati and Bindi, 2006). The Emilia seismic sequence counted two main shakes and around 2000 aftershocks:

- The first mainshock occurred on May 20, 2012, at 4.03 am local time. According to the “Istituto Nazionale di Geofisica e Vulcanologia” (INGV 2012a), the earthquake had a moment magnitude  $M_w$  of 5.9 at a depth of 6.3 km. The epicenter was located between the municipality of Finale Emilia and San Felice sul Panaro (Lat. 44.889°N, Lon. 11.228°), about 36 km north from the city of Bologna (Lo Presti et al. 2012). The sequence was preceded by a few foreshocks, the most energetic one on May 19th, showed a  $M_w$  3.98. (Lo Presti et al., 2012; Malagnini et al, 2012). The subsequent seismic swarms moved towards east with at

least 15 aftershocks of magnitude of between 4.0, for then decreasing in intensity and moving in the direction WSW.

- A second mainshock was recorded on May 29, 2012, (Lat. 44.851°N, Lon. 11.086°E), with moment magnitude  $M_w$  of 5.8 it occurred at a depth of 10.2 km, near the municipality of Medolla, about 12 km in the west-south-west direction from the first event. (ISIDe Database, 2012). After the 29 May, the swarm migrated towards west with three other events of  $M_w > 5$  until 3<sup>rd</sup> June 2012 (Lo Presti et al, 2012; Scisciani & Pizzi, 2012; Chiarabba et al, 2014).

As it possible to appreciate in Figure 3.2-1 the aftershock area extended over more than 50 km elongated in the WNW-ESE, including five major aftershocks with  $5.1 \leq ML \leq 5.3$ , and more than 2000 minor events.

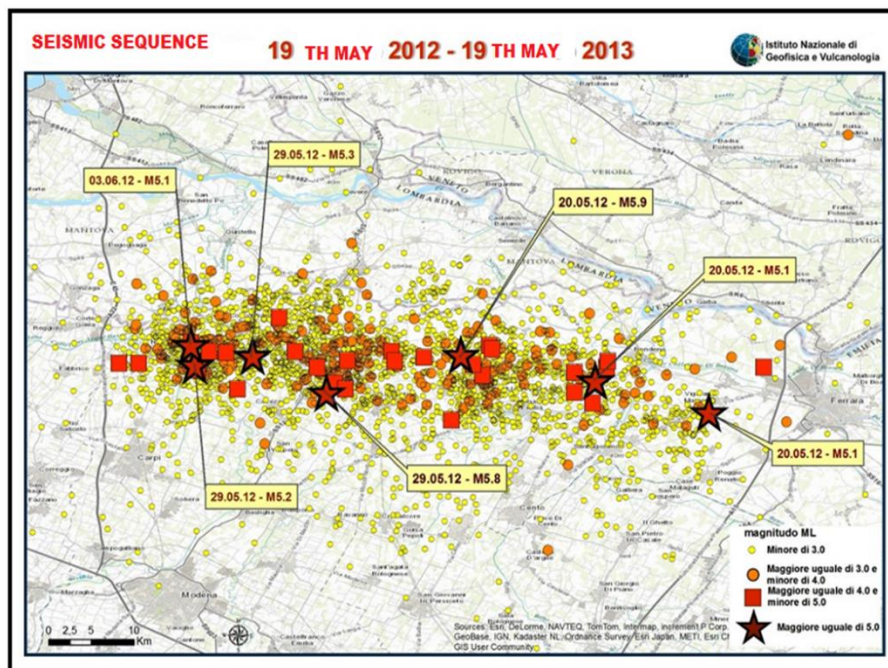


Figure 3.2-1 2012 Seismic Sequence in the Emilia Po Plain from May 19 to June 19, 2012 (ISIDe, <http://iside.rm.ingv.it/>). In a month, more than 2000 seismic events occurred, seven with  $ML \geq 5.0$  (red stars).

The seismic sequence was confined to the upper 10 km of the crust, while minor seismicity with depths ranging from 10 km to 30 km stretched towards the southern sector of the epicentral area (ISIDe, <http://iside.rm.ingv.it/>).

The causative thrust faults of the two mainshocks of May 2012 Emilia sequence were two segments belonging to the Ferrara Arc, which represents the most frontal portion of the Northern Apennine fold-and-thrust buried under the Po Plain Plio-Quaternary sediments (Bigi et al. 1992, Castiglioni

and Pellegrini 200, Bignami et al. 2012, Salvi et al. 2012). The activity and seismogenic potential of the Ferrara arc have been confirmed by InSAR, GPS, and macroseismic studies (Burrato et al., 2003; Boccaletti and Martelli, 2004 Papathanassiou et al., 2015). The Ferrara arc with a total length of more than 100 km presents an internal complex and segmented geometry, where individual segments are commonly 10–30 km-long and characterized by different degrees of overstepping and overlapping geometries (Pieri and Groppi, 1981; Bigi et al., 1992; Boccaletti et al., 2004; Bonini et al., 2014) (see Figure 3.2-2). The Ferrara Arc comprises two major anticlines. The North-East Ferrara system includes WNW–ESE trending structures, and the southwest Mirandola system, strongly bent, it changes in strike from W–E to NW–SE, moving from west towards east (Mantovani et al, 2011; Govoni et al, 2014). The Database of seismogenic sources (Basili et al, 2008; DISS Working Group, 2015) has indicated that the earthquakes of 2012 sequence have been triggered by composite sources namely ITCS051 - Novi-Poggio Renatico for the 20 May shock, and ITCS050 - PoggioRusco-Migliarino for the second main event. All sources are characterized by inverse kinematics, low angle and slip-rates relatively low (0.1-0.5 mm / year) (Camassi et al, 2012; Mazzoli et al, 2015).

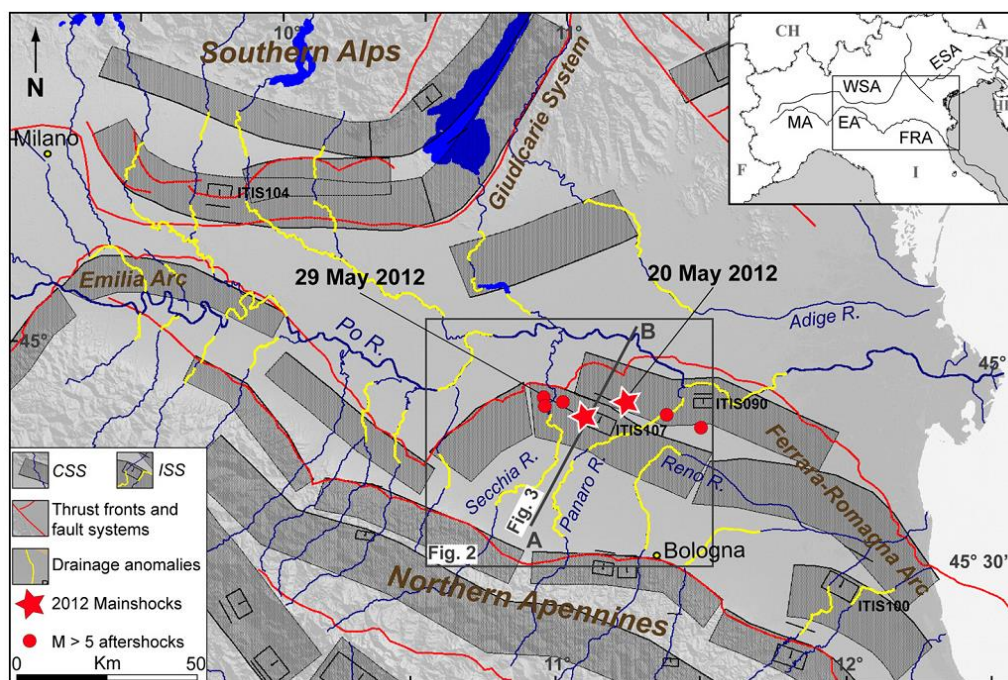


Figure 3.2-2 Seismotectonic Sketch of the Po Plain showing its fluvial system. Seismotectonic sketch of the Po Plain showing its fluvial system. Red lines are the main thrust fronts or fault systems of the northern Apennines and southern Alps. Individual Seismogenic Sources (ISS) and Composite Seismogenic Sources (CSS) are from DISS 3.1.1. ITIS090, Ferrara Individual Source (<http://diss.rm.ingv.it/dissHTML/ITIS090INF.html>), ITIS107 Mirandola Individual Source (<http://diss.rm.ingv.it/dissHTML/ITIS107INF.html>); MA, Monferrato Arc, EA, Emilia Arc; FRA, Ferrara-Romagna Arc; WSA, western southern Alps; ESA, eastern southern Alps. Drainage anomalies are highlighted in yellow ( Burrato et al. 2012).

While the shallow architecture of fold-and-thrust structures down to about 5–7 km depth appears known from seismic reflection profiles, the deep geometry of the thrust planes is less clear because data quality and reflectivity strongly weaken at depth. This drawback is particularly apparent in the footwall side of thrusts where lithological contrasts disappear. These uncertainties arise various tectonic models and interpretations about the deep thrust structure of the Ferrara arc (Picotti and Pazzaglia; 2008 Boccaletti et al., 2011; Carminati et al., 2010). The interpretations are divided between those who not involved the basement of the Mesozoic deposits Carminati et al, 2010), and whom that take it into consideration in buried thrust deformations (Boccaletti et al, 2011; Fantoni & Franciosi 2008; Picotti & Pazzaglia, 2008; Toscani et al, 2009; Carannante et al, 2015). For example, as it is showed in Figure 3.2-3 (a, b), Galli et al. (2000) identify the hypocenter of the earthquakes along the continuation in depth within the sediments Triassic-Cretaceous of the Ferrara arc, well above the magnetic basement (a); the shock of May 29, however, would be located along the basal thrust beneath the high structural of Mirandola, at the base of the Mesozoic sediments (b).

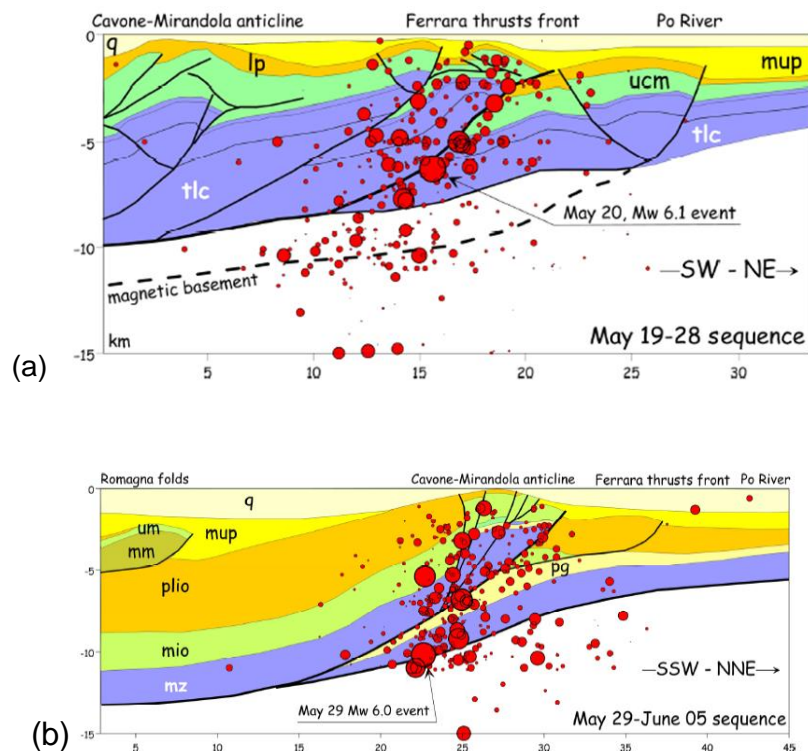


Figure 3.2-3 Thrust faulting focal mechanism of the main shocks in 2012. (a, b). The thrust faulting focal mechanisms of the main shocks and the strongest aftershocks show fault planes with E-W, ENE-WSW, and WNW-ESE orientations compatible with the approximately N-S direction of the compression in the area- In fact, focal mechanisms relating to the sequence indicate values of maximum shortening (Maximum Shortening -  $Sh_{max}$ ) perpendicular to the front of the thrust (Galli et al., 2012).

Within other clarifications, advanced modeling based on a finite-element structural–mechanical methods have confirmed the activation of a single, low-angle, fault segment for the 20th May, ML 5.9, shock. Conversely, the best-fit source model for the 29th May, ML 5.8, event includes the involvement of three fault-segments describing an overall listric geometry, with the steeper part that dips about 65° between 5 and 8 km depths (Tizzani et al. 2013). The updated source models of the 20<sup>th</sup> and the 29<sup>th</sup> May shocks obtained by ground deformation InSAR data have identified the different dip of the two faults segments (Tizzani et al., 2013). Moreover, these techniques applied to the Emilia sequence have clearly documented the consequential uplift of the epicentral area with elliptical shape 10–30 km-long by 5–15 km-wide and a maximum vertical displacement of some tens of centimeters (e.g. Bignami et al., 2012; Salvi et al., 2012). In particular, the seismic activity of May 20 induced a vertical deformation of the surface with peaks between 15 to 21 cm with a length about 25 km (direct WNW) and about 10 km wide, while the 29<sup>th</sup> May shock has deformed an area 25 km long (oriented E-W), corresponding to an uplift of 10 cm (Bignami et al. 2012).

Figure 3.2-4 presents the surface displacement field along the line-of-sight. Most of the deformation presents to uplift up to a maximum of about 20 cm. The uplifted region is encircled by an area that experienced minor subsidence. This pattern is in good agreement with the expected kinematics of the buried tectonic structures (Vannoli et al. 2004).

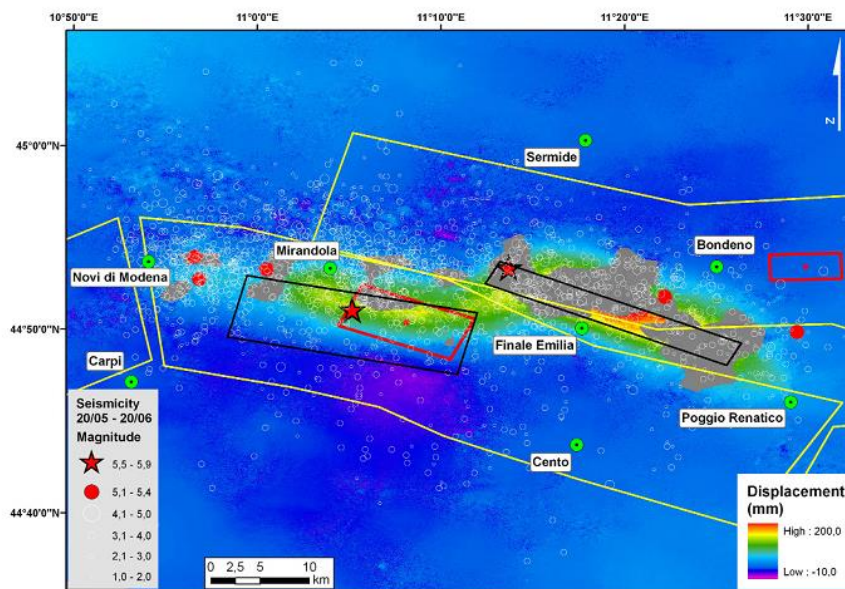
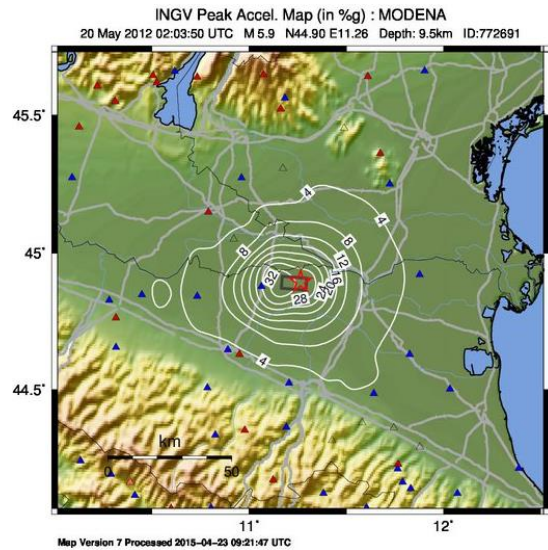
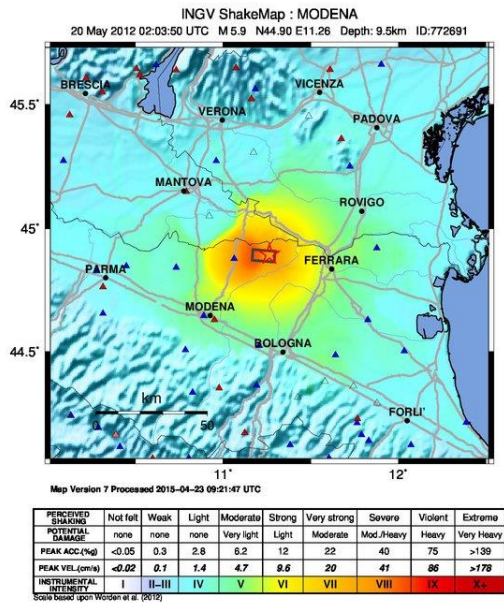


Figure 3.2-4 From InSAR interferogram Displacement caused by the mainshocks. Red stars, position of May 20 and 29 mainshocks; black rectangles, surface projection of modeled faults; yellow polygons, surface projection of the ITCS050 ('Poggio Rusco-Migliarino') and ITCS051 ('Novi-Poggio Renatico') composite seismogenic sources; red polygons, surface projection of the ITIS107 ('Mirandola') and ITIS090 ('Ferrara') individual seismogenic sources of the DISS database. (Bignami et al., 2012).

Subsequently, the satellite interferometry data have been modelled to derive the slip distribution along faults activated by the earthquake. For the event of May 20, it was calculated a slip of 120 cm to 5 km depth, while for the one of May 29th the slip derived was of 54 cm to 6 km deep (Piece et al, 2012; Salvi et al, 2012). Additionally, important seismic parameters are given by the shakes maps and Peak ground acceleration maps (Figure 3.2-5 a.b.c.d). Shake Map is a software package that can be used to generate maps of ground shaking for various peak ground motion (PGM) parameters, including peak ground acceleration (PGA), peak ground velocity, and spectral acceleration response at 0.3 s, 1.0 s and 3.0 s, and instrumentally derived intensities. ShakeMap has been produced and published in Italy by the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV; National Institute of Geophysics and Volcanology) since 2006 (<http://shakemap.rm.ingv.it>). The primary aim is to help the *Dipartimento della Protezione Civile* (DPC; Civil Protection Department), civil defense agency to define rapidly accurate seismic information concerning the localization of epicenters and the spatial dimension of the earthquake. (Michelini et al. 2008).

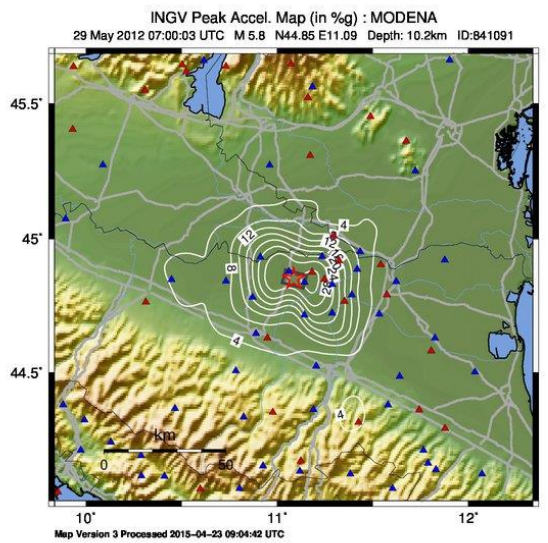
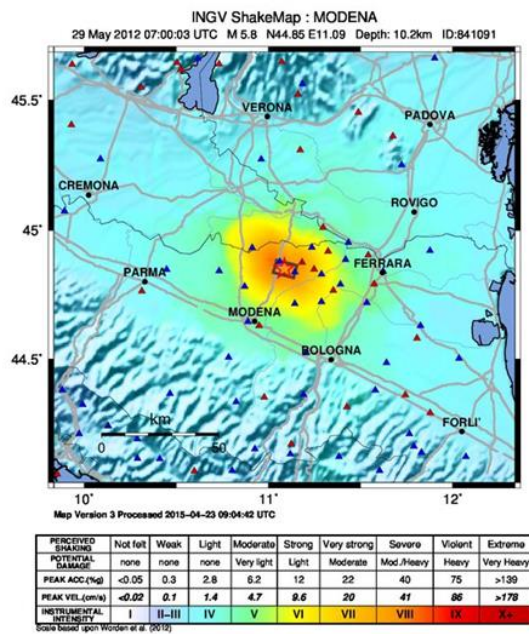
For the two main events (May 20 and May 29) the intensity instrumental grade ranged from VII-VIII (Fioravanti et al., 2013), with peak ground acceleration (PGA) of not more than 0.32 g (and a peak ground velocity (PGV) maximum of 54 cm / s (from the Mirandola station, in May 20 ,2012).

These maps are usually based on the maximum value of the three components (two horizontal and one vertical) recorded by the seismic stations of the ground motion. The shaking between two stations is estimated using empirical relationships that correlate to the magnitude and the epicentral distance or from the fault (Maps of shaking – [www.terremoti.ingv.it](http://www.terremoti.ingv.it), Law 122/2012).



(a)

(b)



(c)

(d)

Figure 3.2-5 Shake Maps for the May 20 and 29 shocks. (a. b. c. d.). Event location and magnitude from INGV seismic center, peak ground motion data from INGV (red triangles) and RAN (blue triangles). Intensities expressed in terms of the Mercalli modified scale and PGA.

Summarizing the contents of this chapter, is possible to assert that several aspects as: historical and instrumental earthquakes (e.g. Boschi et al. 2000, Rovida et al. 2011), drainage anomalies

controlled by buried anticlines, active compression and a shortening rate of ca.  $<1$  mm/a (Toscani et al. 2009) testify the Quaternary thrusts activity (DISS Working Group 2010). In particular, the activity of the Ferrara and Mirandola thrusts (DISS Working Group 2010) has been responsible for historical drainage diversions of the Po, Secchia, Panaro and Reno rivers (Castaldini et al. 1979; Panizza and Castaldini, 1987; Burrato et al. 2003, Burrato et al. 2012). The Emilia earthquake sequence has added strong hints to the definition of the active structures of this portion of the Northern Apennines external fronts. In fact, although with some differences, seismic, InSAR, GPS, and macroseismic data, consistently suggest that two blind thrusts of the Ferrara arc activated during the 2012 mainshocks, confirming the activity of the buried external fronts (e.g. Burrato et al., 2003; Boccaletti and Martelli, 2004). The seismic history of the past 30 yr (ISIDe Database, 2012; CSI1.1, 2006) shows low seismicity in coincidence of the area hit by the 2012 sequence and the same appears true for the location of the main historical events (Rovida et al., 2011). In fact, apart from the VII–VIII MCS 1639 earthquake, only earthquakes of moderate magnitude occurred during the past in the area surrounding the 2012 seismic sequence (Camassi et al., 2011). As shown in the historical seismic map of Figure 3.2-6, the closest and more relevant event was certainly the 1570 earthquake, that on 17<sup>th</sup> November hit the area of Ferrara about 30km east of the 2012 sequence (I=VIII MCS, Mw 5.5) (Postpischl 1985). According to historical sources, the area interested by the 2012 quakes has not been previously affected by events with epicentral intensity  $>6$  MCS, which, conversely, have fallen at the eastern and western boundaries of this region hit in May 2012 (Galli et al., 2012). Prior to 1570, a coeval chronicle (Giacomo da Marano, 15<sup>th</sup> century) suggested that there was another strong earthquake in Ferrara in the year 1346, when on February 22, "*...many houses fell down, palaces, towers...and in the villages, tenements, barns...and other buildings*". However, due to the little information available, this could have occurred anywhere around Ferrara, and for instance, also in the eastern part of the region that was struck in 2012. Over the past 1000 years, there have been no strong ( $M \geq 5.0$ ) earthquakes associated with this portion of the Ferrara arc. Apart from minor events ( $MW < 4.5$ ) in the epicentral area of the 2012 seismic sequence the historical and instrumental catalogs report five earthquakes with MW between 4.5 and 4.7 (in 1561, 1574, 1978, 1986, 1987) (Castello et al. 2005, CPTI11 catalogue at <http://emidius.mi.ingv.it/>, ISIDe database). Conversely, the eastern, NWSE striking segment of the Ferrara Arc has been activated by several historical earthquakes: 14 events localized around Ferrara of  $4.5 \leq MW \leq 5.5$ , including the already cited Ferrara 1570 earthquake (MW 5.5, Io VII-VIII) and the Argenta 1624 earthquake (MW 5.5, Io VII-VIII). The western, WSW-ENE-striking segment of the Ferrara Arc was activated at its

southern end by two earthquakes of MW 5.5 in 1831 and 1832, and more recently by the Reggio-Emilia 1996 earthquake (MW 5.4). Since instrumental measurements have been applied, several seismic sequences that originated at mid-to-lower crustal depths (of ca. 20-25 km) have been reported, which activated the basal thrust of the Ferrara Arc (e.g., 2008, MW 5.5) (Bragato et al. 2012) or its antithetic splays (e.g., Faenza 2000, MW 4.8; Monghidoro 2003, MW 5.3) (Ciaccio and Chiarabba 2002, Lavecchia et al. 2003, Piccinini et al. 2006). The focal mechanisms of all the instrumental events possibly associated with the Ferrara Arc show prevalent reverse and reverse oblique kinematics with P-axes nearly perpendicular to the average structural trend (Boncio and Bracone 2009, Montone et al. 2012).

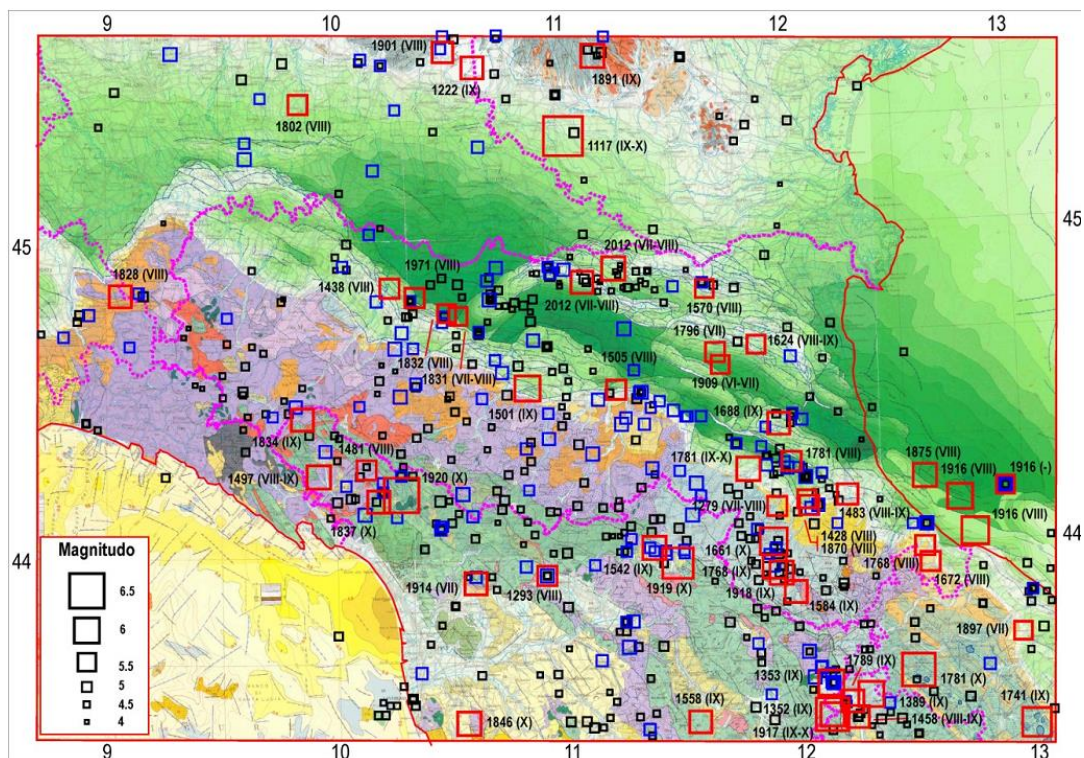


Figure 3.2-6 Map of Historical Seismicity of Emilia Romagna Region and surrounding areas. Historical seismicity of Emilia Romagna and surrounding areas reported on the structural map of Italy (Bigi et alii, 1992). For the strongest shock ( $M > 5.5$ , red symbols) was reported the year and the intensity MCS. The blue symbols indicate the shocks with  $5.0 < M < 5.5$  (CPTI1, Rovida et alii, 2011). (Mantovani et al., 2013).

### 3.3 Overview on Coseismic Surface Effects induced by the 2012 Seismic Sequence

The 2012 Emilia earthquake sequence triggered widespread CSE-liquefactions through a vast area in Emilia-Romagna and Lombardia regions over an area of 1200 km<sup>2</sup> affecting about 15 municipalities within 30 km from the epicenter of May 20 and May 29. The epicentral distance of local manifestations found confirmation on the empirical relationships available between earthquake magnitude and maximum distance for the occurrence of liquefaction phenomena (Obermeier, 1996; Galli, 2000). The CSE occurred during the 2012 seismic sequence have been surveyed by different teams of researchers (Di Manna et al., 2012; Caputo et al. 2012; Emergeo Workinggroup 2013).

The widespread CSE manifestation (mostly liquefaction phenomena), triggered by the main quakes, called numerous scientific teams from all over Italy to survey the effects over the epicentral area, ascertaining moreover damages to buildings, infrastructures and in agriculture sector. Sharing preliminary data among scientists, informing people and media about CSE occurrences in a short time was crucial. In this thesis definition of CSE, explanations concerning triggering and casual factors of coseismic surface effects have been done in chapter 2.1. Furthermore, the following chapter exemplifies the different inventories and catalogues of CSE that have been implemented in these last years. This section is mainly dedicated to understand the relation between occurrences and geomorphological context, the different types of effects, their spatial distribution and impacts in urban and rural areas. The 2012 seismic sequence didn't leave marks of primary coseismic, this aspect agrees with the blind nature of the seismogenic source, as corroborated by seismological and DinSAR analysis (Atzori et al., 2012). The 2012 earthquake triggered around 1900 secondary effect, mostly consisted in liquefaction phenomena. The occurrences have been recorded and then classified in different ways by the numerous technical and scientific teams involved in the effects reconnaissance (Bertolini and Fioroni, 2012; Di Manna et al., 2012; Marcaccio and Martinelli, 2012; Pizzi and Scisciani, 2012; Vannucchi et al., 2012, Emergeo Working Group, 2013).

Images of Figures 3.3-1, illustrate part of the typology of occurrences recognized and listed herein below:

- a. Sand volcanoes (punctual);
- b. Eruption of wet sands from ground fissures;
- c. Eruption of wet sands from foundations (usually along the perimeters of buildings);
- d. Eruption of sands (and water) from domestic wells;
- e. Tension cracks and graben-like fissures (without or with eruption of sand or water);

- f. 'Dry' craters (or sink-holes) of average diameters of 1-2 m;
- g. Lateral spreading effects (on slopes);
- h. Small collapses along the banks of irrigation ditches;
- i. 'Yellow corn spots' due to local corn withering (saltwater/ gas/heat emissions)
- j. Hydrological anomalies as changing in water level and temperature in wells and strong water-table fluctuations.

The huge amount of data on coseismic liquefaction related to the May–June 2012 events (EMERGEO Working Group, 2012a, 2013) gave the opportunity to improve knowledge and methodologies to better comprehend how geomorphological setting, besides the stratigraphic and hydrologic conditions, may favor the occurrence of CSE phenomena. As stated by Civico et al. (2012), the last Emilia seismic sequence confirmed the susceptibility to CSE of the central southern Po Plain environment. This issue can be found mentioned in several historical reports of earthquakes that have occurred in northern Italy, such as the Ferrara 1570, Argenta 1624, Cesenatico 1875, Rimini 1916 events (Galli, 2000; Calabrese et al., 2012). Further documentation of the occurrence of liquefaction events older than the May 2012 earthquakes have been demonstrated by palaeo-sismologic studies, carried for example through a trench excavated south of the village of San Carlo after the May 2012, which have showed structural evidences of ancient liquefaction (Caputo et al., 2012). This study indicated that the 1570 and 1624 earthquakes could be the events inducing these old liquefaction phenomena.

Looking at the distribution of the liquefaction features, mostly were arranged in clusters and rectilinear or meander alignments along the abandoned riverbeds (Secchia, Reno, Panaro and Po rivers) (Lo Presti et al., 2012). Indeed, the presence of fluvial landforms in the area, struck by the 2012 seismic sequence, strongly favored the occurrence of CSE-liquefactions (Bertolini and Fioroni, 2012; Di Manna et al., 2012; Ninfo et al., 2012; Papathanassiou et al., 2012; EMERGEO Working Group, 2013; De Martini et al., 2014;). As previously described, the investigated area is characterized by the presence of fluvial levees, paleoriverbeds, out-flow channels and crevasse splays, which are characterized by sandy layers in the upper 5 meters. These fluvial landforms, in the first 20 m of succession, mainly are aquitard or acquiclude silty-clay alternating with sandy levels belonging to ancient fluvial paths that frame the confined aquifers.

The Po Plain, filled by alluvial sediments with multilayered confined aquifers and phreatic aquifers in the first 10 presents a strong potential of susceptibility to CSE. Most the effects were triggered by the first main shock of May 20 (Regione Emilia Romagna, ENI-Agip, 1998; Marcaccio and Martinelli,

2012). Most of them were then reactivated during the 29<sup>th</sup> May shock, which principally affected San Felice sul Panaro. Seventy percent of the observed effects befallen in urbanized areas while the remaining 30% was observed in open agricultural fields (Bertolini and Fioroni, 2012). The first event, with epicenter in the countryside near Finale Emilia (Modena Province) induced CSE in the area of St. Carlo, St. Agostino, Mirabello, Scortichino, (Ferrara Province) and San Felice sul Panaro and Mirandola (Modena Province). From the second main shock near Medolla, CSE occurred in Medolla, Cavezzo, S. Possidonio, Concordia in Modena province, and in the villages of Quistello, Zambone, Moglia in the province of Mantua.



(a)



(b)



(c)



(d)

3.3-1 Picture showing different types of CSE occurrences in the following localities: a) St. Carlo, b) S. Felice, c) Uccivello, d) Finale Emilia. Photos taken by Prof. Dorian Castaldini UNIMORE.

From a general observation of the phenomena it was noticeable that most of the evidence appeared in the border of significant deformation area measured by InSAR, while very few effects occurred in zones of maximum uplift (e.g., Burrato et al., 2012). The high resolution of the COSMOSkyMed images allowed additional inferences on the spatial distribution of the local geological effects at surface (Emergeo workinggroup, 2013). The zone with the most widespread effects was the hamlet of St. Carlo (St. Agostino municipality) which is located on a fluvial ridge corresponding to a Reno ancient channel known as “St. Agostino levee” (Castaldini and Raimondi, 1985). The ancient riverbed of the Reno River, as already mentioned was active from the medieval

times until the end of the 18th century, when it was subjected to an artificial diversion near St. Agostino village (Castaldini and Raimondi 1985, Castaldini 1989b) to discard the recurrent floods affecting the surrounding plain. In 2012 CSE have been surveyed, in particular, along this SW-NE alignment of the old Reno riverbed, which is densely urbanized and the large quantity of sand ejected from the subsoil have caused major damages to the buildings of the village of St. Carlo (Prestininzi et al., 2012). Furthermore, borehole logs carried out before the seismic sequence at St. Carlo showed that water table was about 3 m depth, and the liquefaction occurred in a lens of fine and medium sand located at a depth 4 m and at 6 m (ancient bank fill). From a geomorphologic viewpoint, the site is located between the Po, Panaro and Secchia rivers, in the lowest sector of the Modena plain (8 - 9 m a.s.l.). This area was flooded many times by the Po River and the clayey sediments buried older fluvial sandy deposits and the CSE material come from sediments of ancient riverbed known in literature as "Barchessoni riverbed" (Castaldini et al. 1992). In St. Felice sul Panaro the effects have been reactivated by the May 29th shock, in fact, the village (17 m a.s.l.) is in a sector where silt and clay deposits crop out (Castiglioni et al. 1997). Several effects occurred in the urban area (in the stadium and in a school yard) that lies at the confluence of a S-N Panaro ancient channel and a W-E flowing ancient riverbed of the Secchia. CSE at Uccivello di Cavezzo, St. Possidonio and Quistello were triggered by the May 29th (M= 5.8) earthquake. Uccivello di Cavezzo and S. Possidonio are located on an ancient course of the Secchia River (Castaldini 1989a, 1989b). Uccivello di Cavezzo (23 m a.s.l.) is on the Secchia fluvial ridge, NW-SE orientated, it crosses S. Martino Secchia, Cavezzo and Medolla. Also St. Possidonio (20 m a.s.l.) lies on a NW-SE trending sandy fluvial ridge corresponding to a Secchia ancient riverbed, which was abandoned between XIII-XIV centuries. In all liquefaction events the areal extension of ejected material range from a few square meters up to many hundreds square meters. The most visible alignments of liquefaction, surface fracturing and sand ejection are represented by the liquefaction phenomena observed from St. Agostino to the Mirabello municipalities (SW-NE following the old Reno river plain) and of Cavezzo (NE-SW following the ancient channel of the Secchia River), which are several kilometers long. Ground cracks were also widespread and affected paved roads, buildings and farmed land. The fractures with no sand extrusion had a similar strike, were up to a few hundred meters long, displayed usually a clear opening to 30 cm, and locally showed a vertical separation up to 20cm. Furthermore, the large amount of extruded sand in the St. Carlo area produced important emptying and compaction in the liquefied beds that produced at the surface a localized subsidence, sometimes accompanied by ponding. Subsidence started with the occurrence of liquefactions but,

because settling and compaction of sediments is represented an additional hazard affecting the man-made structures. (EmergeoWorkinggroup 2013). Moreover, the ground ruptures damaged seriously all construction, especially houses in S. Carlo and industrial settlements between S. Carlo and Mirabello.

Within other types of effects, lateral spreading occurring along the levees of this ancient channel, from S. Agostino to Mirabello caused many ground ruptures. Within other evidences, bottom of canals and ditches uplifts, bulging and cracks due to sand ejection under the bottom of the minor watercourses channel. Another effect of the earthquakes was the ejection of sand from water wells and hydrogeological water level variations with uprising phenomena up to 1.5 meter (Marcaccio and Martinelli, 2012).

## 4 INTEGRATED GIS-BASED CATALOGUE OF 2012 EMILIA INDUCED COSEISMIC SURFACE EFFECTS

### 4.1 Introduction

Natural disasters in the last decades have become a key argument taking the attention of the scientific community, beside other different stakeholders such as: policy makers, social media and civil population. Resulting from the occurrence of hazardous natural phenomenon, natural disasters induce direct and indirect negative socio-economic impacts on territories and communities. (Alexander 2000; Wisner et al. 2004; NRCNA 2006). Manifestations of coseismic surface effects amplify the consequences, causing significant collateral damages during strong earthquakes. Devoli et al. (2007) has underlined the importance of natural disaster databases in risk prevention and management. In fact, from inventories is possible to appreciate the spatial distribution of dangerous natural phenomena and the existence of vulnerable elements (e.g., people, assets and activities), that are quantifiable through human and material losses (Zêzere et al. 2014). In this context, the collection and the investigation of earthquake-induced ground effects is relevant to seismic risk mitigation. The understanding of triggering processes and the zonation of those areas that might be affected by CSE in case of future seismic events are the most significant intrinsic values associated to inventory. Although the specific objective of this chapter is to illustrate the catalogue of the coseismic surface effects triggered in Emilia Region, specifically for the CSE of 2012 seismic sequence, an overview of some CSE inventories is herein presented. Moreover, is it important to mention how the strongest shakes in the 2012 Po Plain earthquake ( $M_w = 5.9$  and  $M_w = 5.8$ ) caused widespread CSE also in several districts in the southern part of Mantua Province (Lombardy region) which have been well documented in a report redacted by Ravazzi et al. (2013). From the last decades, a noticeable number of publications, inventories, studies have been directed to asses, forecast and map the occurrence of coseismic effects in relation to past worldwide earthquakes (e.g. Bommer and Rodriguez, 2002; Keefer, 2002; Sepulveda et al., 2005; Porfido et al., 2007; Tosatti et al., 2008; Alfaro et al., 2012; Prestininzi et al., 2014).

Several empirical databases (Kuribayashi and Tatsuoka, 1975, Ambraseys, 1988, Wakamatsu, 1991, 1993, Galli, 2000), have correlated the occurrence of liquefaction with epicentral distance and magnitude.

For the complexity of procedures and data management, the implementation of diachronic and inclusive catalogues of coseismic effects is always a demanding task (Prestininzi and Romeo, 2000). Initially, Youd and Hoose (1978) reported important recollections of coseismic manifestations in relation to the 46 earthquakes which have occurred between 1800 and 1970 in Northern California. (Prestininzi et al. 2012). Beyond the disastrous earthquake of San Francisco in 1906 (M=8.3 around), during the temporal interval of 170 years, 350 localities were affected by ground failures (landslides, lateral spreads, ground settlement and surface cracks). Worldwide massive liquefaction recorded phenomena were triggered by the 1964 M9.2 Alaska earthquake (Waller, 1966; Seed, 1968) and by the 1964 M7.5 Niigata earthquake (Seed and Idriss, 1967), as well as by the 1810–1811 M8 New Madrid earthquakes (Obermeier, 1989), the 1995 M6.9 Kobe (Japan), the 1999 M7.5 Chi-Chi (Taiwan) and the 1999 M7.4 Izmit (Turkey) earthquakes (Wang et al., 2003; Aydan et al., 2008). Considering the scientific and informative contribution of some catalogs which have traced the major seismic events, the United States Geological Survey (USGS) (PAGER-CAT) is well described by Allen et al. (2009). Although until present most important inventories have not established a direct access to the database of earthquake-induced ground failures, most of the them report nevertheless useful descriptions of tsunamis, landslides, fires and liquefaction related to earthquake records (Hoyois et al., 2007). In Europe, the Emergency Events Database (EM-DAT) and the Euro-Mediterranean Earthquake Catalogue (EMEC– Grünthal and Wahlström, 2012) are the most updated versions of collections describing earthquakes secondary effects, although the coseismic phenomena are not directly consultable with a specific querying tool.

Over the last decade, many Italian earthquake inventories reporting coseismic effects have been published online (e.g. CFTI – ING 1995; NT4.1 – Camassi and Stucchi, 1997; DBMI04 – Stucchi et al., 2007; CPTI04 – CPTI, 2004; ITC 2.0 –CPTI11 – Rovida et al., 2011). Nevertheless, in all these catalogues the information associated to CSE are not directly accessible. In this chapter, as stated above, the focused is directed towards CSE induced by the 2012 seismic sequence which affected the Emilia territory.

Taking into account the provisional presence of the geological coseismic effects, just after the 20<sup>th</sup> and 29<sup>th</sup> of May 2012 quakes, different scientific teams (e.g. ISPRA, INGV, UNIMORE), were active in surveying the epicentral area for CSE recognition in order to localize, map and describe those phenomena. In addition to the databases that have been granted by the University of Ferrara, by ISPRA and Emergeo (INGV) for the inventory implemented within the framework of this PhD, many other databased were created by geoengineering and scientific teams to store the CSE occurrences induced by the 2012 seismic sequence.

For instance, Di Manna et al. (2012) has contributed with the collection of more than 500 ground effects spread over an area of about 700 km. Moreover, Bertolini and Fioroni (2012) documented more than 700 occurrences by 300 aerial photographs.

Furthermore, a reference map inventory was produced by the Emilia Romagna Region (*Servizio Geologico e Sismico dei Suoli*) integrating different databases belonging to several scientific institutions (e.g. the University of Ferrara, GEOPROCIV, Basin authority of Reno and Po rivers within others) (<http://mappegis.regione.emiliaromagna.it>). With the only propose to promptly publish a map inventory of the CSE spatial distribution the database assembled by the Region doesn't contain any effects classification or description associated. The following three sections describe in details the inventories that have been integrated to create the comprehensive catalogue that was conceived in the context of this doctoral research, which is deeply illustrated in section 4.3. However, a part of this chapter is dedicated to the CEDIT catalog. It has considered in a systematic way the effects induced by the most important earthquakes of the Italian seismic history.

## 4.2 Existing Catalogues of CSE induced by the Emilia Seismic Sequence

### 4.2.1 CEDIT Catalogue

The Italian Catalogue of Earthquake-Induced Ground Failures (CEDIT) could be considered one of the main national reference database of ground failures generated by the strongest Italian earthquakes with an epicentral intensity of at least VIII (MCS). The importance of this catalogue couldn't be ignored in this study although it was not joint to the catalogue completed within this doctoral research. The current version of CEDIT database is an update of the former version released at the end of the 1990s, (Romeo and Delfino, 1997) (See Figure 4.2.1-1).

Inventory reports more than 160 earthquakes which affected 2000 localities where ground failures were induced by the strong seismic events. The current version of the catalogue reports about 3000 CSE occurred from 1000 until 2016. It has included about 1500 manifestations generated during the 2012 earthquakes and about 150 evidences induced by the Amatrice earthquake (2016) (<http://www.ceri.uniroma1.it/index.php/2016/08/sisma-centro-italia>). Table 4.2.1-1 illustrates a subset of the list of historical earthquakes. The historical elaboration of the data acquisition has been retrieved from chronicle and archives documentation, moreover the data that have flowed into the CEDIT were collected from different existing seismic catalogues such as: CPTI04 catalogue of earthquakes (Gruppo di lavoro CPTI, 2004), the DBMI04 macroseismic catalogue (Stucchi et al., 2007) among others. The ground effects stored in the CEDIT database were classified in five main categories and in more detailed subcategories: landslides, ground cracks, liquefaction, surface faulting and ground changes. CEDIT is a relational database based on of five tables: "terremoti" (earthquakes), *località* (localities), *frasi* (sentences), *biblio* (references), and *effetti* (ground failures).

CEDIT database is online for public access at: <http://www.ceri.uniroma1.it/cn/gis.jsp> and is hosted by the web server of the Research Centre for the Geological Risks (CERI) of the Sapienza University of Rome (Fortunato et al., 2012). The query system was based on the services of ArcGIS®-online from ESRI™ cloud technology. The system provides a geo-database consulting and querying interface with graph or table outputs with data relating to earthquakes and associated to the surface effects. (Martino, Prestininzi, and Romeo 2014).

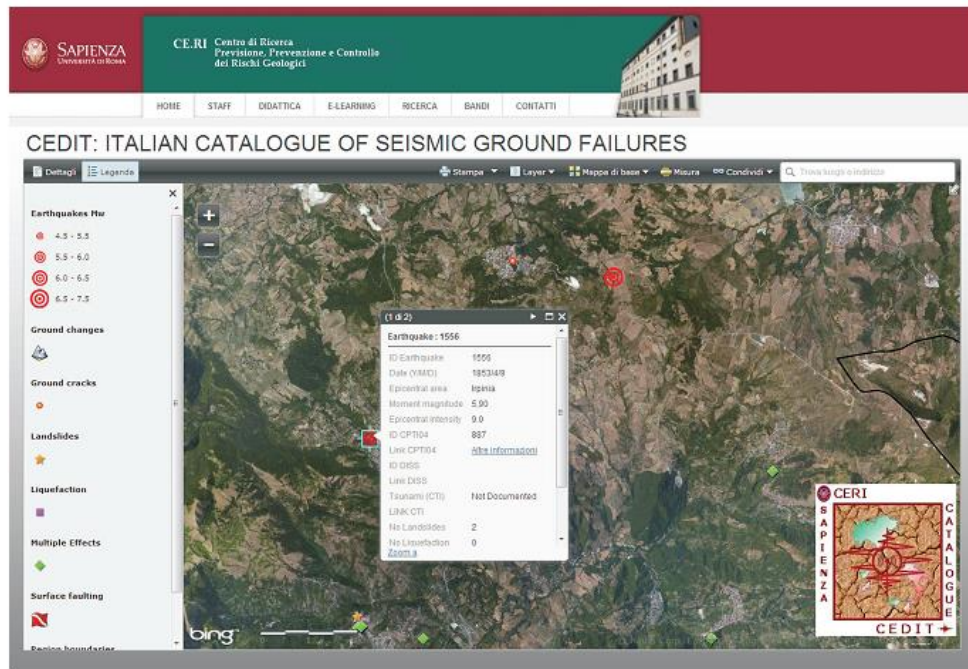


Figure 4.2.1-1 Screenshot of CEDIT website. Online querying of CEDIT on the website [www.ceri.uniroma1.it](http://www.ceri.uniroma1.it) : example of pop-up window. screen of the Web-GIS for querying CEDIT on the website [www.ceri.uniroma1.it](http://www.ceri.uniroma1.it) (last consultation, October 2016).

# eqk	ID CPTI04	Epicentral area	Date	Lat °	Long °	Io(MCS)	$M_w$ (depth)	Sites	Landslides	Ground-cracks	Liquefaction	Surface faulting	Ground-changes
136	1630	Alto Adriatico	1916-05-17	44.000	12.630	8.0	5.85	1		1			
<b>137</b>	<b>1637</b>	<b>Alto Adriatico</b>	<b>1916-08-16</b>	<b>43.970</b>	<b>12.670</b>	<b>8.0</b>	<b>5.92</b>	<b>5</b>		<b>3</b>	<b>7</b>		<b>1</b>
138	1650	Ternano	1917-04-26	43.465	12.125	9.0	5.80	4	1	3	3		
139	1651	Monterchi-Citerna	1917-05-12	42.580	12.630	7.5	5.11	1	1				
140	1684	Mugello	1919-06-29	43.950	11.480	9.0	6.18	7	3	5	4		
141	1687	Piancastagnaio	1919-09-10	42.793	11.788	8.0	5.38	1			1		
142	1708	Garfagnana	1920-09-07	44.180	10.280	9.5	6.48	23	25	6			1
143	1800	Colli Albani	1927-12-26	41.700	12.700	7.0	5.02	1	2				
144	1805	Carnia	1928-03-27	46.372	12.975	8.5	5.75	17	26	4			
145	1841	Senigallia	1930-07-23	41.050	15.370	10.0	6.72 (15)	29	32	15		4	2
146	1847	Irpinia	1930-10-30	43.659	13.331	9.0	5.94	2	1		1		
147	1886	Maiella	1933-09-26	42.050	14.180	8.5	5.68	2	2				
148	1921	Bosco Cansiglio	1936-10-18	46.088	12.380	9.0	5.90	6	2	5			1
149	1950	Garfagnana	1939-10-15	44.119	10.255	6.5	5.20	1	1				
150	1995	Valle dello Staffora	1945-06-29	44.830	9.130	7.5	5.15	1	1				
151	2007	Calabria centrale	1947-05-11	38.650	16.520	8.0	5.71	1	1				
152	2175	Irpinia	1962-08-21	41.130	14.970	9.0	6.19	2	1			1	1
<b>153</b>	<b>2246</b>	<b>Valle del Belice</b>	<b>1968-01-15</b>	<b>37.770</b>	<b>12.980</b>	<b>10.0</b>	<b>6.12</b>	<b>15</b>	<b>7</b>	<b>9</b>	<b>7</b>		
154	2294	Tuscania	1971-02-06	42.442	11.846	7.5	4.90	2	2	1			1
155	2363	Friuli	1976-05-06	46.241	13.119	9.5	6.43 (06)	103	84	17	46		14
156	2366	Friuli	1976-09-15	46.250	13.120	8.5	5.92 (11)	9	5	5	5		2
157	2400	Valnerina	1979-09-19	42.720	13.070	8.5	5.90 (06)	1	1				
158	2413	Irpinia-Basilicata	1980-11-23	40.850	15.280	10.0	6.89 (12)	216	239	119	27	86	17
159	2441	Appennino Abruzzese	1984-05-07	41.666	14.057	8.0	5.93 (20)	6	4	2			
160	2478	Sicilia sud-orientale	1990-12-13	37.266	15.121	7.0	5.68 (07)	1			2		
<b>161</b>	<b>2515</b>	<b>Umbria-Marche</b>	<b>1997-09-26</b>	<b>43.019</b>	<b>12.879</b>	<b>8.5</b>	<b>6.05 (10)</b>	<b>203</b>	<b>194</b>	<b>82</b>		<b>3</b>	<b>4</b>
162	2522	Appennino Calabro-Lucano	1998-09-09	40.038	15.937	6.5	5.68 (29)	51	56	5		2	
163	2546	Tirreno meridionale	2002-09-06	38.081	13.422	6.0	5.90 (27)	1	1	1			
<b>164</b>	<b>2550</b>	<b>Molise</b>	<b>2002-10-31</b>	<b>41.694</b>	<b>14.925</b>	<b>7.5</b>	<b>5.74 (25)</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>		
<b>165</b>	<b>NA</b>	<b>L'Aquila</b>	<b>2009-04-06</b>	<b>42.334</b>	<b>13.334</b>	<b>9.0</b>	<b>6.20 (08)</b>	<b>168</b>	<b>95</b>	<b>5</b>	<b>5</b>	<b>65</b>	<b>1</b>
<b>166</b>	<b>NA</b>	<b>Emilia</b>	<b>2012-05-20</b>	<b>44.889</b>	<b>11.228</b>	<b>7.5</b>	<b>5.90 (06)</b>	<b>1343</b>	<b>12</b>	<b>16</b>	<b>1514</b>		

Table 4.2.1.-1 Subsect of the CEDIT database. The table illustrates the most important seismic event specifying the CSE occurrences which include those of the Emilia seismic sequence (Martino et al., 2014).

Data incompleteness is an unavoidable problem when relating to historical or even pre-historical events (Harp et al., 2011). Therefore, a locality affected by several ground failures is considered only once, since in many cases there is no information about the number of triggered failures.

Despite the limitation at present the CEDIT represents the most updated and complete online catalogue of earthquake induced effects at national scale.

#### 4.2.2 ISPRA Catalogue

Under the coordination of ISPRA, the Italian Catalogue of Earthquake Environmental Effects (EEEs), was published in 2011, contextually with the INQUA TERPRO Project titled: "A global catalogue and mapping of earthquake environmental effects" (2008–2011) (Esposito et al. 2015). Before exploring the content, the structure and functions of the catalogue, it is important to underline the fact that its conception lies in the context of the elaboration of the Environmental Seismic Intensity Scale (ESI) published in 2007 (Michetti et al., 2007). The ESI scale allows the assessment of epicentral and local seismic intensity based only on the characteristics, size and areal distribution of EEEs, which are independent from time (modern, historical or paleo) and from the socio-economic variables of the damaged area.

The use of the scale mentioned above, when integrated with the other traditional scales provides a better picture of the earthquake scenario, because only environmental effects consent suitable comparisons of the earthquake intensity.

The scale represented by figure 4.2.2-1 has already been applied to many cases around the world: Guerrieri et al. (2009), Lalinde et al. (2007), Papathanassiou and Pavlides (2007), Porfido et al. (2007), Serva et al. (2007), Alì et al. (2009), Mosquera-Machado et al. (2009), Lekkas (2010), Papanikolaou (2011), Gosar (2012), Fontoulis and Mavroulis (2013), Velazquez Bucio et al. (2013), Bashir et al. (2014).

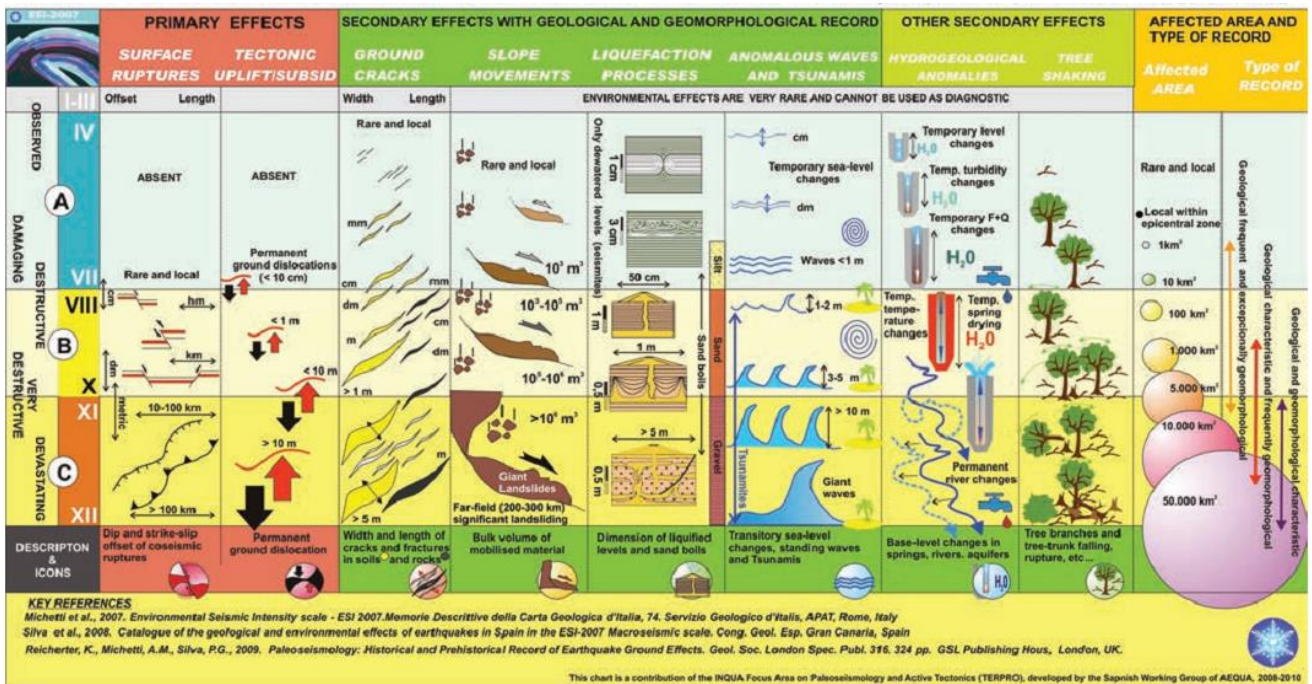


Figure 4.2.2-1 Chart representing the Earthquake Environmental Effects (EEE) scale. Chart of the INQUA Environmental Seismic Intensity Scale 2007 – ESI 07 (modified from Silva et al., 2008).

The EEE Catalogue was implemented to store information about the characteristics, size and spatial distribution of Earthquake Environmental Effects from modern, historical and paleo-earthquakes. The free accessible database of EEEs, became of strategic importance in order to compare seismic hazard studies worldwide. The catalogue implemented by ISPRA reports and maps the site evidences induced by 39 strong earthquakes of modern, historical and paleo ages occurred in the Italian territory as it is shown in Table 4.2.2-1.

Year	Month	Day	Epicentral Area	Magnitude (Mw)	SRL (km)	MaxD (cm)	Total area (km2)	Number of effects	ESI	Damage based Intensity (MCS)
<b>Modern Earthquakes</b>										
2012	5	20	Finale Emilia	5.9	-	-	370	210	8	8
2012	5	29	Medolla, Emilia Romagna	5.8	-	-	360	103	8	8
2009	4	6	L'Aquila, Abruzzo	6.3	6	15	1000	192	9	9
1997	9	26	Colfiorito	6.0	12	8	1400	275	9	9
1980	11	23	Irpinia	6.9	40	90	7400	346	10	10
1976	5	6	Friuli	6.4	18	50	400	35		10
<b>Historical Earthquakes</b>										
1930	7	23	Vulture, Southern Apennines	6.6	38	40	3900	132	10	10
1919	6	29	Mugello, Northern Apennines	6.1	-	-	900	17	9	9
1915	1	13	Fucino	7.0	24	100	400	18	10	11
1908	12	28	Messina Straits	7.2	?	?	20000	486	11	11
1905	9	8	Southern Calabria	7.0	?	?	15000	212	11	11
1857	12	16	Basilicata	7.0	45	250	13200	104	10	11
1805	7	26	Bojano	6.9	40	150	5300	106	10	10
1783	2	5	Cittanova, Calabria	7.0	35	>80	3500	68	10	11
1703	1	14	Norcia, Umbria	6.8	10	?	700	5	10	11
1703	2	2	L'Aquila, Abruzzo	6.6	10	60	1000	19	10	10
1694	9	5	Irpinia	6.9	38	-	6300	16	10	10
1688	6	5	Sannio	6.7	32	-	1700	21	10	11
<b>Paleo Earthquakes</b>										
745±145			Pollino, Italy	6.6	-	160	-	-	10	-
700±200			Fucino	7.0	-	1	-	5	10	-
590±100			Eastern Cagno Basin, Calabria	6.8	-	120	-	2	10	-
372±2			Cittanova, Calabria	6.9	26	80	-	-	10	-
-241±1095			Campo Imperatore	7.0	-	38	-	1	10	-
-580±470			Aremogna- 5 Miglia Plain	6.3	-	100	-	-	10	-
-828±1389			M. Vettore Fault (Central Ap.)	6.5	-	45	-	1	10	-
-1050±100			Northern Cagno Basin, Calabria	6.8	-	120	-	-	10	-
-1500±100			Fucino	7.0	-	150	-	-	10	-
-1550±4500			Campotosto area (Laga Mts.)	6.6	-	-	-	-	10	-
-1875±2130			Cittanova, Calabria	6.9	26	-	-	-	10	-
-2050±100			Cagno basin (northern sector)	6.8	-	120	-	1	10	-
-2050±100			M. Vettore (Central Ap.)	6.5	-	-	-	-	10	-
-3338±398			Aremogna- 5 Miglia Plain	6.3	-	30	-	-	10	-
-3813±3227			Pollino, Italy	6.6	-	160	-	-	10	-
-4074±549			Campo Imperatore	7.0	38	-	-	-	10	-

Table 4.2.2-1 Subset of the EEE catalogue. Subset of the Italian EEE Catalogue. The table shows the majors earthquakes occurred in modern, historical and ancient periods, listing the number of secondary effects induced by each seismic event.

The content of the catalogue is available at the following link:

<http://www.eeecatalog.sinanet.apat.it/italy/earthquake/index.php>.

Beside some general information related to the specific earthquakes, about locality (e.g. local intensity) and site the database shows the EEE classification, description, references and photographs. The EEEs are classified in seven categories: surface faulting, slope movement, ground settlement, ground cracks, hydrological anomaly anomalous waves, other effects.

Considering the six most recent earthquakes (“modern earthquakes”), the consistency, completeness and resolution of location of EEEs are very high; while the information related to the historical and paleo earthquakes is less detailed. The 313 widespread evidences associated to the 2012 Emilia earthquake are the results coming from the integration of field surveys conducted by different research groups; the same procedure has been applied for the 2009 L’Aquila earthquake (Mw=6.3), including a detailed pattern of surface faulting along the Paganica fault (Vittori et al., 2011). Also for the 1997 Colfiorito earthquake (Mw=6.0) the EEE dataset is quite complete, due to the integration of surveys from several teams, allowing the comparison of the ESI and MCS intensity scenarios (Guerrieri et al., 2008). Regarding the 1980 Irpinia (Mw=6.9) and the 1976 Friuli (Mw=6.6) earthquakes, the EEE scenario has been built on data collected from contemporary reports and maps.(Guerrieri et al. 2015). The compilation of the Italian Catalogue of Earthquake Environmental Effects is still in progress. A web interface is available to upload data from a remote position to increment the database of EEE occurrences. These data let to identify the areas more exposed to the occurrence of EEEs and to evaluate the seismic intensity through the ESI scale.

#### 4.2.3 EMERGEIO WORKING GROUP Inventory

Few hours after the quake of the 20<sup>th</sup> May teams of about 30 researchers and technicians of the National Institute of Geophysics and Volcanology (INGV) promptly surveyed the epicentral area to identify coseismic geological effects. The catalogue of CSE carried out by Emergeio working group depicts until present one of the most significant contribution in CSE recognition, storage and communication for the 2012 earthquake. Three main methods have been adopted for data acquisition: field and aerial surveys, online crowdsourcing and personal communications. A standardized form enabled to annotate locations of the CSE and photographs, afterward stored directly as georeferenced data. Furthermore, for real-time census of evidences smartphones were useful tools for quick data-sharing among field teams. Additionally, an internet form was specifically designed to gather information on surface effects coming from the population available at: <http://www.haisentitoilterremoto.it/emergeio.html>). Initially, the form provided at a list of possible CSE and a dedicated section useful to locate the phenomena (i.e. street, city, and/or geographical coordinates). Figure 4.2.3-1 shows the spatial distribution of the recorded evidences distinguished by the two main shakes, the green triangles for the 20<sup>th</sup> May and purple triangles for the 29<sup>th</sup> May quakes (Emergeio Workingrouo, 2013).

The entire system was implemented on an open-source relational database management system. For an extended description of the methodologies and technologies used for the survey of the geological effects, see Emergeio Working Group (2012a). The reliable information was discerned and communicated daily to the field teams in the epicentral area, for verification. More than 200 forms were completed by the inhabitants of the epicentral area which has contributed to the scientific teams. Chart of Figure 4.2-4 summarizes the contribution for each data sources employed, both for row and validated data. The contribution of each group of data source has then been normalized with respect to the specific effectiveness (i.e., the amount of validated data *versus* the total amount of data). 63% of the total data collected (2156) provided reliable records concerning geologic coseismic surface effects. The data were then merged in a geodatabase and analyzed using geographical information system (GIS) tools. Based on the morphologic and structural characteristics the 1362 effects were grouped into three main categories. 485 findings were classified as liquefactions related to overpressure of aquifers, occurring through several aligned vents forming coalescent flat cones. 768 liquefactions with huge amounts of liquefied sand and fine sand ejected from fractures tens of meters long were discriminated. A third group of 109 occurrences referred to extensional fractures with small vertical throws, apparently organized in an

en-echelon pattern, with no effects of liquefaction. The percentage of each CSE typology is displayed by chart d. of Figure 4.2.3-2, as charts e. and f. represent the contribution of each specific investigating tool towards surveying fractures and liquefaction phenomena (Emergeo Workinggroup, 2013).

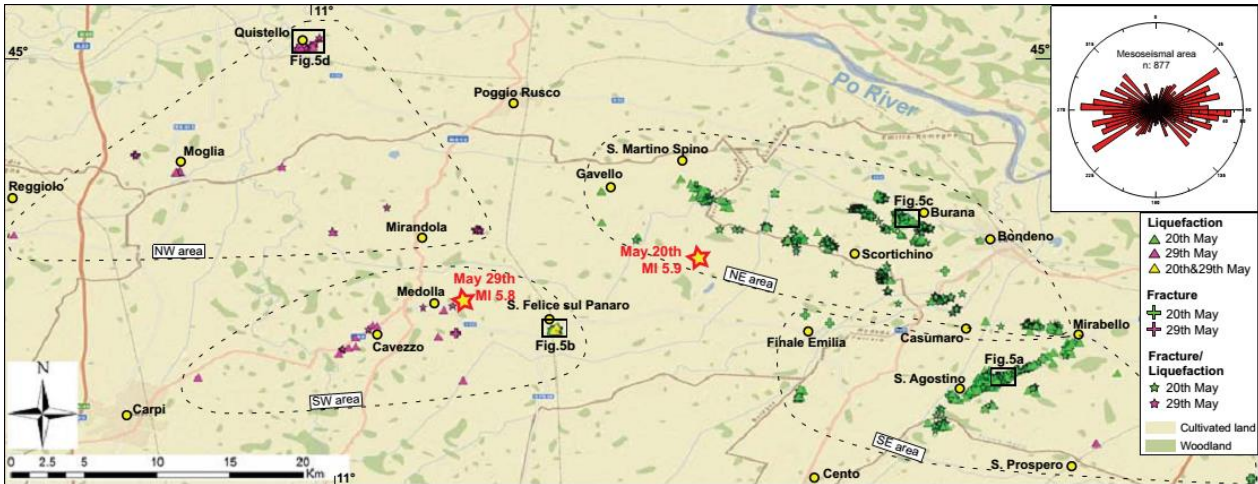


Figure 4.2.3-1 Distribution of CSE from Emergeo Workinggroup database. Location of CSE (1362 data points) discriminated according to the three main categories and the triggering seismic event. The picture highlights the Main shocks of 20<sup>th</sup> and 29<sup>th</sup> May and the four study areas. The inset shows the rose diagram evidencing the trend (INGV).

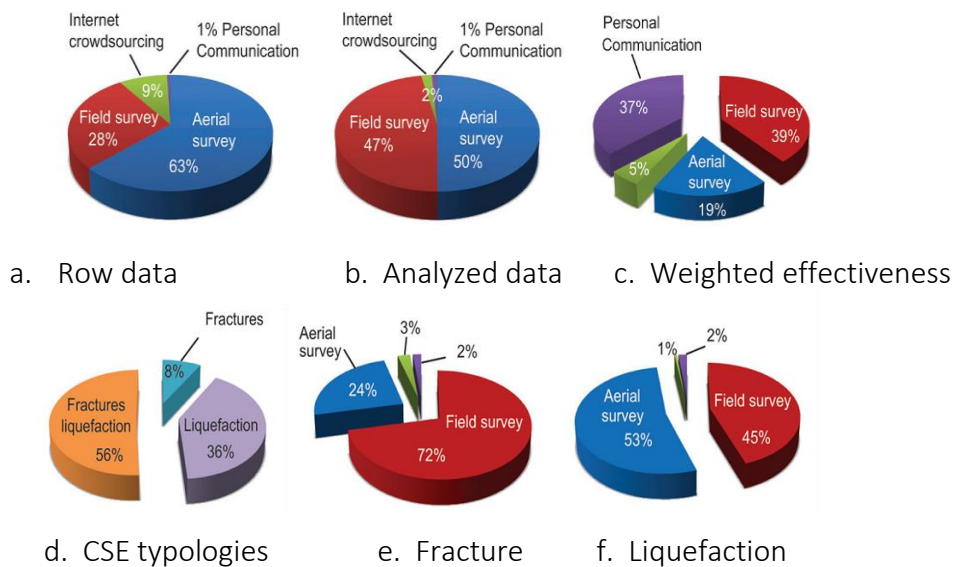


Figure 4.2.3-2 Charts representing the tools of CSE survey and the different typologies of CSE. (Giuliana Alessio et al. 2012).

Structural and morphological assessments of the observed geological surface effects went with the CSE census and focused on (1) thickness of the sand volcanoes and area of sand draping, (2) morphology and diameter of the sand outlets, (3) spacing of the sand outlets, length and strike of their alignments, (4) spacing, length and strike of the fractures and of the sand outlet alignments,

(5) style of the fractures' pattern and (6) opening and offset of the fractures. Moreover, samples of the liquefied extruded sand were collected for sedimentological analysis (Emergeo workinggroup, 2013b). The public interface of the web catalogue is appreciable in Figure 4.2.3-3.

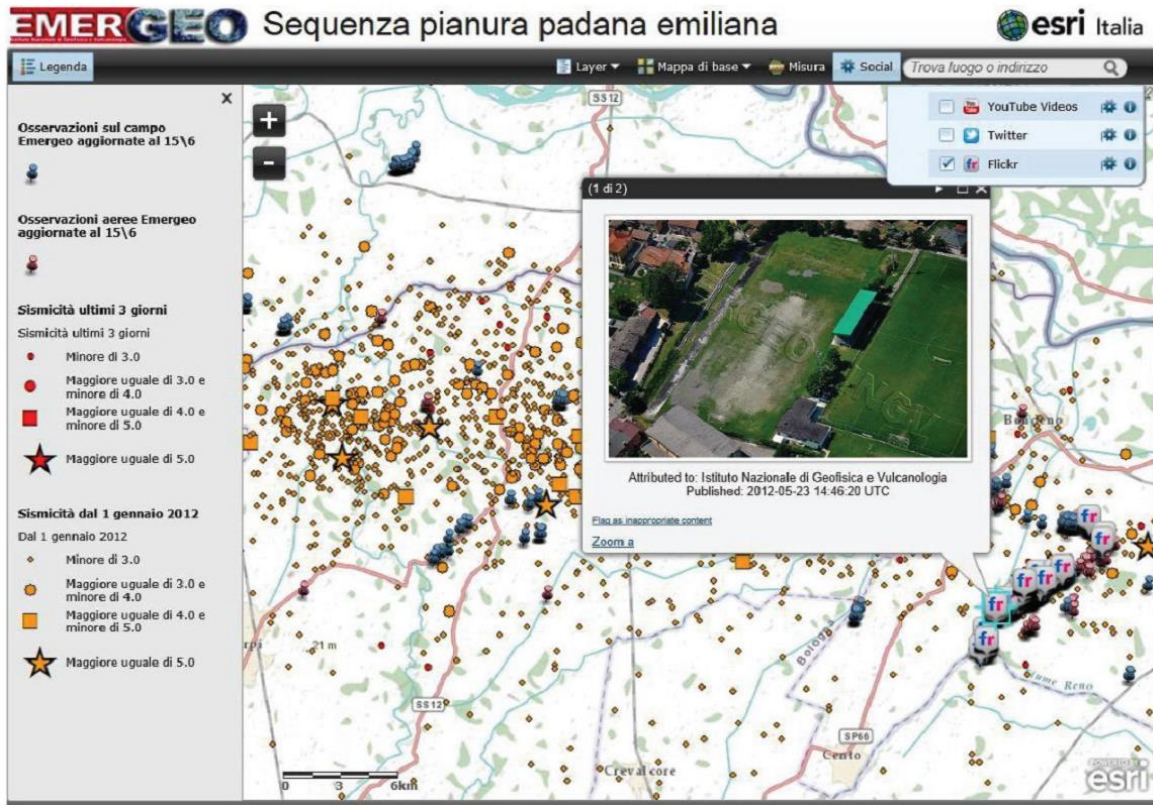


Figure 4.2.3-3 Screenshot portraying the Emergeo webgis. WebGIS interface and the content that was accessible at <http://www.esriitalia.it/emergeo/it>.

Field and aerial surveys produced a wide dataset of information, which allowed the reconstruction of the CSE widespread in the epicentral area. The experimental approach of information collection exemplifies the importance of citizen involvement by the scientist's side. Beside the scientific propose, the public catalogue has corroborated important informative functions concerning coseismic phenomena which are generally unknown to the civil population.

#### 4.2.4 UNIFE DATABASE

The University of Ferrara UNIFE (team coordinated by prof. Riccardo Caputo), has contributed to the achievement of the CSE catalogue built in the frame of this doctoral research (section 4.3), by granting a substantial set of data. As stated in Caputo et al. (2012a), the two main goals of UNIFE were to document through sedimentological unit's recognition the possible occurrence of past liquefaction phenomena; for this purpose, a paleo seismological trench was excavated in San Carlo (Province of Ferrara). Besides, another important investigation has been addressed on liquefaction potential indexes assessment for the epicentral area (G. Papathanassiou et al. 2015). Concerning the coseismic effects recognition, the UNIFE surveyed more than 150 sites, where the characteristics of liquefaction surface manifestations were evaluated and carefully recorded.

The post-earthquake coseismic effects reconnaissance has been mostly concentrated within the area between the villages of St. Agostino, San Carlo and Mirabello located along a former reach of the Reno River. In particular, the length and the width of vent fractures and the diameter of sand craters were measured, while samples of ejected materials at representative sites were collected in order to evaluate the granulometric distribution. The secondary effects were mainly classified as: crack, liquefaction and ejection of sand material.

Furthermore, the extensive presence of surficial geological effects in the study area allows to assess the macroseismic intensity of the area applying the ESI scale (Michetti et al., 2007). For instance, taking into account the length and width of the ground cracks and the dimensions of vent fractures and sand boils of liquefaction phenomena, for the area of San Carlo a macroseismic intensity of VIII was established. Also for the reactivated fracture induced by the second strongest quake on 29<sup>th</sup> May which have reached more than 100 cm, it has been suggested a seismic intensity of IX degree considering the ESI scale (Caputo et al. 2012). The UNIFE didn't build up a specific online-catalogue of the CSE surveyed, but it has contributed for example to enrich the database of the Servizio Geologico e Sismico dei Suoli of the Emilia Romagna Region (<http://ambiente.regione.emilia-romagna.it/geologia/cartografia/webgis-banchedati/>). Moreover, it has provided 300 coseismic effects (as point features in kmz format), contributing to the implementation of the catalogue herein presented.

## 4.3 Integrated GIS-based catalogue of CSE related to the 2012 Emilia Earthquakes

### 4.3.1 Introduction

After the 2012 seismic sequence, beside a wide literature, several databases and inventories related to the CSE of the 2012 Emilia earthquake have been produced during the last four years. Otherwise until present, a comprehensive catalogue integrating different databases is still missing. This lack has oriented this doctoral research to develop a more inclusive online GIS-based informative catalogue concerning the coseismic effects occurred in the southern central Po Plain.

The major purposes of the present catalogue are:

- (i.) to incorporate the most important CSE existing datasets in a systematic way;
- (ii.) to carry out an inclusive and homogeneous CSE catalogue;
- (iii.) to fulfill an important source of information with broad potential of applications. One goal was to implement an exhaustive database useful for local seismic hazard intensity and CSE susceptibility assessments. Next, the added value is to guarantee free access to this information to a wider public giving the opportunity to enhance knowledge about this specific phenomenon to a wider public.

### 4.3.2 Study area for CSE inventory

The study area is located in the Po Plain within the provinces of Modena, Ferrara and Bologna in the Emilia Romagna Region. This part of northern Italy is economically well developed, with a high-specialized industrial sector, intensive agriculture and high population density. Extending for 1,480 km<sup>2</sup> over 19 municipalities, 16 of which were interested by several CSE on May 2012. Map of Figure 4.3.2-1 shows the considered study area that includes two municipalities not directly affected by CSE according to the available inventory map and the database. However, phenomena such as the presence of hot water have been observed in the district of Camposanto (Marcaccio and Martinelli, 20012), but also for their contiguity Novi di Modena and Vigarano Mainarda have been included. Particularly, Table 4.3.2-1 shows the CSE frequency distribution for each district highlighting the higher impact of effects in Sant'Agostino (35.5%), Bondeno (28.4%), and Mirabello (12.6%). The hydrography of the area is defined by the rivers Po, Reno, Reno and Secchia, flowing through the alluvial flood plain at altitude ranging from +32.3 m a.s.l to - 0.2 m with an average slope lower than 3° eastward. The Geomorphological, geological and seismotectonic aspects characterizing this part of the Po Plain have been described in chapter 2.

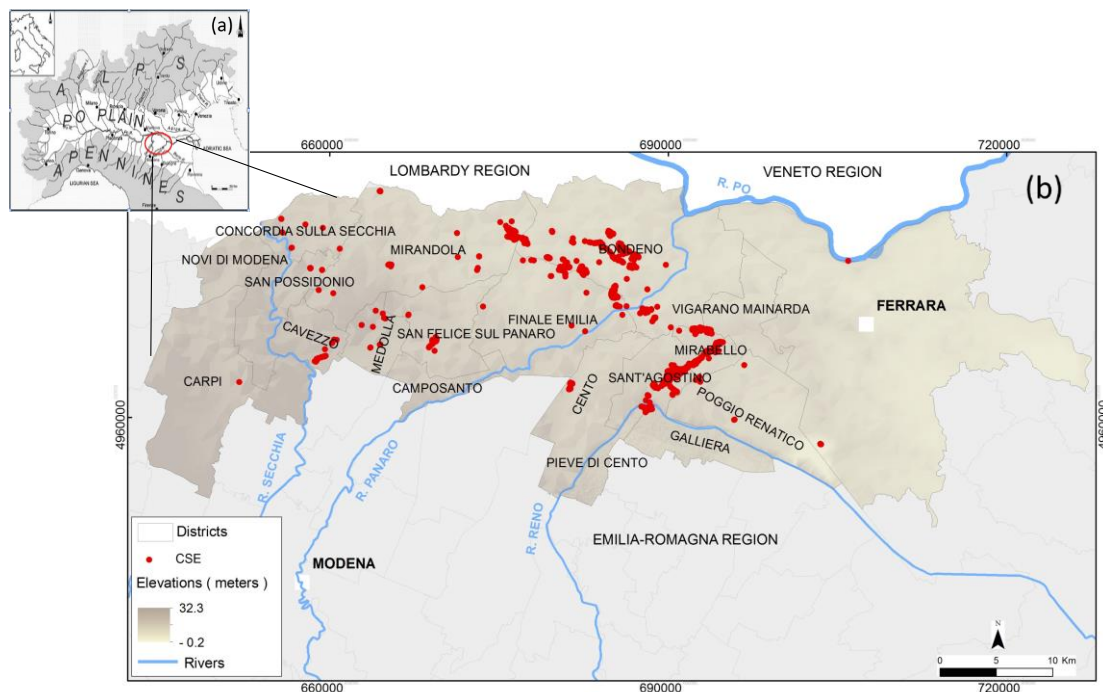


Figure 4.3.2-1 Map of the Study Area. Location of the study area in the Italian territory (a) and spatial distribution of the coseismic surface effects in the municipalities of the study area (b).

ID	MUNICIPALITY	AREA km <sup>2</sup>	Population n.	Pop.density km <sup>2</sup>	CSE Frequency	CSE %
1	BONDENO	175,199	14887	85	542	28,4
2	CAMPOSANTO	22,654	3218	140	0	0,0
3	CARPI	131,467	70644	570	1	0,1
4	CAVEZZO	26,825	7072	260	27	1,4
5	CENTO	64,769	34585	540	16	0,8
6	CONCORDIA SULLA SECCHIA	41,189	8860	220	9	0,5
7	FERRARA	404,525	133485	330	7	0,4
8	FINALE EMILIA	104,738	15735	150	72	3,8
9	GALLIERA	37,162	5555	150	9	0,5
10	MEDOLLA	26,799	5901	220	16	0,8
11	MIRABELLO	16,110	3407	210	241	12,6
12	MIRANDOLA	137,055	22068	160	105	5,5
13	NOVI DI MODENA	51,852	11268	220	0	0,0
14	PIEVE DI CENTO	15,882	6959	440	25	1,3
15	POGGIO RENATICO	79,789	9087	110	5	0,3
16	SAN FELICE SUL PANARO	51,573	10453	200	147	7,7
17	SAN POSSIDONIO	17,042	3770	220	10	0,5
18	SANT'AGOSTINO	35,208	7106	200	678	35,5
19	VIGARANO MAINARDA	42,283	7626	180	0	0,0
		1.482	366.954	242,4	1.910	100

*Table 4.3.2-1 List of Municipality included in the Study Area.* The table shows the surface in square kilometer, the population, the population density of each municipality and the CSE frequency distribution in absolute number and in percentage.

### 4.3.3 Methodology

The scheme of Figure 4.3.3-1 summarizes the steps adopted to implement an inclusive catalogue with the aim to facilitate the understanding of its content, structure and functionality. The work has employed procedures of data acquisition and data treatment, correlation with cartographic thematic layers, the redaction of descriptive sheets, and the website implementation for the online catalogue publication.

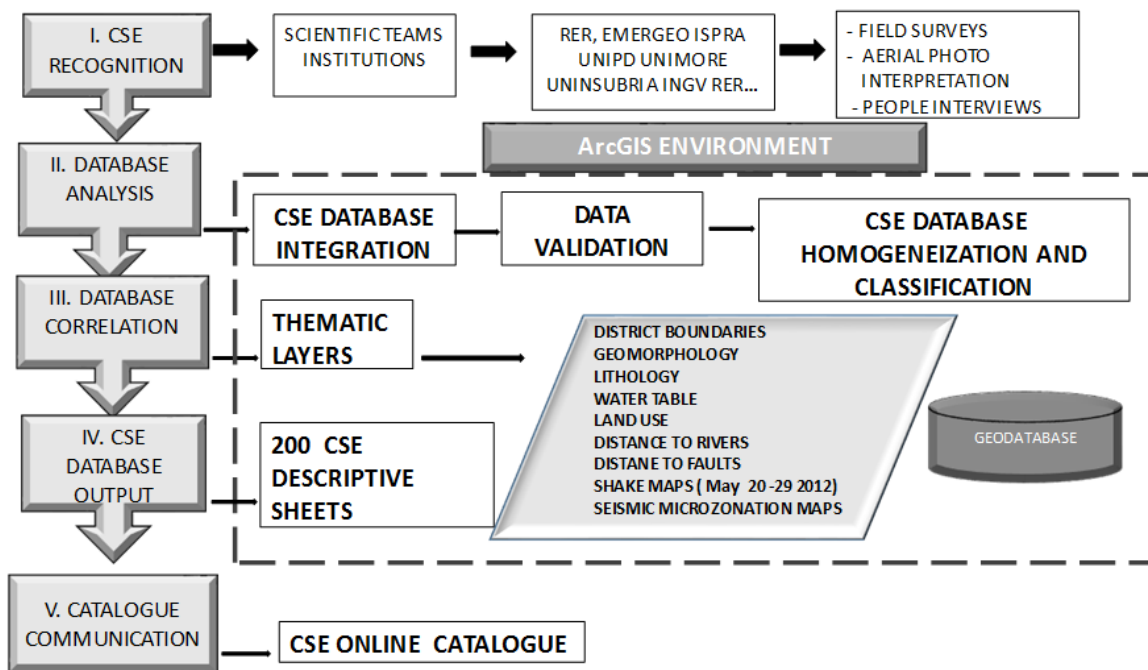


Figure 4.3.3-1 Flow chart representing the procedures for the CSE catalogue implementation.

#### - I Data Recognition

The phase of CSE reconnaissance was prior to this PhD research. Data acquisition was done by many scientific teams through different investigating survey approaches, such as:

- Field and aerial surveys,
- Internet crowd sourcing
- Personal communication through interviews.

The CSE have been generally stored as point features in kml format with GPS or using googleearth software. Ground fissures have been also recorded as linear shapes or as sequence of multiple points. The integrated CSE catalogue has incorporated three specific datasets, which were obtained from the Emergeo working group (INGV) and from the Istituto *Superiore per la Protezione e la*

*Ricerca Ambientale* (ISPRA), from the University of Ferrara. The ISPRA inventory was the result of the close cooperation between the universities of Modena and Reggio Emilia, Insubria, Padova, Milano among others.

#### - II Database Analysis

The available datasets have been merged under one single geodatabase in a GIS-based environment (ArcGIS 10.3). Through geoprocesses of data homogenization, validation, classification the integrated database has stored 1910 coseismic effects, counting the limited number of them surveyed through aerial photos interpretation (Agea: WorldView 2 30/05/2012 Scala 1:5000). CSE have been mapped as point features data on WGS\_1984\_UTM\_Zone\_32N projection.

Three database sources have been encoded in the attribute table giving the code of number 1 for ISPRA (316 CSE), 2 for Emergeo (1279 CSE), number 3 was the code for UNIFE (300 CSE) and number 4 for the Orthophoto (15 CSE).

A procedure of data validation was adopted to avoid any redundancy which has meant the automatic deletion of any repeated (double) point or for those evidences closer than 30 cm of distance, which were considered to represent the same effect. The different effects categorization done by the sources entailed to a forced generalization for the CSE classification (Figure 4.3.3-2). Description associated to the effects allow the classification of the phenomena in four typologies as follows:

1. Liquefaction (890 CSE)
2. Crack (126 CSE)
3. Crack with liquefaction (860 CSE)
4. Other (34 CSE)

The last category of CSE contains various types of effects as: subsidence, hydrological anomalies etc. Furthermore, absolute and percentage frequency distribution for each typology of CSE, which have been associated to a univocal graphic symbol as shown in Figure 4.3.3-3.

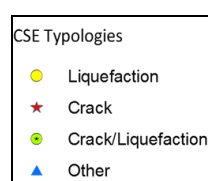


Figure 4.3.3-2 Legend illustrating the Symbols associated to the four types of CSE in maps.

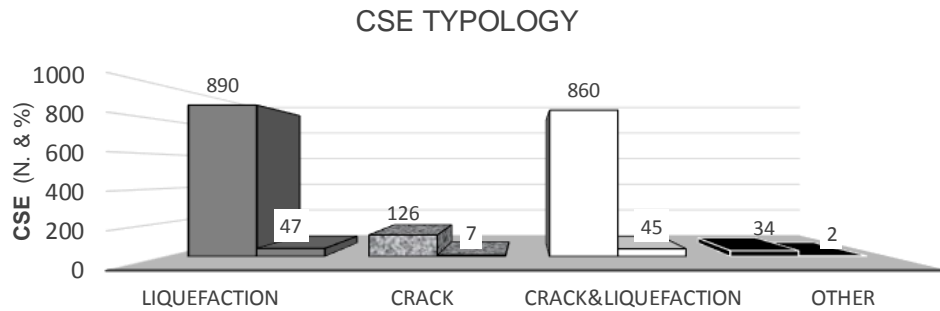
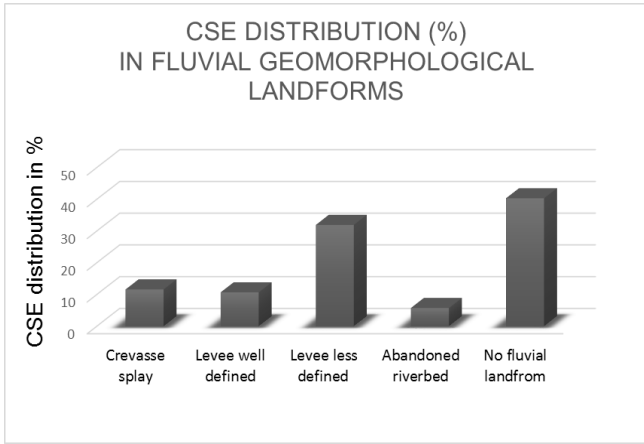


Figure 4.3.3-3 Chart. Absolute and percentage frequency distribution of CSE.

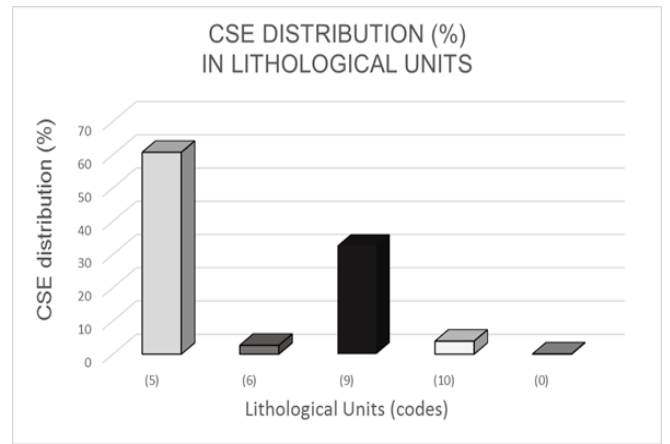
### - III Database Correlation with thematic Maps

The integration of various thematic layers, aiming to better understand the subsoil and characteristics of this area, has led to infer correspondences between the CSE occurrences with lithological, geomorphological, seismic, environmental aspects for the study area. Indeed, statistical analyses have been performed correlating the spatial distribution of CSE with the thematic layers such as land use, distance from epicenter, shake maps (PGA) of the main shocks, and area that have been included in the recent micro-zoning studies financed by the Emilia-Romagna Region (<http://ambiente.regione.emilia-romagna.it>). Charts of Figures 4.4.3-4 have considered the CSE-liquefaction phenomena distribution in percentage in relation to different local conditions.

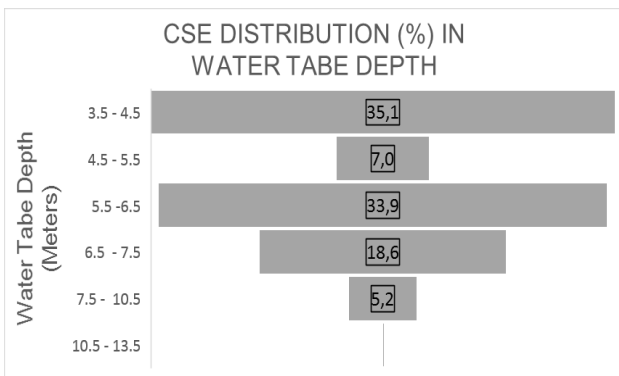
The charts of this section present the factors that have not been farther presented in chapter 5 of this thesis, which were employed for the CSE susceptibility assessment. In particular, are herein illustrated the CSE distribution in percent values in relation to: a) fluvial landforms, b) lithological units c) water table depth, d) distance to rivers, e-f) PGA (g) of the two major quakes (May 20 and 29) g) areas of SM, h) land use. The thematic layers representing the casual factors for CSE susceptibility evaluation have been then illustrated in chapter 5 of this thesis.



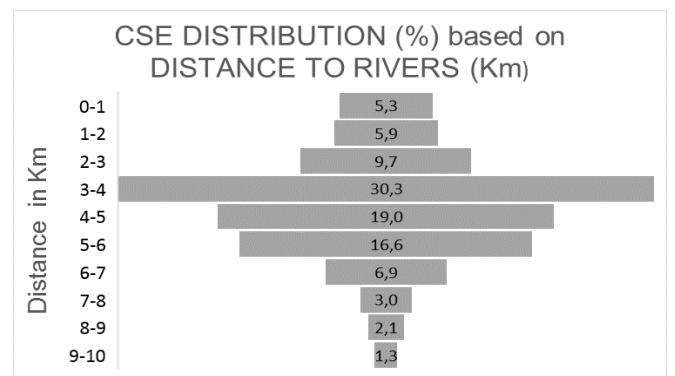
a.



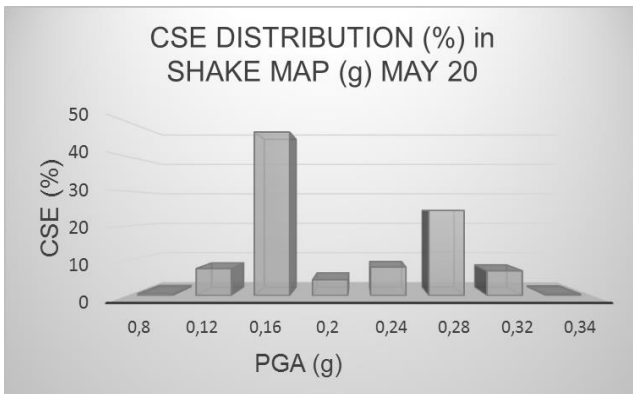
b.



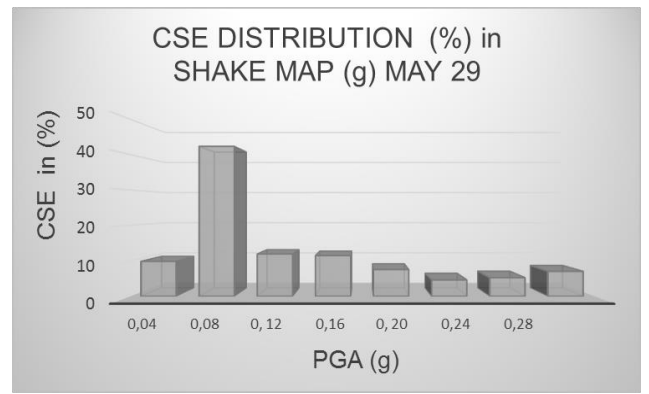
c.



d.

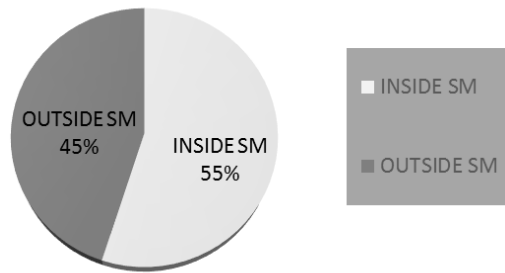


e.

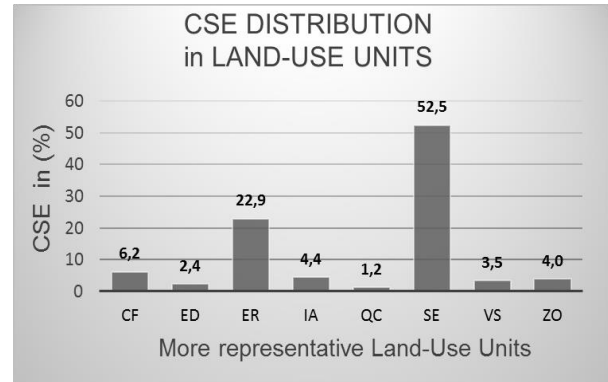


f.

CSE DISTRIBUTION (%)  
INSIDE OR OUTSIDE AREAS  
DEFINED BY SEISMIC MICROZONATION



g.



h.

Figure 4.3.3-4 Charts representing CSE distribution, considering geological, geographical, environmental variables. In Charts the CSE distribution in correspondence to geomorphology (a), lithology (b), water table depth (c), distance to river (d), Shakes Maps (INGV) for the May 20 and May 29 shocks, seismic microzonation study 2012 (ERR), Land Use 2011 (ERR). Lithological Units codes corresponds to this legend: Medium and fine sand in beds tens of centimeters thick, changing laterally and /or intercalated to fine and very fine silty sand, smaller amount of clayey silt; locally medium and coarse and in lenticular ribbon shaped bodies. Channel and proximal levee. At the top, soils with various degree of evolution (5); Sandy silt, fine and very fine sand, silty clay and smaller amounts of silty-clayey sand intercalated in beds tens of centimeters thick. Distal levee deposits. At the top soils with various degree of evolution (6); Silty clay, clay and laminated clayey silt, locally concentrations of partially decomposed organic matter (9); Medium and coarse sand, to a lesser extent gravel and sandy gravel, smaller amounts of silt and sandy silt in bed tens of centimeters thick. Meander belt deposits. At the top, soils of various degree of evolution (9); Po Riverbed (10). For the most representative Land use units the code corresponds to the following legend: orchards and small fruit (CF); Discontinuous residential areas (ED); Residential area (ER); industrial area (IA); construction site (QC); arable irrigated area (SE); Sports area (VS); cultivated and particle complex systems (ZO).

#### 4.3.4 Results and Catalogue Outputs

The catalogue is composed by of 200 descriptive sheets, directly linked to each CSE. To define a clustering criterion, the study area has been subdivided over a net of squares having a side of 450 m, that corresponds to the average cross length of the elongated fluvial geomorphologies such as the levees. The informative sheets selected in correspondence with the presence of effects contain:(i) seismic information about the triggering quakes that induced the phenomena, (ii) a table indicating the typologies of CSE (effect ID, code of effect typology, code data source or rather the institution which provide the data, UTM coordinates), (iii) several geomorphological, geological, seismotectonic, MS official cartographical subsets (see Figure 4.3.4-1and 2).

The final purpose of the catalogue was its public dissemination through an open source mapping interface to communicate the phenomena distribution in relation to the 2012 Emilia earthquake freely. With the aim of improving the catalogue with images illustrating the effects on the environment, around 100 photos have been taken and inserted from Emergeo Working group

(2012 n.16). A separate shape file of points was created and linked to georeferenced photos representing the evidence have been then uploaded in the online catalogue.

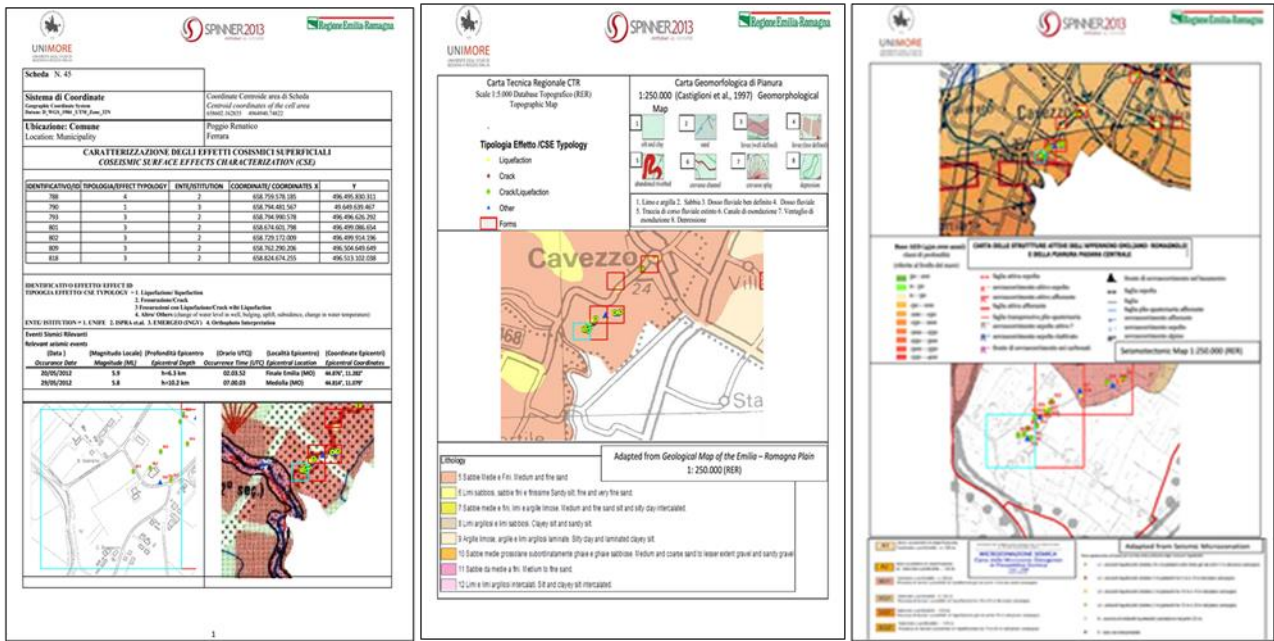






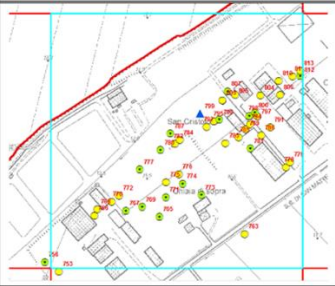
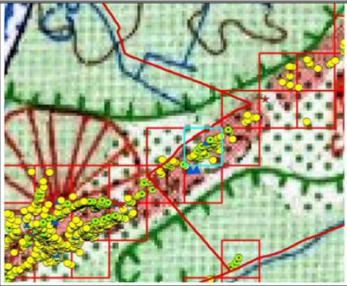


Figure 4.3.4-1. Example of Data Sheet of CSE. The data sheets contain information of earthquake environmental effects: typology, epicentres, evidence location with precise coordinates, brief descriptions, subsets of different seismic local terrain condition, hazard and risk cartography.

  				
<b>Scheda N. 48</b>				
<b>Sistema di Coordinate</b> Geographic Coordinate System Datum: D_WGS_1984_UTM_Zone_32N	Coordinate Centroide area di Scheda Centroid coordinates of the cell area 692352.162835 4964940.74822			
<b>Ubicazione: Comune</b> Location: Municipality	Mirabello Ferrara			
<b>CARATTERIZZAZIONE DEGLI EFFETTI COSISMICI SUPERFICIALI</b> <b>COSEISMIC SURFACE EFFECTS CHARACTERIZATION (CSE)</b>				
IDENTIFICATIVO/ID	TIPOLOGIA/EFFECT TYPOLOGY	ENTE/INSTITUTION	COORDINATE/ COORDINATES X	Y
763	1	1	692.474.595.798	496.477.571.911
765	3	3	692.322.504.843	496.480.626.377
766	1	2	692.206.290.937	496.480.752.239
767	3	3	692.262.311.962	496.481.684.706
768	1	1	692.211.102.443	49.648.194.896
769	3	3	692.291.416.198	496.482.346.163
770	1	1	692.236.884.102	496.483.246.969
771	3	3	692.333.925.408	496.484.071.456
772	1	1	692.250.244.041	496.484.297.701
773	3	3	692.397.249.771	496.484.462.828
774	3	3	69.236.429.757	496.486.471.091
775	1	1	692.334.308.505	496.486.681.048
776	1	1	692.356.747.109	496.488.084.925
777	3	3	692.287.442.056	496.488.996.443
778	1	1	692.548.921.491	496.489.366.692
779	1	1	692.555.775.204	49.649.020.815
780	3	3	692.324.489.188	496.492.400.351
781	3	3	692.484.562.423	496.492.664.945
782	1	1	692.350.039.479	496.493.538.527
783	1	3	692.440.244.655	496.493.590.984
784	1	1	692.358.619.341	496.494.164.541
785	1	1	692.464.148.914	496.494.632.138
786	1	1	692.504.069.532	496.494.994.133
787	3	3	69.234.234.859	496.495.310.769
789	1	1	692.476.298.126	496.496.085.666
791	1	1	692.520.525.713	496.496.425.646
792	1	1	692.406.111.207	496.496.478.205
794	1	1	692.484.236.846	49.649.698.039
795	1	1	692.419.479.839	496.497.499.885
796	3	3	692.429.498.819	496.497.794.388
797	1	1	692.497.508.735	496.498.327.003
798	3	3	692.483.481.608	496.498.457.358
799	4	1	692.393.660.212	496.498.603.718
800	3	3	692.492.560.368	49.649.902.675
803	1	1	692.434.913.148	496.501.172.493
804	1	2	692.502.705.178	496.502.070.417
805	1	1	692.457.211.737	496.502.188.267
806	1	3	692.537.479.191	49.650.218.996
807	3	3	692.444.213.424	496.502.785.269
810	1	2	692.535.322.344	496.504.653.075
811	1	1	69.255.956.606	496.505.445.716
812	3	2	692.574.169.345	496.505.480.903
813	1	1	69.257.379.487	49.650.640.978

  																									
<b>IDENTIFICATIVO EFFETTO/ EFFECT ID</b> <b>TIPOLOGIA EFFETTO/ CSE TYPOLOGY</b> = 1. Liquefazione/ Liquefaction 2. Fessurazione/ Crack 3. Fessurazioni con Liquefazione/ Crack with Liquefaction 4. Altri/ Others (change of water level in well, bulging, uplift, subsidence, change in water temperature) <b>ENTE/ INSTITUTION</b> = 1. UNIFE 2. ISPRA et al. 3. EMERGO (INGV) 4. Orthophoto Interpretation																									
<b>Eventi Sismici Rilevanti</b> <b>Relevant seismic events</b> <table border="1"> <thead> <tr> <th>(Data)</th> <th>(Magnitudo Locale)</th> <th>(Profondità Epicentro)</th> <th>(Orario UTC)</th> <th>(Località Epicentro)</th> <th>(Coordinate Epicentri)</th> </tr> <tr> <th>Occurrence Date</th> <th>Magnitude (ML)</th> <th>Epicentral Depth</th> <th>Occurrence Time (UTC)</th> <th>Epicentral Location</th> <th>Epicentral Coordinates</th> </tr> </thead> <tbody> <tr> <td>20/05/2012</td> <td>5.9</td> <td>h=6.3 km</td> <td>02.03.52</td> <td>Finale Emilia (MO)</td> <td>44.876°, 11.282°</td> </tr> <tr> <td>29/05/2012</td> <td>5.8</td> <td>h=10.2 km</td> <td>07.00.03</td> <td>Medolla (MO)</td> <td>44.814°, 11.079°</td> </tr> </tbody> </table>		(Data)	(Magnitudo Locale)	(Profondità Epicentro)	(Orario UTC)	(Località Epicentro)	(Coordinate Epicentri)	Occurrence Date	Magnitude (ML)	Epicentral Depth	Occurrence Time (UTC)	Epicentral Location	Epicentral Coordinates	20/05/2012	5.9	h=6.3 km	02.03.52	Finale Emilia (MO)	44.876°, 11.282°	29/05/2012	5.8	h=10.2 km	07.00.03	Medolla (MO)	44.814°, 11.079°
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29/05/2012	5.8	h=10.2 km	07.00.03	Medolla (MO)	44.814°, 11.079°																				
 <p>Carta Tecnica Regionale CTR Scale 1:5.000 Database Topografico (RER) Topographic Map</p> <p><b>Tipologia Effetto / CSE Typology</b></p> <ul style="list-style-type: none"> <li>● Liquefaction</li> <li>★ Crack</li> <li>● Crack/Liquefaction</li> <li>▲ Other</li> <li>□ Forms</li> </ul>	 <p>Carta Geomorfologica di Pianura 1:250.000 (Castiglioni et al., 1997) Geomorphological Map</p> <table border="1"> <tr> <td>1 silt and clay</td> <td>2 sand</td> <td>3 levee (well defined)</td> <td>4 levee (less defined)</td> </tr> <tr> <td>5 abandoned riverbed</td> <td>6 crevasse channel</td> <td>7 crevasse splay</td> <td>8 depression</td> </tr> </table> <p>1. Limo e argilla 2. Sabbia 3. Dossso fluviale ben definito 4. Dossso fluviale 5. Traccia di corso fluviale estinto 6. Canale di esondazione 7. Ventaglio di esondazione 8. Depressione</p>	1 silt and clay	2 sand	3 levee (well defined)	4 levee (less defined)	5 abandoned riverbed	6 crevasse channel	7 crevasse splay	8 depression																
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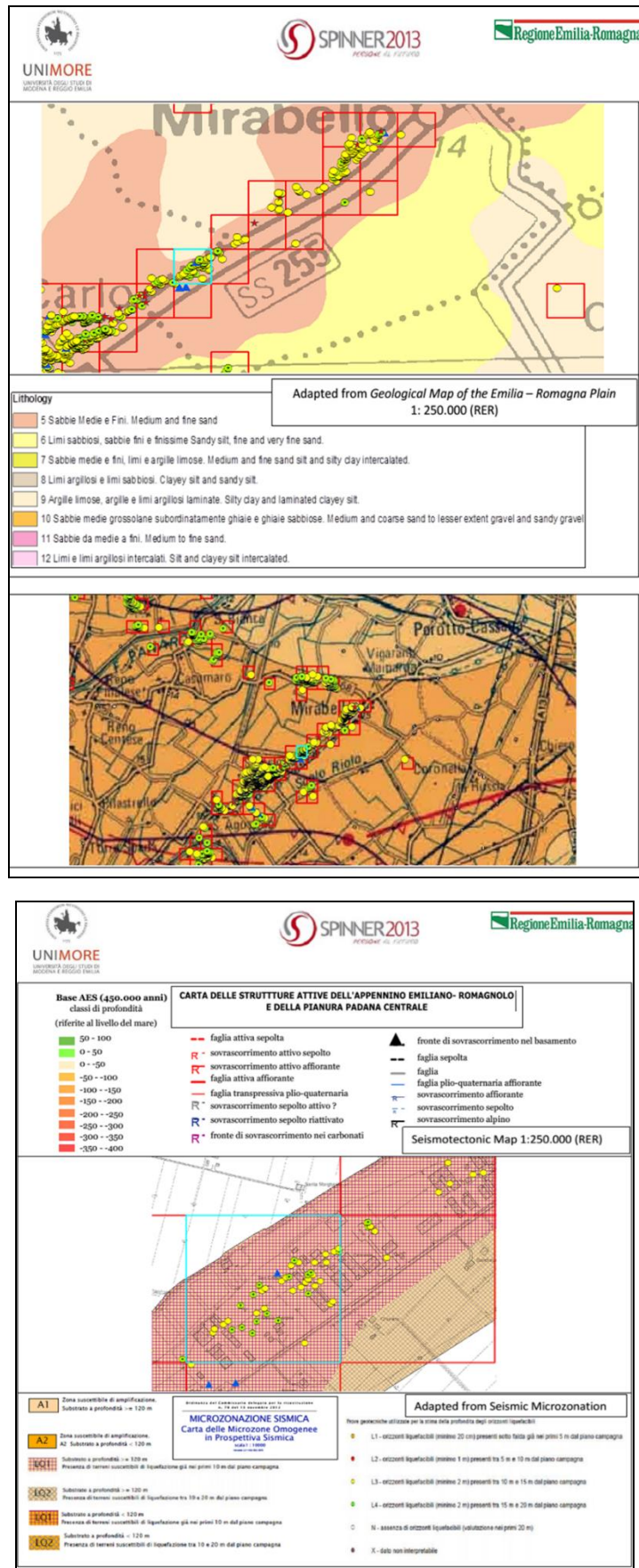


Figure 4.3.4-2 Example of CSE descriptive data sheet at larger size to better appreciate the information.



#### 4.3.5 Conclusions

Heterogeneous and multiparametric seismic datasets were collected from the beginning of the Emilia earthquake by different institutions, in fact as referred in many articles (Anzidei et al. 2012). Beside the scientific aspects, catalogues on earthquake environmental effects are important sources of information for a wider public. Inventories should be conceived as tools that allow enhancing local knowledges, in relation in this case to earthquake-secondary effects that were in generally misunderstood or associated to human causes (as fracking) during the during the 2012 Emilia seismic events. The exchange of data and information among scientists, but also directed to the media and people about the causes and effects of the earthquake in a short time was crucial to better understand this phenomenon.

With this purpose the implementation of a unique and integrated databases collecting the higher number of CSE occurred during the 2012 earthquakes, it has represented an important contribution in terms of information's and communication.

This chapter wishes to demonstrate how catalogues can play a key role in local natural hazard and risk communication. The public access to the catalogue permits to get data regarding, as in this case, areas prone to CSE. Information are usually spread within multiples databases usually belonging to numerous different institutions. The comprehensive CSE catalogue implemented within this doctoral dissertation represents and added value to the existing widespread and heterogeneous contributions. It becomes an univocal information source for the CSE induced during the 2012 seismic sequence.

#### 4.4 Anomalous geological phenomena reported in the area affected by 2012

The present dissertation deepens the existing knowledge about CSE, particularly referred to the 2012 seismic sequence. Firstly, is important to recognize that CSE induced by historical earthquakes are mainly documented in chronicles or specific catalogues, which have usually remained unknown to general public. During the field surveys, the CSE recognition was done mainly by geoscientists although the descriptions of these phenomena by villagers have been a significant support for understanding the coseismic occurrences in the central area of Po plain. If on the one hand the contribution done by the population was crucial, on the other hand the lack of scientific knowledge brought inhabitants to consider those effects as possible earthquakes precursors. The media in addition have empathized the appraisal of CSE generating alarmism and false convictions. Although experts have repeatedly stressed the unpredictable nature of earthquakes, the population has given credit to various groundless alarms, which were spread around (Bertacchini, Castaldini, and Tosatti 2012). Popular beliefs associate any unusual local terrain effects or environmental events, as for example metrological phenomena, to earthquakes. Natural phenomena like hot springs, gas emissions, releases of native oil, natural soil subsidence, local increase of soil temperature, were reported in literature, but they are otherwise elements belonging to the peculiarities of the landscape of this area of northern Italy. Studies refer about fires of perennial character (Cremonini et al., 2008), soils with abnormal temperature (Spinelli, 1893), outgassing phenomena in the marine environment, or sinkholes in the low plains environments in the provinces of Parma, Modena, Bologna and Ferrara (Scicli, 1972 Curzon, 2011). Groundwaters in localities of Bobbio, Porretta and Bagno di Romagna are known as part of geothermal circuits known for a long time; moreover, some variations in the fluids of Porretta in conjunction with local seismic events have been studied by Albarello et al. (1991) and by Ciancabilla et al. (2007). Within other examples, mud volcanoes caused by the emission of clay mixed with salt water and methane are known local phenomena. In Emilia-Romagna Region methane emissions of dry type, small native oil emissions of methane gas bubbling phenomena in water wells are recurrent local events (Scicli, 1972; Martinelli et al., 2012).

Many phenomena of this nature, occurring in the Italian territory or in the past, have been studied and reported with essentially focus on the historic scientific literature and often were referred to earthquakes. Try to better understand these phenomena it seems appropriate to recall some historical information that have already shown these types of events in the Emilia-Romagna region.

The main bibliographical sources related to the reporting of unusual geological natural phenomena, also not happened in recent times, on the entire Italian territory are based on the census carried out by Cordier (Cordier, 1996; Cordier, 1999) and Centini (2003). Woods et al. (1995) and Woods et al. (1997) have deepened the geological phenomenology especially for the environmental effects referred to earthquakes. Recent historical researches from Pancaldi and Tamplini (2013) has allowed to better describe some geological phenomena, especially to scientifically clarify their casual factors against the popular culture believes persisting in the Emilia-Romagna (Baldini, 2014). Looking at the most important references, Baratta (1901), for instance, relates directly the local population reports for the earthquake of Ferrara in 1570:

*"Among the effects of this earthquake were noticed subterranean rumbles, sudden flashes in the atmosphere, sudden swelling of the river Po, uplifts and depressions soil outside Porta San Pietro and San Paolo ... where occurred even violent emissions of blackish water and sand".*

Another example, highlights how during the earthquake in the Rimini on 25<sup>th</sup> December 1786 Mw = 5.6 were observed important luminous phenomena as described by Vannucci (1787).

News of recent light phenomena from other sources have been reported and confirmed (Comastri, 1986; Guidoboni, 1986). The historical records thus refer to luminous phenomena, or changes in the characteristics of the waters in wells. Many luminous phenomena were classified and studied by Galli (1910), he had already guessed the distinction between electrical type phenomena due to ionization and combustion of methane gas phenomena.

In Emilia-Romagna after the 2012 seismic sequence, the population started to be quite watchful to any unusual environmental change of soil or in relation to any water wells variation in depth or temperature. Several reporting of unusual terrain surface effects was referred to the scientific community, capturing the increasing attention of the media. The renewed interest on unusual natural phenomena after the seismic sequence encouraged the institutions and researchers to verify and give explanations to the community about these occurrences.

In fact, following numerous reports from the population about unusual geological phenomena, the Region Emilia-Romagna, the Regional Agency of civil protection and Arpae have organized a scientific working group, dedicated to the unusual phenomena, to monitoring the manifestations, brought to attention by the inhabitants. Picture of Figure 4.4.4-1, illustrates the brochure related to the project promoted by the Emilia-Romagna Region regarding the unusual phenomena.



Figure 4.4-1 Brochure published by the ER Region to advertise the possibility to the population in signalize any unusual geological evidence to the Scientific Team uncharged of the project that involved The ER Region, the Regional agency of Civil Protection, and ARPAe (Agenzia ambientale della Regione Emilia Romagna).

The University of Bologna, Ferrara and Modena-Reggio, and the INGV are also part of the scientific team, which also works in strictly relation with media, to better support the correct information with scientific relates. To address different stakeholders and to inform directly the population about this concern, the Emilia-Romagna Region has implemented a webgis platform with the aim to record and illustrate all the anomalous environmental or geological phenomena denounced over the region (Figure 4.4-2).

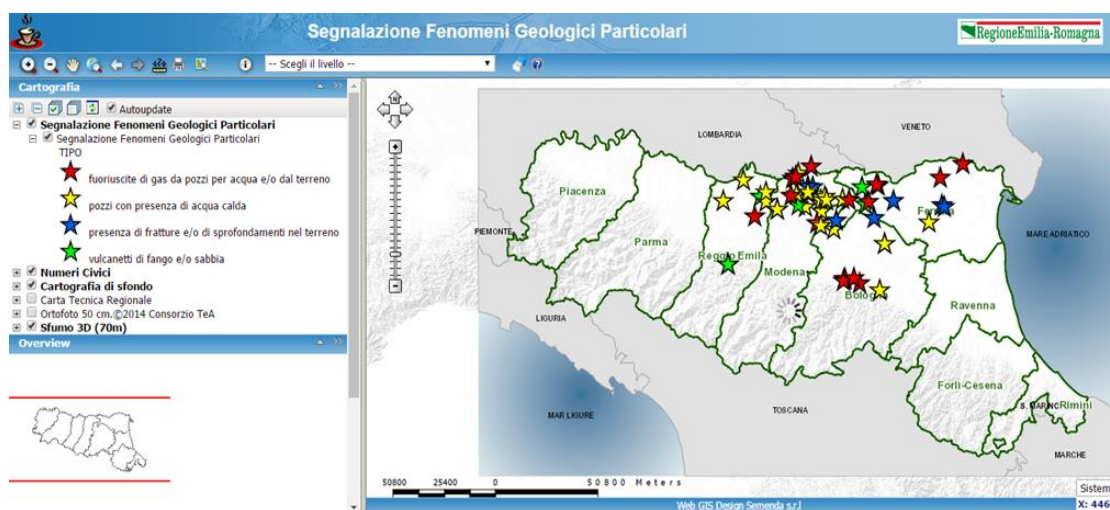


Figure 4.4-2 Web concerning unusual geological phenomena reported by the population from May 2012.

The interactive functions within the website allow selecting each phenomenon and opening the related form containing additional scientific explanations of their casual factors; the form is completed by lithological, seismotectonic cartographies as illustrated in Figure 4.4-3.

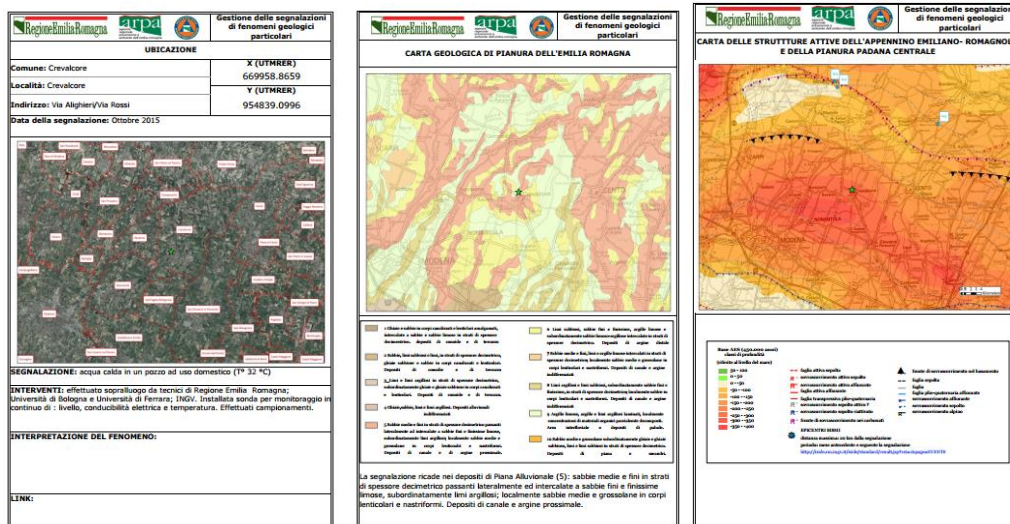


Figure 4.4-3. Example of Form linked to the geological anomalous phenomena presented into the dedicated WebGIS of the ER Region. ([http://mappegis.regione.emiliaromagna.it/gstatico/documenti/Segnalaz\\_Fenomeni\\_Terremoto/ID53\\_OTTOBRE\\_2015.pdf](http://mappegis.regione.emiliaromagna.it/gstatico/documenti/Segnalaz_Fenomeni_Terremoto/ID53_OTTOBRE_2015.pdf)).

The catalogue refers 54 warnings reported from May 2012 to November 2015 by the population. It shows the frequency of the alarms during 43 months. The recurrence of unusual geological phenomena remained unchanged during the three years, while as report in the same period the number of detected seismic events INGV has decreased dramatically. This confirms any correlation between the seismic activity and the occurrence of the phenomena (Figure 4.4-4). The interactive functions within the website allow selecting each phenomenon and opening the related form containing additional scientific explanations of their causal factors; the form is completed by lithological, seismotectonic cartographies. All the alarms coming from civilians were discriminated by typologies as follows: a.17 gas emissions from wells or from soil, b.21 wells with presence of hot water, c. 7 presence of soil fractures, or sinkholes, d. 6 sand boils, e.3 fish death.



Figure 4.4-4. Picture showing examples of unusual manifestations. (a) The alarm date from August 2013, it is located in the urban area of Ferrara and it shows an important terrain fissure apparently similar to the fissures or cracks induced by the 2012 seismic sequence. (b) The alarm dates from September 2014, it is located in the district of Crevalcore (BO) and it concerns relations to anomalous fish death. (c) The alarm dates on May 2014 and it was located in the district of Bondeno. It shows an example of sand boil. (Photo taken by Giovanni Martinelli). ([http://mappegis.regione.emiliaromagna.it/gstatico/documenti/Segnalaz\\_Fenomeni\\_Terremoto/](http://mappegis.regione.emiliaromagna.it/gstatico/documenti/Segnalaz_Fenomeni_Terremoto/)).

The working group of scientists has verified each single alarm, looking for the causal factors of every single event. For example, some lightning phenomena noticed during the 2012 seismic sequence

in the epicentral area, were scientifically attributable to ionization of atmospheric gases. In 2013, gas gurgles events in San Giovanni del Dosso (Mantua) and in Campagnola Emilia (Reggio Emilia) were in both cases related to the atmospheric gases extrusion. The high increases of positive thermal anomalies in wells for water, with thermal excursions ranges from 15 to over 40 ° C were most related to malfunctions of pumps inside the wells. After the main events, but also in 2013 the media have also accentuated the phenomena occurrences, as were the salted warm waters, with striking presence of methane in various locations such as in Ambrose Copparo or Serravalle di Berra etc. Phenomena of oxidation in well are commonly considered the joints responsible for water and gas.

After the 2012 Emilia earthquake, the scientific attention focused on anomalous geological phenomena aimed to clarify and certify the real causes of ambiguous natural phenomena to avoid useless alarms and false convictions within the population. In this chapter the present section has been introduced to document the existing differences between CSE related to earthquakes and others unusual natural phenomena, well described in literature, but which are not seismic related.

## 5 SUSCEPTIBILITY ASSESSMENT TO COSEISMIC SURFACE EFFECTS BASED ON STATISTICAL DATA-DRIVEN MODELS

### 5.1 Introduction

As already stated in the previous chapters, coseismic surface effects (CSE) related to liquefaction of saturated sandy deposits are among the most important indirect hazardous phenomena associated with earthquakes. In free-field conditions, CSE include phenomena such as soil fissures, sand boils, soil bulging and lateral spreading, ejections of sand and water from wells (Huang and Yu 2013). In built environments, liquefaction causes the loss of bearing capacity of soils, thus provoking sudden settlements or even failure of buildings and severe damages to urban structures and infrastructures, as well as losses in agriculture (Galli et al. 2012; Huang and Yu 2013; Civico et al. 2015). The occurrence of CSE is therefore strongly associated to the stratigraphy of recent normally consolidated deposits. The presence of saturated loose silty-sand layers confined by impermeable silt-clay layers is a major predisposing condition for liquefaction. Nevertheless, CSE occurrence in floodplain areas is also related to geomorphological features such as sandy abandoned streambeds, abandoned river levees, and buried dunes of alluvial sands (Owen and Moretti 2011; De Martini et al. 2012).

To prevent risks related to CSE, one of the most important non-structural measures is to assess and map locations susceptible to liquefaction. This can be done on the basis of deterministic approaches, which are generally used at site scale, for micro-zonation studies, or as presented in this work, on the basis of spatial statistical approaches, that can result advantageous for regional scale studies when a good inventory of past CSE occurrences is available. Susceptibility is generally the expression of the degree to which a terrain can be affected by a hazardous phenomenon. Thus, susceptibility does not contemplate the temporal probability or return period, in this case of CSE (i.e., when or how frequently), nor their magnitude, such as the size of the future liquefaction evidences, but just the spatial distribution (Guzzetti, 2005). In other terms, susceptibility is only part of the Hazard assessment, that requires the probability that a dangerous phenomenon of a given magnitude to occur in a given period and in a specified area. Besides predicting the spatial dimension, hazard forecasts the temporal probability and magnitude of entities, “when” or “how frequently” it will occur, and “how large” it will be (Guzzetti et al., 1999; Van Westen, 1994; Guzzetti et al., 2005a).

The objective of this study is to assess and map CSE susceptibility at regional scale in the central southern area of the Po Plain (Italy) by using bivariate and multivariate geostatistical data-driven methods. Specifically, the study area includes a 1400 km<sup>2</sup> portion of Emilia-Romagna Region in which hundreds of CSE took place and were inventoried during the May 2012 seismic sequence peaking to Mw 5.9, as already defined in chapter four of this thesis. In terms of damages due to CSE, the 2012 seismic sequence was very similar to the Ferrara earthquake of 1570 (Guidoboni 1984; Guidoboni et al. 2007) and other historic earthquakes of MCS intensity above VII, occurred in 1346, 1570 and 1796 (Galli 2000; Locati et al. 2011). Nevertheless, historic chronicles are not accurate enough to allow the exact location of CSE to be determined. Therefore, the availability of a georeferenced inventory of hundreds of CSE occurred during the 2012 earthquake, provides the

unique opportunity to use geostatistical data-driven methods to assess liquefaction prone areas by exploring, with geostatistical tools, the relationships between the location of CSE (supporting evidences) and the variability of geologic, geomorphic, hydrogeological and topographic conditions (predisposing factors). Probabilistic methods such as Logistic Regression analysis (Liao et al. 1988), Bayesian mapping analysis (Juang et al. 2001; Juang et al. 2002), Bayesian regression analysis (Cetin et al. 2002; Cetin et al. 2004; Moss et al. 2006) and Artificial Neural Networks (Pal 2006; Samui et al. 2008; Xue and Yang 2014) have been recently applied in liquefaction studies to assess the factor of safety against liquefaction on the vertical soil column. In this study, in order to map CSE susceptibility in the target area, Information Value (IV), Weights of Evidence (WofE) (Bonham-Carter et al. 1989; Lee et al. 2002) and the Logistic Regression (LR) methods (Cox 1958; Agterberg et al. 1993; Gorsevski et al. 2006) have been compared and integrated.

The reason why, in this regional study, the application of geostatistical data-driven approaches might be preferable to deterministic approaches, is that the latter require a large amount of site-investigations to be properly applied over large areas. As a matter of fact, the assessment of the factor of safety against liquefaction in a uniform soil layer in geoenvironmental practice is based on the ratio between cyclic resistance ratio of the soil (CRR) and the cyclic stress ratio induced by design seismic acceleration (CSR) (Youd and Idriss 2001; Seed et al. 2003; Cetin et al. 2004; Idriss and Boulanger 2008) and the CRR is defined using in-site investigations such as cone, standard and Becker penetration tests or shear wave velocity determinations (Youd and Idriss 2001; Jafarian et al. 2010; Monaco 2014). Similarly, to compute the liquefaction potential index (LPI) of stratified deposits (Iwasaki et al. 1978), the factor of safety of each single layers must be assessed (Papathanassiou et al. 2015). Thus, over large areas, the application of deterministic methods is a very demanding task in terms of the large number of in-situ tests needed in order to properly assess the spatial variability of geotechnical and hydrogeological properties of the subsoil. Only if multiple borings or soundings are available it is eventually possible to cope with under-sampled locations by estimating the spatial variability of the LPI using different interpolation methods (Baise et al. 2006; Holzer et al. 2006; Chen et al. 2008; Facciorusso et al. 2010; Pokhrel et al. 2012). Nevertheless, the reliability of such interpolations largely depend on the complexity of the subsoil, the density and spatial homogeneity of data and on the adequacy of interpolation methods (Facciorusso et al. 2010).

Considering that sectors of the Po Plain have not been investigated by seismic microzonation studies and in-situ tests in all areas, the assessment and mapping of CSE susceptibility on the basis of the occurrence of hundreds of CSE during the 2012 seismic sequence, is believed to be a well justified option for contributing to the regional seismic risk planning and management by means of an innovative approach based on spatial geostatistical methods. More in details the objectives of this chapter are:

- Define assertive and valid methodologies able to predict the CSE susceptibility at regional scale and to advocate methods which are replicable in other contexts.
- Suggest an approach for CSE evaluations not yet explored in this field of study, which presents intrinsic advantages in terms of reliability, rapidity and low operational costs.

- Contribute with the definition (through maps) of zones susceptible to CSE, that are able to integrate and display information, in terms of susceptibility also for part of the territory that is not taken into consideration by the seismic Microzonation (SM)
- Produce CSE susceptibility maps for a synthetic overview of the phenomena at regional scale, otherwise able to discriminate spatially the phenomena into different grades of susceptibility at local level, within the municipality boundaries.
- Predict and discriminate the potential of susceptibility for each different types-specific CSE datasets.
- Integrate the models results in one single output (susceptibility map) able to delineate the most critical areas with higher accuracy.
- Fulfill cartographic outputs conceived as useful information tools for land use planning, preliminary CSE risk assessment that can be helpful during emergency to different stakeholders. Moreover, to be easily understandable, the susceptibility maps produced became possible instrument to enhance seismic knowledge and awareness for a wider not specialized public.

## 5.2 Data and methods

### 5.2.1 General approach

The data-driven statistical methods used in this study are the bivariate methods of Information Value (IV) (Yan,1988; Zêzere 2002 ), Weights of Evidence (WofE) (Bonham-Carter et al. 1989; Lee et al. 2002) and the multivariate method of Logistic Regression (LR) (Cox 1958; Agterberg et al. 1993). These methods have been extensively applied in others fields of geosciences, such as: mineral exploration (Bonham-Carter et al. 1989; Agterberg et al. 1993), landslides susceptibility (Carrara et al. 1995; Guzzetti et al. 2005; Gorsevski et al. 2006; Regmi et al. 2010), groundwater spring potential evaluations (Corsini et al. 2009), avalanches prediction (Ghinoi et al. 2002) and forest fires susceptibility (Viegas et al. 1999).

Although recent technological developments have facilitated the application of spatial statistical modelling (van Westen et al. 1997; Carrara et al. 1999; Guzzetti et al. 1999; Guzzetti 2005), any implementation of such methods requires an important preliminary phase of data acquisition and information processing aimed to the proper selection of supporting evidences and of causal factors to be considered.

In this research, susceptibility modelling with IV, WofE and LR was based on the use of a subset of all the CSE occurred during the 2012 earthquake (as supporting evidence) and of a set of maps representing independent predisposing factors.

The considered predisposing factors are static local terrain conditions, such as lithological, hydrogeological and geomorphological conditions that, according to literature, play the bigger role in determining CSE (Martelli 2012; Monaco 2014). Moreover, the absolute elevation and the distance to faults were also considered as predisposing factors. Prior to application in IV, WoE or LR, the degree of conditional independence existing among these predisposing factors was tested. On the other hand, the 2012 earthquake seismic acceleration was not considered, since it is indeed a triggering parameter that, as such, should by no means be included in a susceptibility assessment.

All thematic maps regarding supporting evidences and causal factors were generated using ArcGIS Desktop 10.3 software. The WoE and LR models were run in the freeware Arc-SDM Spatial Data Modeller extension (Sawatzky et al. 2009). IV calculations and mapping procedures were performed within ArcGis using raster calculator tool. Both CSE evidences (inventory dataset) and the predisposing factors maps (causal factors dataset) were converted from vector to raster structure with a cell size of 5 x 5 m and projected in WGS 1984 UTM Zone 32N.

### 5.2.2 Dataset: CSE inventory map

The liquefaction-related CSE inventory map (Figure 5.2.2-1) indicates the position of almost two thousand CSE occurred in 2012. As described in chapter four, the CSE inventory map was implemented by merging the three CSE databases obtained from the UNIFE, Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) and Emergeo working group (INGV). The lack of information about the actual dimension, in the field, of each CSE evidence, did not allow defining the areal dimension of all the liquefaction phenomena. Therefore, they were indicated as point features. In addition, terrain fissures, which are in truth linear features, were recorded as points located in the middle of the line. The integrated CSE map includes, altogether, a total of 1,910 point features referring to different types of CSE. For modelling purposes, the vector to raster conversion reduced the 1,910 point features in only 1,875 cells with a CSE evidences attribute. It was due to the fact that more than one CSE point occurred in the same pixel area.

For modelling purposes the following supporting evidences datasets have been applied:

- A total CSE dataset, i.e. a dataset in which all different CSE were included disregard the fact that they might refer to different types of CSE. The CSE unranked inventory map was subdivided in two sub-datasets: a modelling sub-dataset with 1,306 CSE supporting evidences (70%) used to train IV, WoE and LR models, and a validation sub-dataset with 569 CSE evidences (30%) used to test and compare the predictive performances of the modelling results. The sub-datasets are the result of different tests of random partitions, which were continued until the percentage of the CSE sampled in the modelling sub-dataset provided a well-distributed representation of CSE occurrences in the whole study area (Figure 5.2.2-1 a.). Even if the highest number of occurrences are mostly concentrated and clustered along geomorphological forms in the district of St. Agostino and Mirabello, both sub-datasets maintain a representative spatial distribution.
- Four type-specific CSE datasets referring to, separately, different type of CSE, were subdivided into: 1) liquefaction, 2) cracks, 3) cracks with liquefaction, 4) other types. For each type-specific CSE dataset, a supporting evidences dataset (including 70% of point of a given type of CSE) was used to train IV, WoE and LR models, and a validation sub-dataset (including the remaining 30% of point of a given type of CSE) was used to test and compare the predictive performances of models.

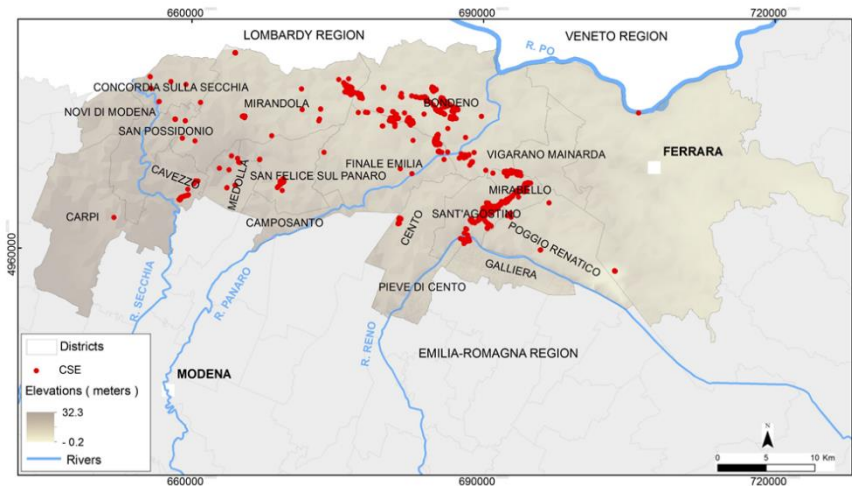


Figure 5.2.1-1 Inventory map presenting the CSE distribution occurred in the Study area.

### 5.2.3 Dataset: predisposing factors maps

The selected predisposing factors for CSE susceptibility modelling were the following: geomorphology; lithology; water table depth; Digital Elevation Model (DEM); and distance to faults, folds and over thrusts. The predisposing factors were classified in categorical layers and further reclassified into integer format to be included in the modelling process.

The geomorphological units were digitized from a geomorphological map of the Po Plain “Carta Geomorfologica di Pianura” at 1:250,000 scale (Castiglione et al. 1997). The geomorphological map used in this study is an adaptation of the previous map with more detailed data. From the original analogical map, the main fluvial geomorphological forms were digitalized in vector format and then converted to raster structure. The five geomorphology classes considered were: (1) crevasse splay; (2) levee well defined; (3) levee less defined; (4) abandoned riverbed; and (5) no fluvial landform (Figure 5.2.3-1 b).

The lithological units were defined based on the official geologic map “Carta Geologica di pianura dell'Emilia-Romagna 1:250.000” (Servizio Geologico, Sismico e dei Suoli, 1999). Specifically, lithology was considered as: (1) medium fine sand, in beds tens of cm thick (2) sandy silt; (3) silty clay; (4) silt and clayey silt; (5) clayey silt and sandy silt; (6) medium to fine sand; (7) medium fine sand, silt and silty clay; (8) medium and coarse sand. Lithological Unit 6 and 7 belong to deltaic and coastal deposits, while unit 9 corresponds to the Po riverbed that is part of the study area. All the other lithological units are associated with the alluvial plain deposits (Figure 5.2.3-1c)

Groundwater depth in the phreatic and upper confined aquifers was mapped using a dataset provided by the Regional Agency for Prevention, Environment and Energy of Emilia-Romagna region (ARPAE) based on a network of hundreds monitored wells. Data regarding year 2012 were rasterized by interpolation of 1m isolines. Considering that the maximum groundwater depth associated to the possible occurrence of CSE is about 16m in these phreatic and upper confined aquifers (Papathanassiou et al. 2012; Monaco 2014), the water table depth was divided in seven classes: (1) 3.5-4.5m; (2) 4.5-5.5m; (3) 5.5-6.5m; (4) 6.5-7.5m; (5) 7.5-10.5m; (6) 10-13.5m; (7) 13.5-16.5m (Figure 5.2.3-1d)

Elevation of the study area was assessed using a Digital Elevation Model (DEM) at a spatial resolution of 5x5 m derived from interpolation of contour lines and elevation points of the Regional

Technical Map at the scale 1: 5,000. Nine classes of elevation were defined: (1) 0–3m; (2) 3–6m; (3) 6–9m; (4) 9–12m; (5) 12–15m; (6) 15–18m; (7) 18–21m; (8) 21–26m; (9) 26–32m (Figure 5.2.3-1e). The interval of the classes for water table depth and the altimetry were defined considering the density of the evidences. For this reason, water table depth and DEM thematic layers' present wider intervals for their last two correspondent classes.

Structural-geological elements were taken into consideration by computing the distance to faults. Fault lineaments were derived from the official geological map “Carta geologica regionale 1:25,000” (Servizio Geologico, Sismico e dei Suoli, 2005). The Euclidean calculation allowed obtaining a raster that was subdivided into six classes of distances to faults: (1) 0–500m; (2) 500–1000m; (3) 1000–2000m; (4) 2000–3000m; (5) 3000–4000; (6) >4000m (Figure 5.2.3-1f).

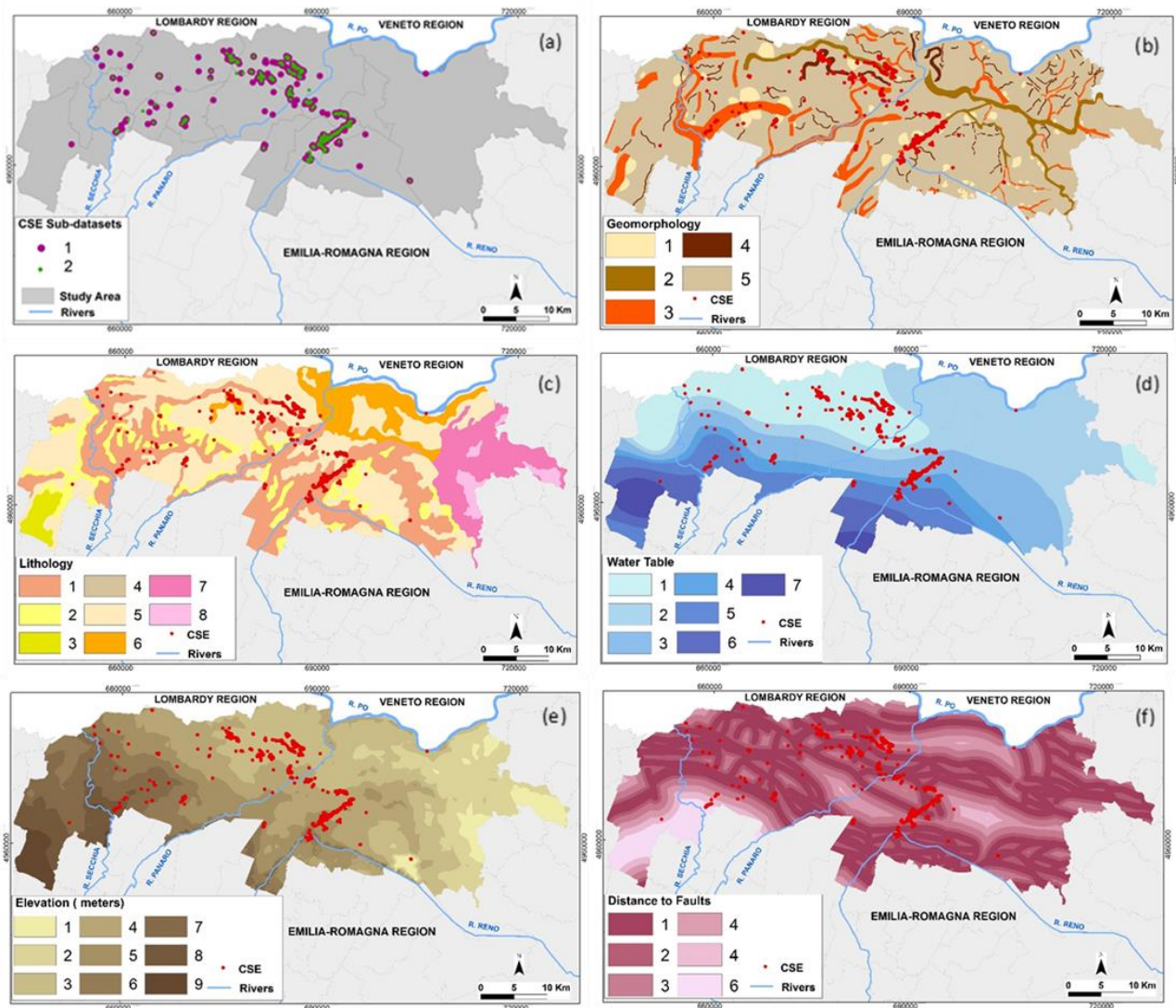


Figure 5.2.3-1 CSE Sub-dataset and conditioning factor maps used to model CSE susceptibility. Training dataset: 1 (70%), Validation dataset: 2 (30%) (a), Geomorphology (b), Lithology (c), Water Table Depth (d), Digital Elevation Model (DEM) (e), Distance to Faults (f). For conditioning factors see legend codes in Table 5.3.1-1 or in Table 5.3.2-1.

## 5.2.4 Formulations of the models

### 5.2.4.1 Information Value (IV)

The Information Value is bivariate statistical methods based on the statistical relationship between the predisposing factors and the dataset of occurrences related to phenomena evaluated. The Information Value method defined by Yan (1988), described in Yin and Yan (1988), it was then well developed for landslides susceptibility by Zêzere (2002). The method defines the prediction of susceptibility by means of a score, even on terrain units not yet affected by liquefaction occurrence. However, correlations among different input variables are not taken into account, and this is perhaps the major limit of this method (Zêzere, 2002). The relationship between each variable class and the supporting evidence data sets is assessed under the form of an Information Value score ( $I_i$ ), calculated from the following equation (Yin and Yan, 1988):

$$I_i = \ln \frac{S_i/N_i}{S/N} \quad \text{Equation 2}$$

Where:

$S_i$  = the number of terrain units (pixels) with liquefaction and the presence of variable (class)  $X_i$ ,

$N_i$  = the number of terrain units (pixels) with variable (class)  $X_i$ ,

$S$  = the total number of terrain units (pixels) with liquefaction of type  $Y$ ,

$N$  = the total number of terrain units (study area).

Negative values of  $I_i$  mean that the presence of the variable  $X_i$  is not relevant for liquefaction occurrence. Otherwise, positive values of  $I_i$  indicate a direct correlation between the presence of the variable and the liquefaction spatial occurrence. For the logarithmic normalization,  $I_i$  is not calculated when  $S_i=0$ . In those cases,  $I_i$  was determined as the lower value within the set of values associated to the variable considered.

The total information value  $I_j$  for a terrain unit  $j$  (pixel) of our study area is expressed by the equation 2 (Yin and Yan, 1988):

$$I_j = \sum_{i=1}^m X_{ji} I_i \quad \text{Equation 3}$$

Where:

$m$  = number of variables,  $X_{ji}$  is 0 if the variable is not present in the terrain unit  $j$ , or 1 if the variable is existing. Hence, the relative susceptibility of a terrain unit to the occurrence of liquefaction is conferred by the total information value  $I_j$ . Higher values are strictly associated to more prone liquefaction terrain units. The computation of the IV method equations required several procedures that were performed in both Excel program and GIS environment. The output tables generated from the intersection of CSE training modelling dataset with each categorical layer of dataset predisposing factors in ArcMap 10.3 was exported in Excel program. From the prior and conditional probability calculation, the  $I_i$  score for each predisposing variable have been calculated with equation n.

#### 5.2.4.2 Weight of Evidence (WofE)

The Weight of Evidence (WofE) is a simple statistical method based on Bayes' theorem (Lee 1989; Agterberg et al, 1993; Bonham-Carter 1994; Denison et al. 2002). The method is applicable when sufficient data are available to estimate the relative importance of evidential themes via statistical means (Bonham-Carter 1994) computing prior (unconditional) probability and posterior (conditional) probability. The method computes the conditional probability that an event (in this case CSE) does or does not belong to a given set of overlaid causal factor maps. If a casual factor is B the classes in it are Bi and supporting CSE evidence is (s) using the Bayes' theorem is possible to calculate the conditional probability for each class Bi as follows:

$$P(s|Bi) = \{P(Bi|s) * P(s)\}/P(Bi) \quad \text{Equation 4}$$

Where P (Bi|s) is the conditional probability to have Bi given s, P (s) is the prior probability to find s within the study area (SA), and P Bi is the prior probability to find the class Bi within the study area (AS).

Then, the conditional probability to have s when the class Bi is not present is:

$$P(Bi^{\wedge}|s) = \{P(Bi^{\wedge}|s) * P(s)\}/P(Bi^{\wedge}) \quad \text{Equation 5}$$

Where P (Bi<sup>^</sup>|s) is the conditional probability not to have the class Bi given s, P (s) is the prior probability to find s within the study area AS, and P (Bi<sup>^</sup>) is the prior probability not to find the class Bi within the study area AS.

In the WofE the weight of every class of causal factors is calculated by a combination of positive and negative correlation values defined with Bayes' method (W<sup>+</sup> and W<sup>-</sup>) and by the difference between them (contrast "C"). This method, assigns positive and negative weights (Wi<sup>+</sup> and Wi<sup>-</sup>) to each pixel of the predisposing factors maps.

$$W^+ = \ln\{P(Bi|s)/P(Bi)\} \quad \text{Equation 6}$$

$$W^- = \ln\{(P(Bi^{\wedge}|s)/P(Bi^{\wedge}))\} \quad \text{Equation 7}$$

The difference between the two weights is known as the weight contrast C. The magnitude of the contrast reflects the overall spatial association between the predictable variable and the CSE.

$$C = W^+ - W^- \quad \text{Equation 8}$$

A value of contrast equal to zero indicates that the considered class of causal factor is not significant for the analysis. A positive (negative) contrast indicates a positive (negative) spatial correlation between factor class and CSE occurrence.

The susceptibility map is obtained by a linear combination of weights of different factor classes. Then the value of posterior probability  $Pp(s)$  is given by the formula:

$$Pp(s) = \sum Wi * lnP(s) \quad \text{Equation 9}$$

#### 5.2.4.3 Logistic regression (LR)

The Logistic regression (LR) is a multivariate statistical method suitable for estimating the probability of a dichotomous dependent variable, such as the occurrence or absence of the phenomenon, from its relations with independent variables (Cox 1958; Agterberg et al. 1993). The method considers several physical parameters (variables) that may affect the probability of an event and yields coefficients for each variable based on sample data. The algorithm of logistic regression applies maximum likelihood estimation after transforming the dependent variable into a logit variable (natural log of the odds of the variable occurring or not). In this way LR estimates the probability of a certain event occurring.

The resulting probability values express the degree of CSE susceptibility, and they range between 0 and 1. LR can be applied when the variables show conditional dependence, contrary to the WofE method. It can also be performed using categorical or continuous variables as well if they are not normally distributed (Hosmer and Lemeshow 1989). The correlation between the CSE evidences in a terrain unit area and the casual factors conjunction is expressed by the following equation:

$$\text{logit}(P) = \log\left[\frac{(e^z)}{(1-P)}\right] = z \quad \text{Equation 10}$$

$$P = \left[\frac{(e^z)}{(e^z+1)}\right] = P = \left[\frac{1}{(1+e^{-z})}\right] \quad \text{Equation 11}$$

Where:  $P$  is the probability that a unit area falls into CSE or no CSE liquefaction condition. Logistic regression fits a special s-shaped curve by taking a linear regression, that may produce any  $y$  - value between  $-\infty$  and  $+\infty$ , and transforming it with the function that produces a probability ( $p$  probability) between 0 (as  $y$  approaches minus infinity) and 1 (as  $y$  approaches plus infinity).  $Z$  is the linear combination of:

$$Z = \beta_0 + \beta_1x_1(r) + \beta_2x_2(r) + \dots + \beta_mx_m(r) + \varepsilon \quad \text{Equation 12}$$

Where:  $\beta_0, \beta_1 \dots$  are the regression parameters;  $x_1(r), x_2(r) \dots x_m(r)$ , are the independent variables for each cartographic unit;  $\varepsilon$  is the error associated to the curvilinear approximation of the model.

In the logistic function, (equation 9) the input is  $z$  and the output is  $P$ . The variable  $z$  represents the exposure to some set of independent variables ( $x_m$ ), while  $P$  represents the estimated probability of CSE, given that set of explanatory variables. It must be noted that the LR approach does not require, or assume, linear dependencies between the dependent term and the variables considered

(independent set of variables representing causal factors). An exponential function is involved. Coefficients  $\beta$  are estimated through the maximum likelihood criterion and correspond to the estimation of the more likely unknown factors. In Logistic Regression, the coefficients  $\beta$  express the relative importance of the classes. A positive  $\beta$  coefficient indicates that the class contributes to susceptibility, whereas a negative  $\beta$  coefficient class reduces CSE susceptibility. Coefficients  $\beta$  close to zero indicate little relation between susceptibility and coefficients equal to zero indicate the class is not influencing the susceptibility.

#### 5.2.5 Models application and validation procedures

The degree of conditional independence existing among predisposing factors is a prerequisite to the application of IV, WoE methods to avoid overestimations of the posterior probability (Blahut et al. 2010; Pereira et al. 2012). In this work, we assume that auto-correlation among variables could exist. For that reason, results are not considered in probabilistic terms but only to rank susceptibility within the study area. Susceptibility classes are defined following the same principle.

The predictive capability of the outputs of IV, WoE and LR models was assessed by using the Prediction Rate Curve (PRC) (Chung and Fabbri 2003; Schmitt 2010) and by computing their Area Under the Curve (AUC) (Begueria 2006; Zêzere et al. 2007), created by plotting the cumulative distribution of validation CSE from high to low posterior probability versus the cumulative area. The PRC have also been compared with other predictive curves, such as the Success Rate Curve (created by plotting the cumulative distribution of all CSE - training and validation - from high to low posterior probability versus the cumulative area, Fabbri and Chung 2008) and the Receiver Operative Curve (ROC curve, a commonly used technique to display the results of a binary classification between the outcomes of a predictive model (or classifier) and the actual occurrence of the forecasted event, see Donner and Barbosa 2008).

More specifically, the analysis of the Area Under the Curve (AUC) of PRC (rather than SRC or ROC curves) is meant to indicate the quality of the predictor. In other terms, models that return an AUC higher than 0.7 are generally considered to have an acceptable discriminant capacity, values ranging between 0.8 and 0.9 indicates a good susceptibility model. Finally, AUC values  $> 0.9$  depict excellent models (Hosmer and Lemeshow, 2000; Guzzetti 2005).

Another procedure herein used to estimate the real predictive capability of each class of susceptibility and then for model comparison was the Ratio of Effectiveness (RofE) (Chung and Fabbri 2003) of CSE susceptibility classes. Chung and Fabbri (2003) pointed out that a RofE equal to 1 indicates a random and unresponsive class prediction. Good class power predictions correspond to RofE higher than 3 (less than 0.2) for high (low) susceptibility classes. Significantly, effective classes, show RofE higher than 6 (less than 0.1) for high (low) susceptibility classes. Hence, the numeric representations can be assumed as quantitative measures of the predictive power of the class when the probability function is used to precise the susceptibility of future CSE.

As previously mentioned, the application IV, WoE and LR methods was carried out with respect to different types of supporting evidences datasets:

- A total CSE dataset, i.e. a dataset in which all different CSE were included disregard the fact that they might refer to different types of CSE.

- Four type-specific CSE datasets referring to, separately, different type of CSE, subdivided into: 1) liquefaction, 2) cracks, 3) cracks with liquefaction, 4) other types.

For what regards the results obtained by using the total CSE dataset, in order to compare the CSE susceptibility maps obtained by the three predictive models (IV, LR, WofE), the susceptibility maps have been classified using the same number of classes, defined by ranking results in decreasing order of susceptibility and by fixing the limits between classes by using the same values, for all models, of cumulated spatial extent. The limited scores obtained for the posterior probability (LR) have forced to subdivide the study area in only four classes where, the first 30 % was discriminated in three classes representing each the 10% of the total study area. The fourth class occupies the 70% of the target area and corresponds to the low and very low susceptibility.

The degree of spatial correlation and the relative degree of class dispersion between CSE susceptibility maps obtained with IV, WofE and LR was estimated on the basis of the Cohen's kappa coefficient (Cohen 1960; Hoehler 2000).

Moreover, maps comparison was performed using the "difference rank" tool of ArcSDM (Sawatzky et al., 2009), which quantifies the degree of agreement between maps, by expressing the difference between the two maps in a range from 0 (both maps have the same class in a given pixel) to N (where N represents the distance in classes between the two maps in a given pixel: e.g. a value +1 means that in the leading map the susceptibility is classified in 1 class higher with respect to the other map; - 1 in the leading map the susceptibility is classified in 1 class lower with respect to the other map).

At last, in order to highlight the extent to which CSE susceptibility should be considered more certain, the output of the two models were merged in raster calculator (ArcMap) so to obtain a final synthetic map of the more susceptible zones that highlights which areas are considered at a high level of susceptibility by one or both models.

These "merged" maps have been finally compared to official Microzonation Maps (MZM) that the different municipalities have produced by applying the conventional Liquefaction Index approach.

## 5.3 Results of the application of models with the total CSE dataset

### 5.3.1 Distribution of CSE with respect to predisposing factors

The distribution of the CSE in the different classes of each predisposing factor is represented in Table 5.3.1-1 and the related Figure 5.3.1-1. Regarding geomorphological features, it should be highlighted that fluvial landforms covering 27% of the study area, include 60% of all the CSE. As can be seen, the majority of CSE were distributed along the main ancient fluvial landforms.

This finding is consistent with the fact that levees, crevasse splays or abandoned riverbed or land reclamation areas generally act as preferential location for the CSE occurrence (Civico et al. 2015).

The sub-surface lithology seems also to play a discriminant role, as almost 60% of CSE are associated to the medium fine sand of alluvial deposits (1) and 32.7 % to the silty clay lithology class (3). The CSE distribution seems also directly related to groundwater depth. In the study area, 35% of CSE are associated to groundwater depth of 3.5 to 4.5 meters and another 53% of CSE is located in areas with groundwater depth between 5.5 - 7.5 m. This is consistent with the observation of Monaco (2014), which indicates 15m as the maximum groundwater depth associated to liquefaction phenomena. Despite the almost flat morphology of the Po Plain, to verify any possible influence of elevation on CSE occurrence, the DEM was also integrated in this evaluation. The elevation ranges of 12 to 15 m a.s.l. has the highest percentage of CSE (36.8%). This elevation is generally associated to the levee of the ancient riverbeds and fluvial depositions forms. For what concerns the distance to faults, the 55.5% of CSE occurs in the class 0 to 500 m, i.e. very close to tectonic structures. The remaining 44.5% is distributed in progressively lower percentages as distance to tectonic structures increases.

CAUSAL FACTORS	ID	VARIABLES	AREA km <sup>2</sup>	AREA %	N.CSE	AREA WITH CSE km <sup>2</sup>	AREA WITH %
<b>Geomorphology</b>							
	1	Crevasse Splay	56.7	3.8	213	5.3	11.5
	2	Levee Well defined	59.1	4.0	196	4.9	10.6
	3	Levee Less defined	158.6	10.7	586	14.7	31.8
	4	Abandoned riverbed	47.7	3.2	105	2.6	5.7
	5	No fluvial features	1160	78,3	745	18,6	40.4
<b>Lithology</b>							
	1	Medium Fine Sand, in beds tens of cm thick	445.8	30.1	1120	28.0	60.7
	2	Sandy Silt	156.2	10.5	49	1.2	2.7
	3	Silty Clay	539.4	36.4	603	15.1	32.7
	4	Silt and Clayey Silt	29.3	2.0	0	0.0	0.0
	5	Clayey Silt and Sandy Silt	0.0	0.0	0	0.0	0.0
	6	Medium to fine Sand	146.0	9.8	0	0.0	0.0
	7	Medium Fine Sand, Silt and silty clay	27.9	1.9	0	0.0	0.0
	8	Medium and coarse Sand	125.8	8.5	72	1.8	3.9
	9	<i>Po Riverbed</i>	11.4	0.8	1	0.0	0.1
<b>Water Table (meters)</b>							
	1	3.5 - 4.5	329.9	22.3	648	16.2	35.1
	2	4.5 - 5.5	460.6	31.1	130	3.3	7.1
	3	5.5 - 6.5	279.3	18.8	625	15.6	33.9
	4	6.5 - 7.5	103.1	7.0	344	8.6	18.7
	5	7.5 - 10.5	174.6	11.8	96	2.4	5.2
	6	10.5 - 13.5	87.1	5.9	1	0.0	0.1
	7	13.5 - 16.5	47.2	3.2	0	0.0	0.0
<b>DEM (meters)</b>							
	1	0 - 3	61.2	4.1	6	0.2	0.3
	2	3 - 6	196.4	13.2	0	0.0	0.0
	3	6 - 9	343.5	23.2	520	13.0	28.2
	4	9 - 12	295.0	19.9	403	10.1	21.8
	5	12 -15	194.3	13.1	679	17.0	36.8
	6	15 -18	128.2	8.7	177	4.4	9.6
	7	18 -21	146.8	9.9	33	0.8	1.8
	8	21 -26	80.1	5.4	27	0.7	1.5
	9	26 -32	35.6	2.4	0	0.0	0.0
<b>Distance to Faults (meters)</b>							
	1	0 - 500	675.8	45.6	1023	25.6	55.4
	2	500 - 1000	330.3	22.3	440	11.0	23.8
	3	1000 -2000	256.0	17.3	335	8.4	18.2
	4	2000- 300	116.3	7.9	23	0.6	1.2
	5	3000 - 4000	41.3	2.8	6	0.2	0.3
	6	>4000	62.4	4.2	18	0.5	1.0

*Po Riverbed is included in the target area.*

Table 5.3.1-1 Predisposing factors and Coseismic Surface Effects (CSE) frequency distribution.

### 5.3.2 CSE susceptibility using IV, WofE and LR models

The application of the IV method resulted in positive and negative score values from 4 to -7.682 (li). Within all the casual factors, the geomorphology presents all positive values for all the variables indicating that fluvial features that were selected are the most significant predisposing factors. This assumption is in accordance with dedicated literature, and with the spatial distribution of the evidences, that appeared mainly distributed along the geomorphological landforms. Table 5.3.2-1 shows that Crevasse splay has the highest information value (li = 1.126). Regarding the detailed lithology, the lithological unit 1. characterized by medium fine sand in beds tens of cm thick, is the lithological class more prone to CSE. for the Water table depth corresponding to 6.5-7.5m show the highest values. The shallower water table spatial distribution comprises the districts of Concordia

sulla Secchia, Mirandola, Bondeno, and in part Finale Emilia. The only relevant role of altimetry is associated to the elevation range between 12 and 15 meters. This is confirmed by the highest positive values of information scores for all the five CSE data sets. Regarding the IV in relation to distance to faults, the class represented by a distance from 0 to 500 m appears the most prone to induce the occurrences. However, for Crack the highest IV is found for class, with distance between 1000-2000m.

The application of the WofE method resulted in the positive and negative weights (W+ and W-) and, consequently, in the weights contrasts (C) listed in Table 5.3.2-1. Regarding geomorphological features, the higher positive values of C are obtained with respect to well or less well defined levees and crevasses splays. With respect to lithology, the higher positive values of C are obtained for medium fine sand, whereas significant negative C is obtained for sandy silt and the Po riverbed deposits. As for groundwater depth, the higher positive values of C correspond to the range of depth 6.5 to 7.5 m and the maximum negative C to the class 10 to 13.5 m below the ground. Other classes are poorly characterized by the contrast. Elevations class from 12 to 15 m shows the higher positive C value. The distance to faults shows the higher positive C value in the class from 0 to 500 m, and the C becomes significantly negative for classes representing distances higher than 2 km.

The application of the LR method resulted in the  $\beta$  coefficients values are that presented in Table 5.3.2-1. Since the  $\beta$  coefficients indicate the degree of importance of each variable in the post probability calculation, it can be stated that the lithology, again, is the most important conditioning factor. In particular, the lithology class "medium fine sand" shows the highest  $\beta$  coefficient. Positive values are obtained also for others lithological units: sandy silt, silty clay, medium and coarse sand and Po riverbed deposits. Depth to groundwater presents positive regression coefficients for all the classes. On the other hand, the lowest values of  $\beta$  coefficients are associated to the distance to faults and to the DEM. Nevertheless, the significant negative values for classes of distances to fault higher than 2 km, indicate that these classes are inversely correlated to the CSE occurrences.

The application of WofE method to the entire dataset of predisposing factors returned posterior probability values ranging from 0 to 0.507, whereas the application of LR generated posterior probability values ranging from 0 to a maximum of 0.252.

To retrieve classified susceptibility maps, the IV, WofE and LR probability values have been classified into four classes by ordering probability values in decreasing order. The higher susceptibility classes ("very high", "high" and "moderate") are defined at fixed 10% intervals of the study area. The "low to very low" class is assigned to the low probability values obtained in the remaining 70% of the study area.

CASUAL FACTORS	ID	VARIABLES	AREA km <sup>2</sup>	NO_POINTS	Wof E W+	WofE CONTRAST	LR BETA	IV VALUE
							Constant Value	
							<b>-29.548</b>	
Geomorphology								
	1	Crevasse Splay	56.7	168	<b>11.894</b>	12.846	1.557	<b>1.126</b>
	2	Levee Well defined	59.1	144	0.9934	10.666	<b>1.762</b>	1.010
	3	Levee Less defined	158.6	428	1.096	<b>13.687</b>	1.738	1.088
	4	Abandoned riverbed	47.6	68	0.4586	0.4781	1.178	0.482
	5	No fluvial landform	1.160	529	-0.6822	-17.052	0	-0.644
Lithology								
	1	Medium Fine Sand, in beds tens of cm thick	445.8	817	<b>0.7087</b>	<b>12.952</b>	<b>11.062</b>	<b>0.699</b>
	2	Sandy Silt	156.2	39	-12.848	-13.666	9.541	-1.261
	3	Silty Clay	539.4	433	-0.1169	-0.1781	10.509	-0.103
	4	Silt and Clayey Silt	29.3	0	0	0	-	-2.400
	5	Clayey Silt and Sandy Silt	0.0	0	0	0	-	-2.400
	6	Medium to fine Sand	146	0	0	0	-	-2.400
	7	Medium Fine Sand, Silt and silty clay	27.9	0	0	0	-	-2.400
	8	Medium and coarse Sand	125.8	47	-0.8819	-0.9348	10.254	-0.858
	9	Po Riverbed	11.4	1	-2.333	-2.34	0.971	-2.310
Water Table (meters)								
	1	3.5 - 4.5	329.9	459	0.4332	0.602	10.551	0.452
	2	4.5 - 5.5	460.6	100	-14.245	-1.719	0.920	-1421
	3	5.5 - 6.5	279.3	477	0.6381	0.8705	10.844	0.612
	4	6.5 - 7.5	103.1	237	<b>0.9351</b>	<b>10.581</b>	<b>11.209</b>	<b>0.946</b>
	5	7.5 - 10.5	174.6	63	-0.9167	-0.9938	9.219	-0.909
	6	10.5 - 13.5	87.1	1	-43.648	-44.247	5.514	-4.341
	7	13.5 - 16.5	47.2	0	0	0	-	-4.400
DEM (meters)								
	1	0 - 3	61.2	5	-24.026	-24.411	-1.377	-2.379
	2	3 - 6	196.4	0	0	0	-	-2.400
	3	6 - 9	343.5	372	0.1824	0.2447	0.436	0.204
	4	9 - 12	295.0	290	0.0854	0.1078	-	0.099
	5	12 - 15	194.3	485	<b>10.174</b>	<b>13.274</b>	<b>0.729</b>	<b>1.014</b>
	6	15 -18	128.2	138	0.1761	0.1945	-0.055	0.101
	7	18 -21	146.8	27	-15.908	-16.748	-2.082	-1.605
	8	21 -26	80.1	20	-12.855	-13.261	-0.676	-1262
	9	26 -32	35.6	0	0	0	-	-2400
Distance to Faults (meters)								
	1	0 - 500 m	675.8	764	<b>0.2257</b>	<b>0.4643</b>	<b>0.714</b>	<b>0.215</b>
	2	500 - 1000 m	330.3	310	0.0397	0.0514	-	0.057
	3	1000 -2000 m	256.0	229	-0.0083	-0.01	-	0.002
	4	2000- 300 m	116.3	16	-1.881	-19.507	-1.754	-1.857
	5	3000 - 4000 m	41.3	6	-18.263	-18.501	-1.225	-1.803
	6	>4000 m	62.4	12	-15.462	-15.803	0.614	-1.523

Table 5.3.2-1 Statistical parameters obtained for each predisposing factor for the total of CSE using IV, WofE and Logistic Regression models. Higher values of W+ and C for WofE e Beta coefficient for LR are highlighted in bold.

### 5.3.3 CSE susceptibility models validation and comparison

#### 5.3.3.1 Validation and comparison based on PRC

The three statistical models were validated and compared through the Prediction Rate Curve (PRC) computed using the validation subset (that includes 569 CSE). Indeed, the Prediction Rate Curve (PRC) of the three susceptibility models expresses their predictive capacity (Figure 5.3.3.1-1). The three methods show very similar results, with an area under the curve (AUC) of 84.28% for IV, 83.85 % for WofE and 85.27% for LR. Thus, based on such criteria, all models can be considered acceptable predictors and the difference between the three models is not significant. Looking at the trend and benchmark values of the PRC (Figure 5.3.3.1-1 and Table 5.3.3.1-1), the three models predict about 60% of validation CSE within 10% of area, 70% of validation CSE in 20% of the study area and 90% of validation CSE in 50% of the study area. According to Guzzetti et al. (2006) when the AUC presents values greater than 80% the quality of a model can be considered satisfactory. Furthermore, in all models, the values of Ratio of Effectiveness corresponding to the very high class is much higher than for the others classes of susceptibility. This, also, is an indicator of good quality of the prediction.

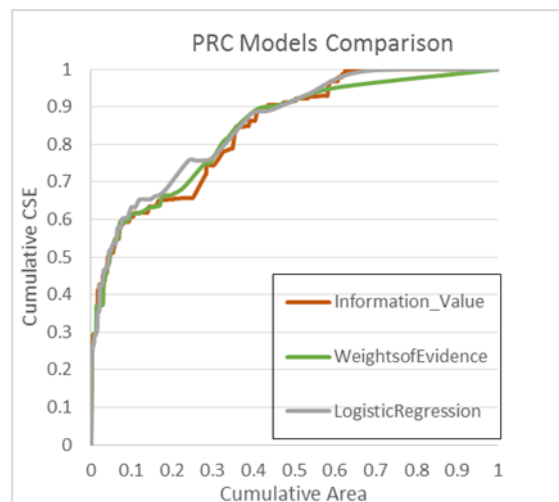


Figure 5.3.3.1-1 Prediction Rate Curve (PRC) of IV, WofE and LR models, and quantification of the Area Under Curve (AUC).

	CLASSES	Susceptibility value	% of study area classified as susceptible (descending order)	% of CSE predicted	% of study area	% of Liquefaction predicted	Ratio of effectiveness
IV	VERY HIGH	4.000 - 1.195	0 - 10	60	10	60	6.00
	HIGH	1.195 - 0.589	10 - 20	65	10	5	0.50
	MODERATE	0.589 - 0.000	20 - 30	74	10	9	0.90
	LOW to VERY LOW	0.000 - - 7.682	30 - 100	100	70	26	0.37
WofE	VERY HIGH	0.0507 - 0.0027	0 - 10	60	10	60	6.00
	HIGH	0.0027 - 0.011	10 - 20	66	10	6	0.60
	MODERATE	0.0011 - 0.0008	20 - 30	75	10	9	0.90
	LOW to VERY LOW	0.0008 - 0	30 - 100	100	70	25	0.36
LR	VERY HIGH	0.252 - 0.021	0 - 10	63	10	63	6.30
	HIGH	0.021 - 0.011	10 - 20	70	10	7	0.70
	MODERATE	0-011- 0.007	20 - 30	77	10	7	0.70
	LOW to VERY LOW	0.007 - 0	30 - 100	100	70	23	0.33

Table 5.3.3.1-1 Percentage of the study area, percentage of CSE predicted and ratio of effectiveness obtained for each CSE susceptibility model classes.

In the three following susceptibility maps resulted from IV, WofE and LR (Figure 5.3.3.1, 2-3-4) the medium, high and very high susceptibility zones are concentrated in the central southern or in the north part of the study area mainly along levees, crevasse splays or within areas of medium to fine sand, in the districts of Bondeno to Mirandola and Concordia, as well as San Felice and St. Agostino.

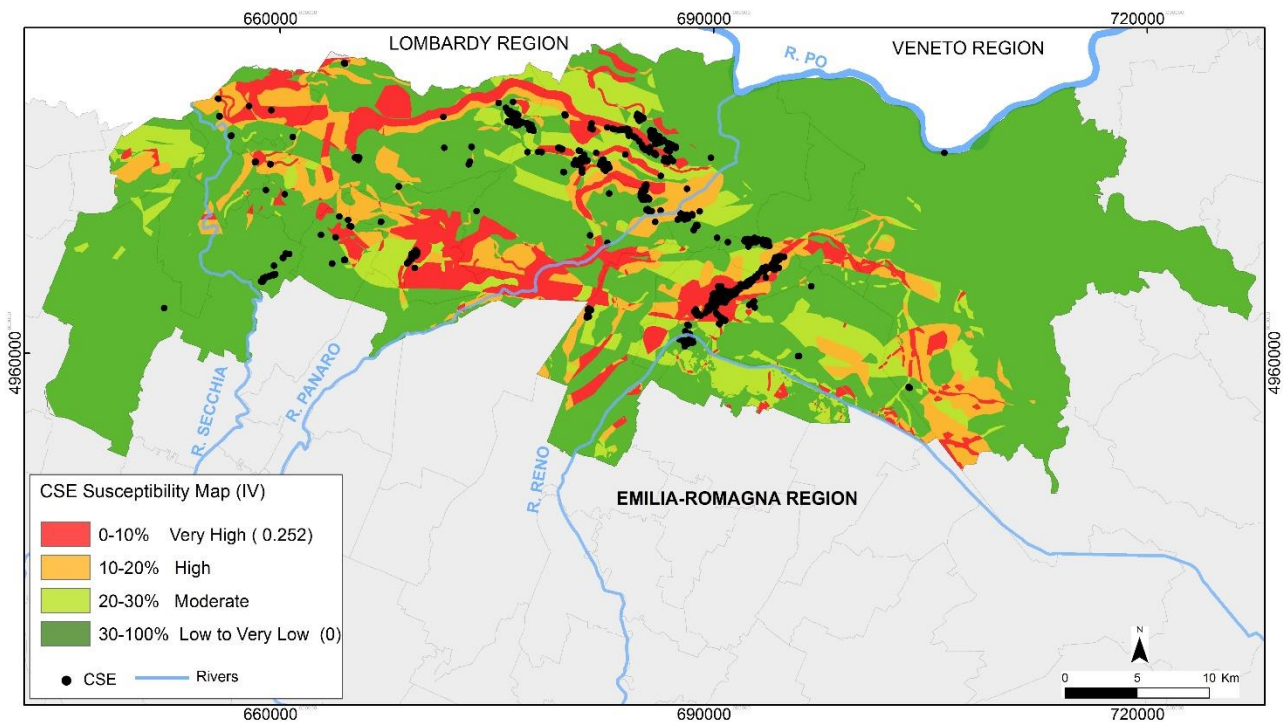


Figure 5.3.3.1-2. CSE susceptibility map produced with IV method. The study area is portioned into four classes considering the aerial intervals of 10% for the first 3 classes and the 70% for the last one.

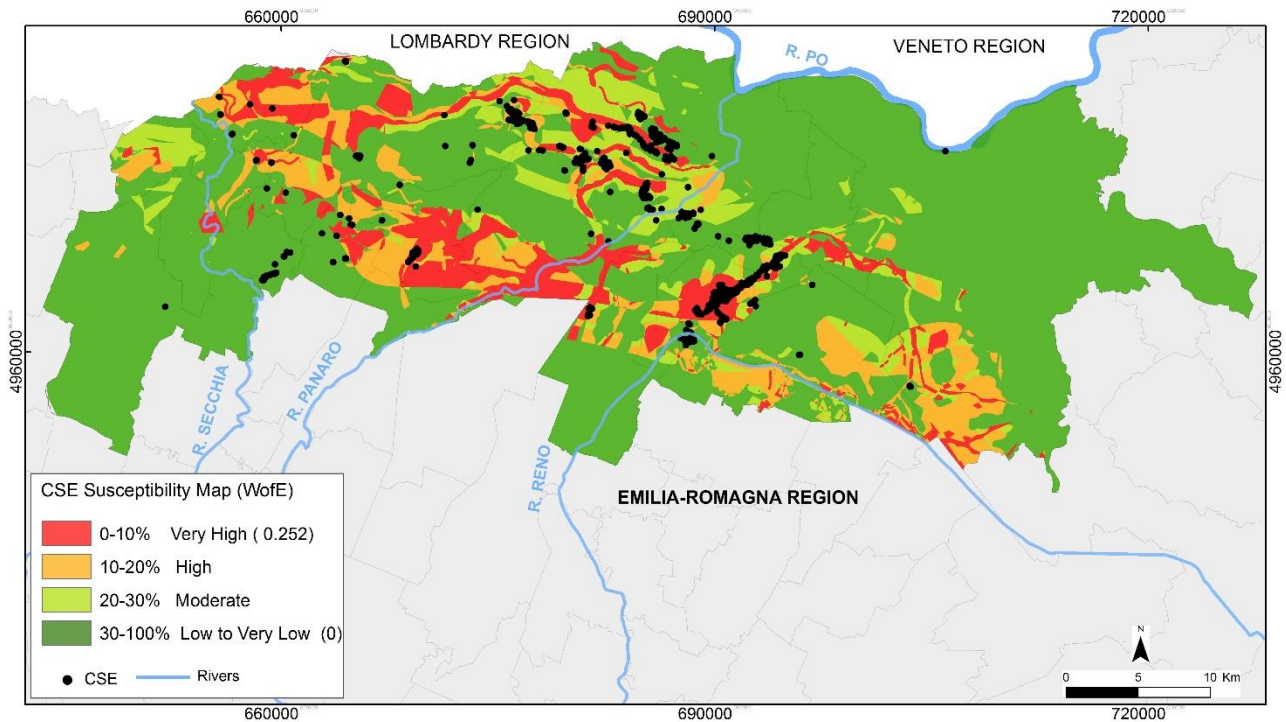


Figure 5.3.3.1-3. CSE susceptibility map produced with WofE method. The study area is portioned into four classes considering the aerial intervals of 10% for the first 3 classes and the 70% for the last one.

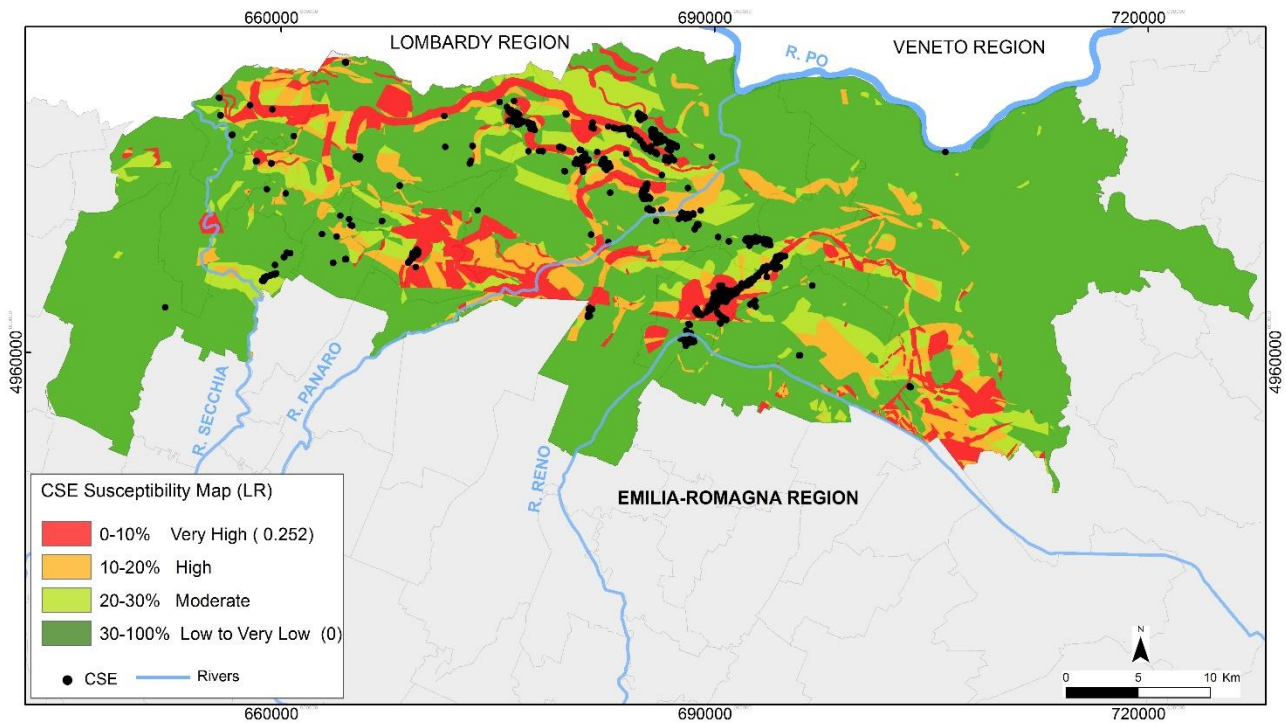


Figure 5.3.3.1-4 CSE susceptibility map produced with LR method. The study area is portioned into four classes considering the aerial intervals of 10% for the first 3 classes and grouping the 70% of the area for the last one (30-100% of cumulate area).

### 5.3.3.2 Comparison based on Cohen's kappa coefficient

The degree of spatial correlation between CSE susceptibility maps was assessed by Cohen's kappa coefficient. The results include the analysis of the similarity between the susceptibility equally classified maps in pairs. The spatial concordance is expressed in percentage of study area predicted per CSE susceptibility class. The highest model spatial agreement is expressed between WofE and IV maps (Cohen's kappa coefficient=0.80) that resulted also in a total spatial correlation of 90.71 % within the study area (Table 5.3.3.2-1). Moderate spatial agreement is related to the comparison between the WofE and LR and between IV and LR models (Cohen's kappa coefficient=0.68) (Table 5.3.3.2-3 and 5.3.3.2-5). The total spatial agreement between WofE and LR and between IV and LR is 85%.

In the following tables, the grey boxes in diagonal direction show the spatial degree (%) of overlapping for each class of susceptibility with the related percentage of aerial dispersions in the adjacent CSE susceptibility classes.

In order to facilitate the reading of the results, Table 5.3.3.2-2, Table 5.3.3.2-4 and Table 5.3.3.2-6 resume the percentage of spatial matching for each class into the models in relation to the total area occupied by the same class. Moreover, the total percentage of the class dispersions sum in one single value. From the tables analysed, is possible to affirm that all the three models comparison show the same tendency. The highest dispersions and consequently lower matching are within the class indicated as high susceptible covering the 10 %-20% of the study area and within the moderate susceptible class encompass in the 20 % -30 % of the study area. Regarding the last assumption, the model discrepancy in the comparison related to the middle classes of the study area is a normal trend also if bring the attention to the degree of accuracy of the models prediction for the area that is considered highly prone to the phenomena occurrence.

Spatial Total Agreement 90.71%  
Kappa 0.8

Map 1 WofE \ Map 2 IV		Susceptibility Classes intervals based on the equal % subdivision of study area				
Susceptibility Classes		Low To Very Low (30 - 100%)	Moderate (20-30%)	High (10- 20%)	Very High (0-10%)	Sum Map 1
Low To Very Low (30 - 100%)	4	68.83	1.32	0.24	0.33	70.72
Moderate (20-30%)	3	0.50	5.80	2.38	0.00	8.68
High (10- 20%)	2	0.32	3.15	6.81	0.37	10.65
Very High (0-10%)	1	0.03	0.05	0.60	9.27	9.94
Sum Map 2		69.67	10.33	10.03	9.97	100.00

Table 5.3.3.2-1 Overlapping degree (%) of the spatial distribution of CSE susceptibility classes between the WofE and IV liquefaction susceptibility maps based on a pair of maps comparison. The grey boxes highlight the percentage of overlapping and the adjunct values represent the degree of dispersion.

Susceptibility Classes	WofE		IV	
	% ToT. Overlap Map 1	% of Dispersion	% ToT. Overlap Map 2	% of Dispersion
Low To Very Low (30 - 100%)	97.32	2.68	98.78	1.22
Moderate (20-30%)	66.85	33.15	56.21	43.79
High (10- 20%)	63.89	36.11	67.86	32.14
Very High (0-10%)	93.23	6.77	92.97	7.03

Table 5.3.3.2-2 Percentage of total overlap and percentage of total dispersion for each class in relation to the area of the class considered.

Spatial total Agreement	85.67%					
Kappa	0.68					
Map 1 WofE \ Map 2 LR	Susceptibility Classes intervals based on the equal % subdivision of study area					
Susceptibility Classes	Low To Very Low (30 - 100%)	Moderate (20-30%)	High (10- 20%)	Very High (0-10%)	Sum Map 1	
Low To Very Low (30 - 100%)	4	67.59	2.08	1.04	0.00	70.72
Moderate (20-30%)	3	2.45	4.97	1.26	0.00	8.68
High (10- 20%)	2	2.24	1.80	5.30	1.32	10.65
Very High (0-10%)	1	0.00	0.24	1.89	7.81	9.94
Sum Map 2		72.28	9.09	9.50	9.14	100

Table 5.3.3.2-3 Overlapping degree (%) of the spatial distribution of CSE susceptibility classes between the WofE and LR liquefaction susceptibility maps based on a pair of maps comparison. The grey boxes highlight the percentage of overlapping and the adjunct values represent the degree of dispersion.

Susceptibility Classes	WofE		LR	
	% ToT. Overlap Map 1	% of Dispersion	% ToT. Overlap Map 2	% of Dispersion
Low To Very Low (30 - 100%)	95.57	4.43	93.52	6.48
Moderate (20-30%)	57.24	42.76	54.69	45.31
High (10- 20%)	49.71	50.29	55.77	44.23
Very High (0-10%)	78.57	21.43	85.49	14.51

Table 5.3.3.2-4 Percentage of total overlap and percentage of total dispersion for each class in relation to the area of the class considered

Spatial total Agreement	85.08%					
Kappa	0.68					
Map 1 IV \ Map 2 LR	Susceptibility Classes intervals based on the equal % subdivision of study area					
Susceptibility Classes	Low To Very Low (30 - 100%)	Moderate (20-30%)	High (10- 20%)	Very High (0-10%)	Sum Map 1	
Low To Very Low (30 - 100%)	4	66.80	1.48	1.36	0.04	69.67
Moderate (20-30%)	3	3.77	5.17	1.17	0.22	10.33
High (10- 20%)	2	1.38	2.40	5.24	1.00	10.03
Very High (0-10%)	1	0.33	0.04	1.73	7.87	9.97
Sum Map 2		72.28	9.09	9.50	9.14	100

Table 5.3.3.2-5 Overlapping degree (%) of the spatial distribution of CSE susceptibility classes between the Iv and LR liquefaction susceptibility maps based on a pair of maps comparison. The grey boxes highlight the percentage of overlapping and the adjunct values represent the degree of dispersion.

Susceptibility Classes	IV		LR	
	% ToT. Overlap Map 1	% of Dispersion	% ToT. Overlap Map 2	% of Dispersion
Low To Very Low (30 - 100%)	95.88	4.12	92.42	7.58
Moderate (20-30%)	50.07	49.93	56.89	43.11
High (10- 20%)	52.26	47.74	55.20	44.80
Very High (0-10%)	78.95	21.05	86.15	13.85

Table 5.3.3.2-6 Percentage of total overlap and percentage of total dispersion for each class in relation to the area of the class considered.

### 5.3.3.3 Comparison based on the Rank Difference

The Rank difference returns maps of values from 0 to N, representing class distances. The value 0 express that the terrain unit was classified in the same way between the both maps, and so exemplify the spatial concordance. In the comparison considering the first map of entrance the reference one, if the value is +1 means that in that map the unit's area are classified with 1 class of increment respect to the other models. - 1 signifies one class of decrease in susceptibility. The extremes +3 or -3, presented for the IV-WofE comparison and for WofE- LR comparison indicate that one of the model classify those terrain units as high susceptible and the other in the opposite way low/ very low susceptible. The results display in maps (Figures 5.3.3.3-1, and 2-3) show how very good spatial concordance in class 0 that for the IV – WofE comparison reach the 90.71 % of the area and for the other compared models the 85%. The critics area, represented by opposite classification are insignificantly from the spatial point of view (See tables 5.3.3.3-1 a.b.c). The area considered very high susceptible by one model and very low susceptible by another model covers low percentage of study area (between 0.33 and 0.40 percent). Within the spatial overlay between WofE and LR none terrain units fall into the extreme opposite classification.

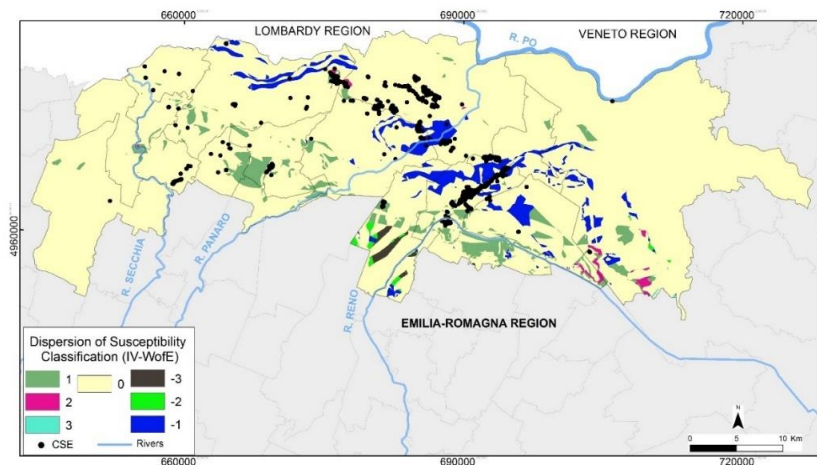


Figure 5.3.3.3-1 Map representing the distribution of class concordance and the degree of class dispersion comparing the model IV-WofE.

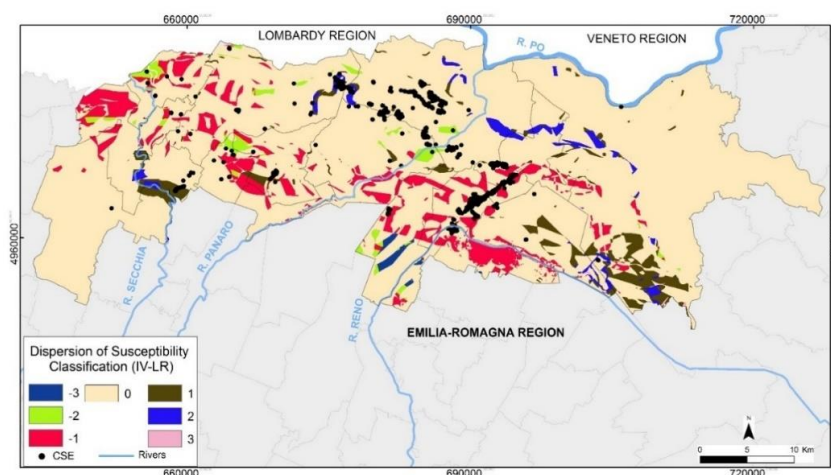


Figure 5.3.3.3-2 Map representing the distribution of class concordance and the degree of class dispersion comparing the model IV-LR.

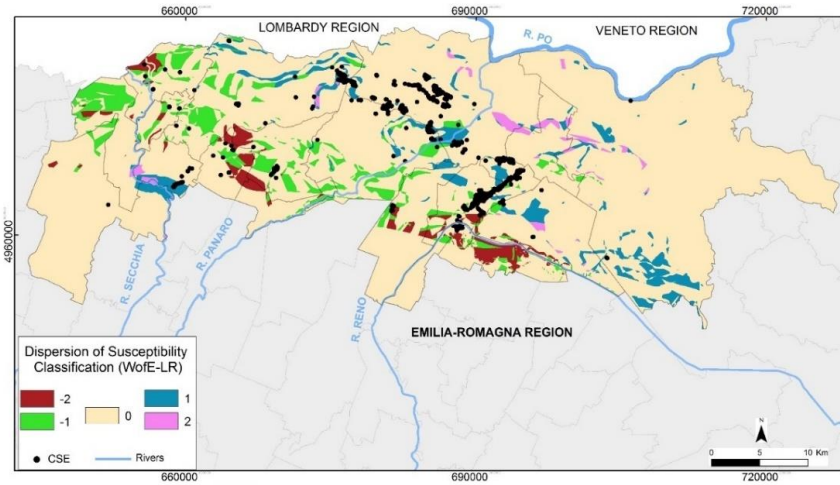


Figure 5.3.3.3-3. Map representing the distribution of class concordance and the degree of class dispersion comparing the model WofE-LR.

**IV-WofE**

Class	N. pixels of the study area	Study Area %
-3	195980	0.33
-2	143841	0.24
-1	2413615	4.07
0	53742611	90.71
1	2518890	4.25
2	217461	0.37
3	16552	0.03
Total	59248950	100

b.

**WofE-LR**

Classes	N. pixels of the study area	Study Area %
-2	1463730	2.47
-1	3640111	6.14
0	50758882	85.67
1	2767019	4.67
2	619208	1.05
Total	59248950	100

c.

**IV-LR**

Class	N. pixels of the study area	Study Area %
-3	195980	0.33
-2	841436	1.42
-1	4681126	7.90
0	50410249	85.08
1	2160515	3.65
2	935414	1.58
3	24230	0.04
Total	59248950	100

Table 5.3.3.3-1 Percentage of class agreement and class dispersion results by model comparison: a. IV less WofE; b. IV less LR; c. WofE less LR using ArcSDM, rank difference tool.

#### 5.3.3.4 Comparison to Seismic Microzonation Maps

One important task of this study concerns the comparison between the official maps produced through the Microzonation studies realized by the ER Region after the 2012 seismic sequence and the synthesized CSE susceptibility map that was obtained merging the classes of higher susceptibility by the three models. The MZ studies occupied the 14.6% of the study area. The SM in seismic perspective studies identifies area susceptible to amplification into which discriminate area prone to liquefaction. The intersection by overlay between the final susceptible maps obtained merging the susceptibility classes from VH to H or from VH to Moderate allowed to appreciate the spatial distribution of the models result for higher susceptibility within the area considered in SM (Figure 5.3.3.4-1 and 5.3.3.4-2). The VH and H classes cover the 47% of the SM. This percentage reach the 65% including the Moderate class of susceptibility. The SM maps do not specify the degree related to the CSE susceptibility. Furthermore, the studies focused on urban area, on area under reconstruction or on area interested by future urbanization, while susceptibility maps to CSE produced by the three methods permit to evaluate the susceptibility overall the study area.

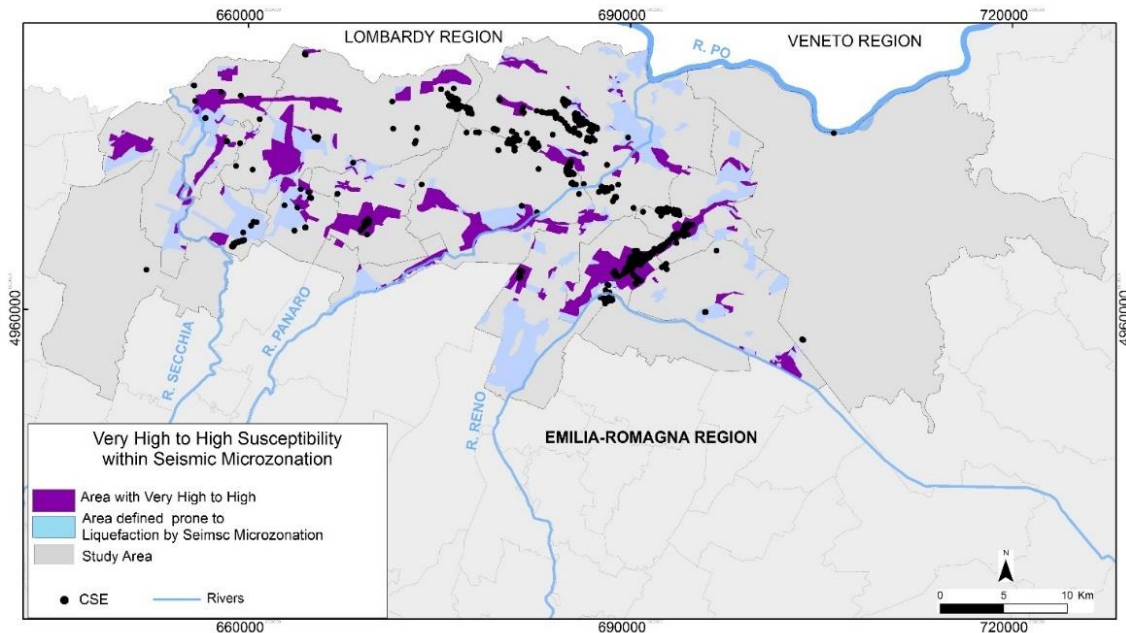


Figure 5.3.3.4-1 Map representing the spatial distribution of the CSE susceptibility obtained from the overlap of the three models considering the Very High and High classes compared to the official Seismic Microzonation of areas prone to liquefaction represented by the blue zones.

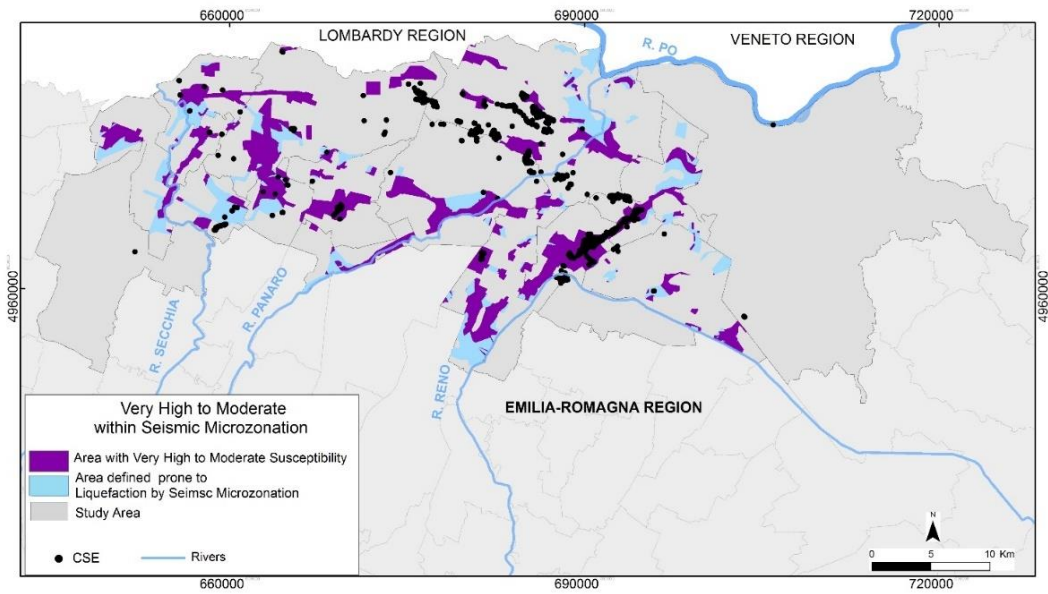


Figure 5.3.3.4-2 Map representing the spatial distribution of the CSE susceptibility obtained from the overlap of the three models considering the classes from Very High to Moderate susceptibility compared to the official Seismic Microzonation of areas prone to liquefaction represented by the blue zones.

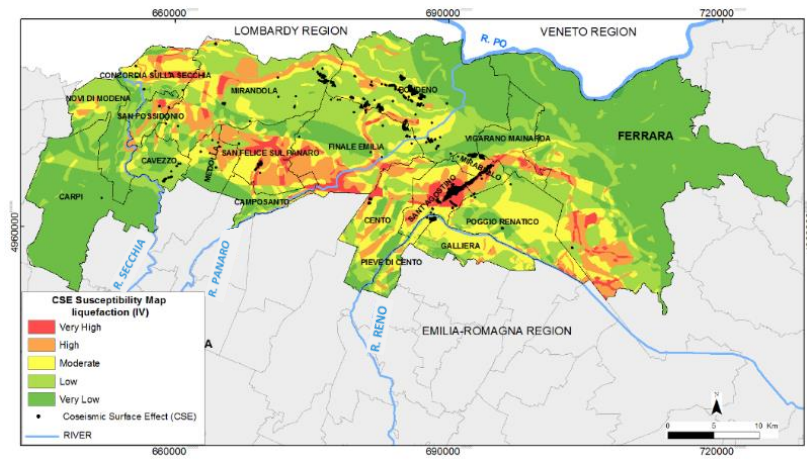
## 5.4 Results of the application of models with the type-specific CSE datasets

### 5.4.1 Type-specific CSE susceptibility using IV, WofE and LR models

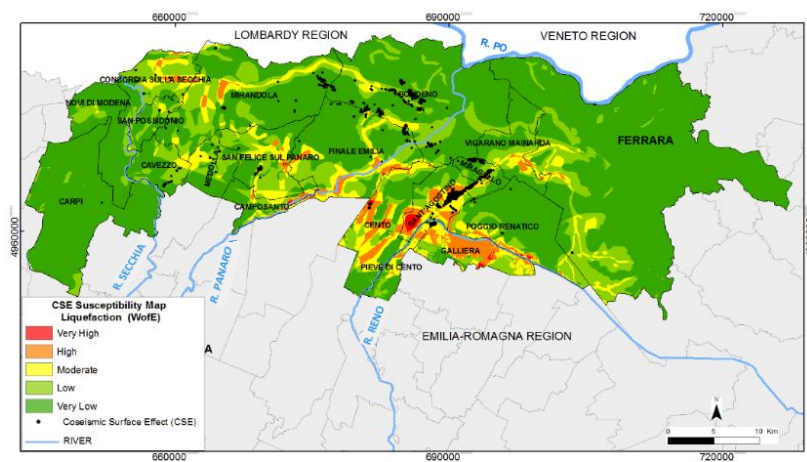
Susceptibility maps obtained with IV, WofE, LR by using specific CSE datasets (i.e. Liquefaction, Cracks, Cracks with liquefaction and, finally, other types,) are presented from Figure 5.4.1-1 to Figure 5.4.1-4.

It should be noticed, that these susceptibility maps have been classified in five classes (Very High to Very Low susceptibility) on the basis of the values returned by the models all over the study area. This is different from the subdivisions based on equal-area percentage used in the maps presented in the previous chapter.

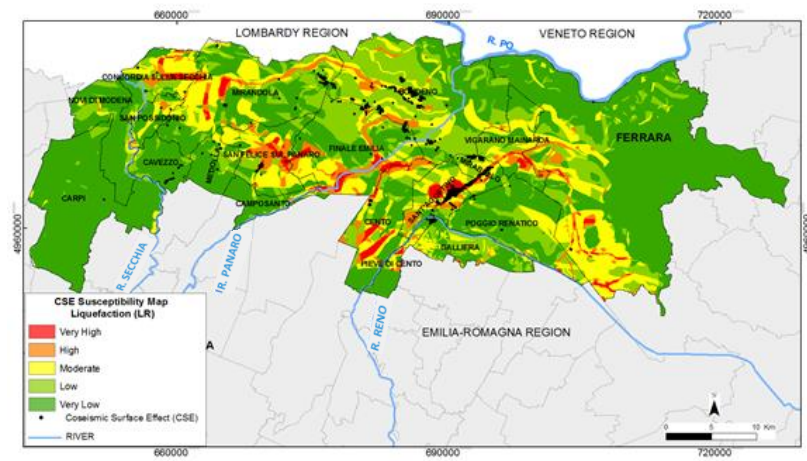
On a qualitative basis, it can be observed that models predict spatially the susceptibility with some discrepancy concerning the different types of evidence. For instance, for “liquefaction” IV allows to define wide area of very high and high susceptibility mainly distributed in the south part of the study area. Particularly the highest susceptibility appears associated to the fluvial landforms. The WofE and LR as moderated susceptible defines most part of those areas. For CSE type “cracks”, the three maps present more similar attitude in zoning the susceptibility. Considering this CSE typology, water table depth and distance to faults seems to have a particular influence on the phenomena spatial distribution. The higher susceptibility for CSE type “crack with liquefaction” appear mainly concentrated in the north part of the target area. For this type of effects, WofE discriminates only some Very high susceptible area in correspondence to the crevasse splay and to levee over a wide area of low and very low susceptibility. Susceptibility maps for CSE type “Other” define as zones prone to the phenomena the area corresponding to the Apennine levees environment in the most southern part of the study area.



a.

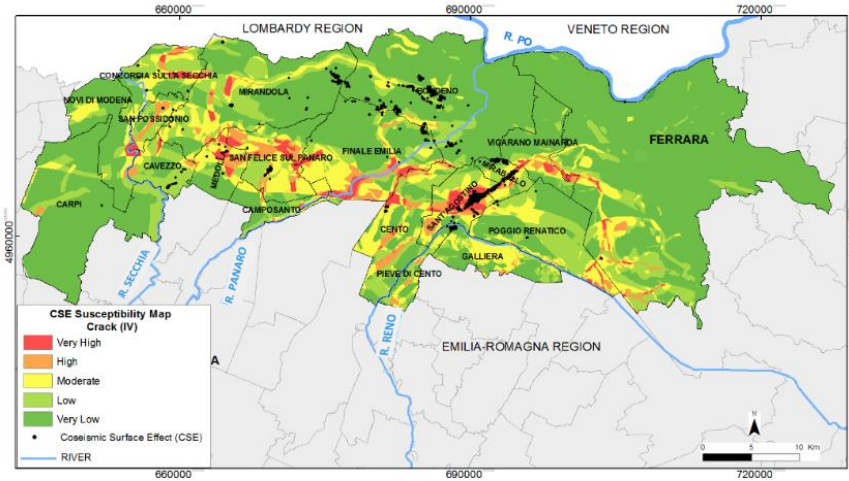


b.

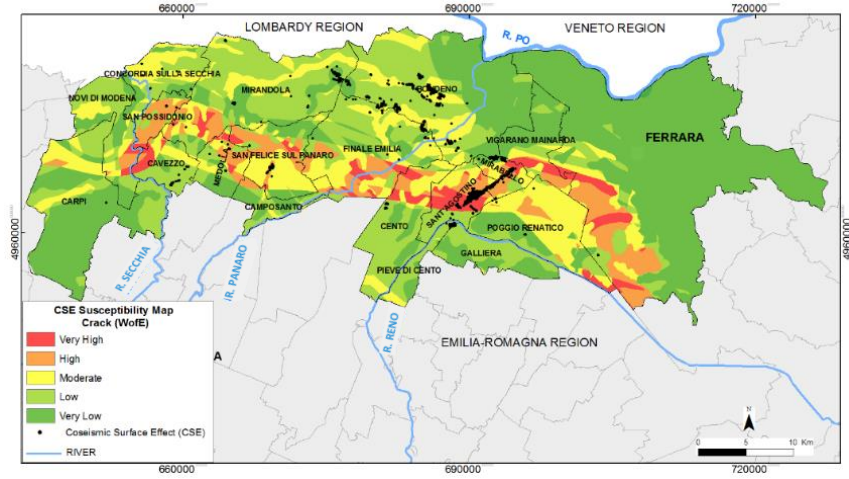


c.

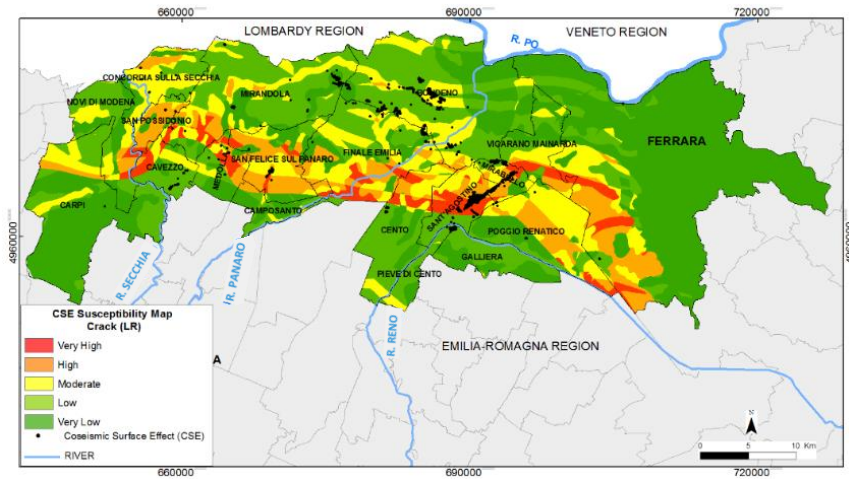
Figure 5.4-1-1 Susceptibility maps for CSE type: Liquefaction obtained with IV (map a), WofE (map b), LR (map c)



a.

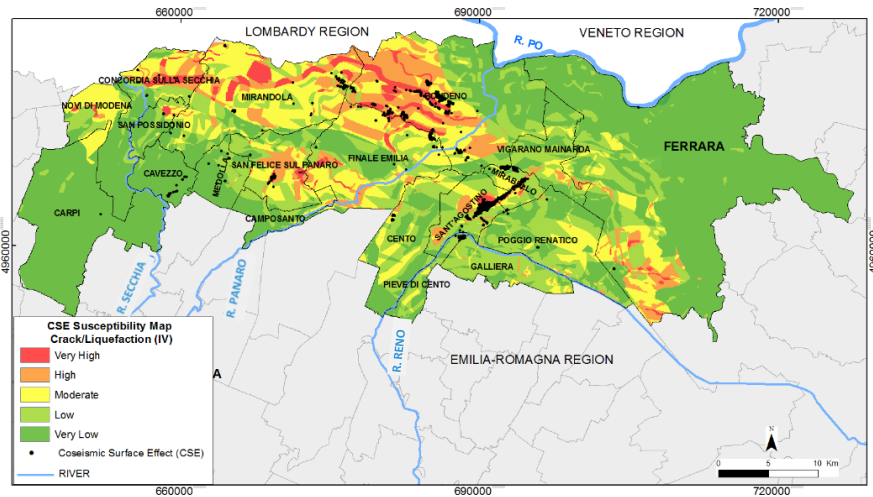


b.

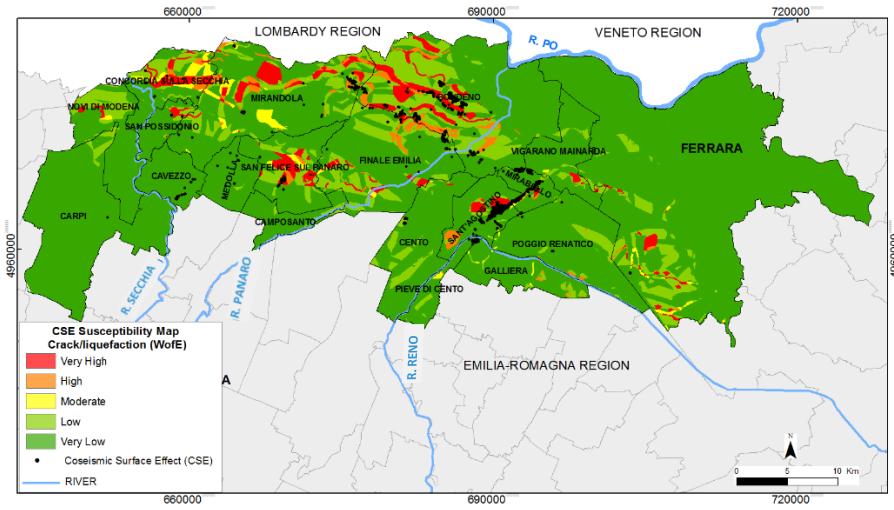


c.

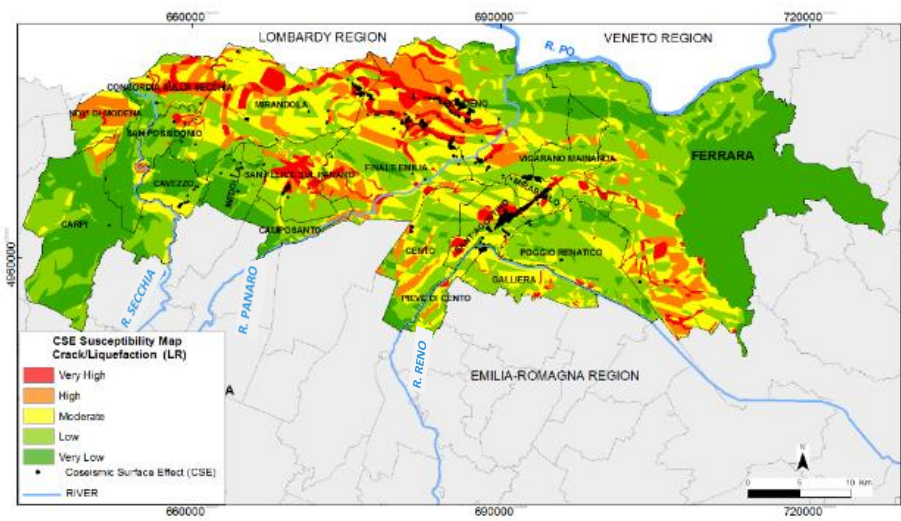
Figure 5.4.1-2 Susceptibility maps for CSE classified as Crack, obtained with IV (map a), WofE (map b), LR (map c)



a.

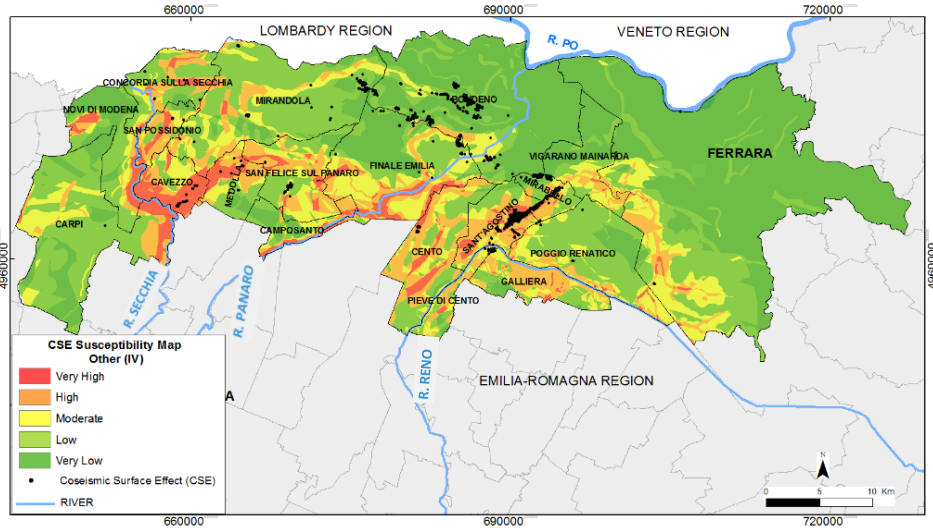


b.

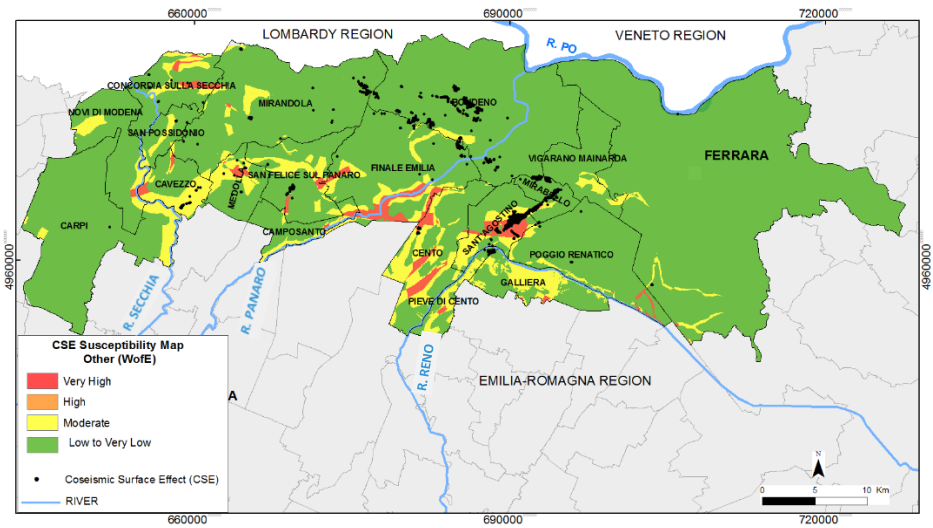


c.

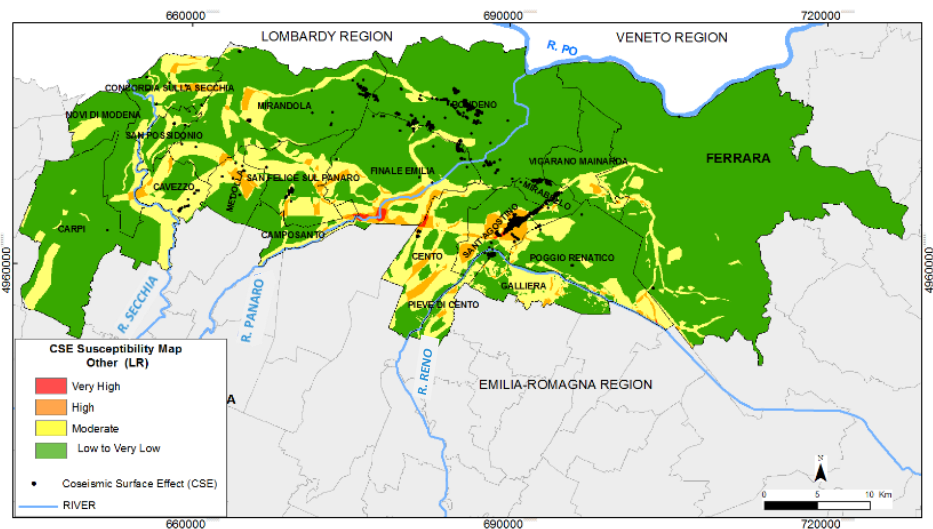
Figure 5.4.1-3 Susceptibility maps for CSE classified as Crack with liquefaction, obtained with IV (map a), WofE (map b), LR (map c).



a.



b.



c.

. Figure 5.4.1-4 Susceptibility maps for CSE classified as Other, obtained with IV (map a), WofE (map b),

### 5.4.2 CSE susceptibility models validation and comparison

Four predictive rate curve (PRC) were made in order to define the success and predictive capacity of the susceptible models related to CSE types liquefaction, crack, and crack with liquefaction and other (Figure 5.4.2-1). The shape of the curve is quite dissimilar within IV, WofE and LR models. The model with better predictive capacity for the highest classes of susceptibility is the IV. Within the 10% of the study area it allows to predict for liquefaction the 63% of evidences, with a little bit higher skills for crack and reaching the 90% for the category of Other. The lowest prediction within the first decile of area is related to Liquefaction and crack typology. One peculiarity concerns the WofE curve for this latter type of effect, for which the curve reach only the 45% of cumulate area.

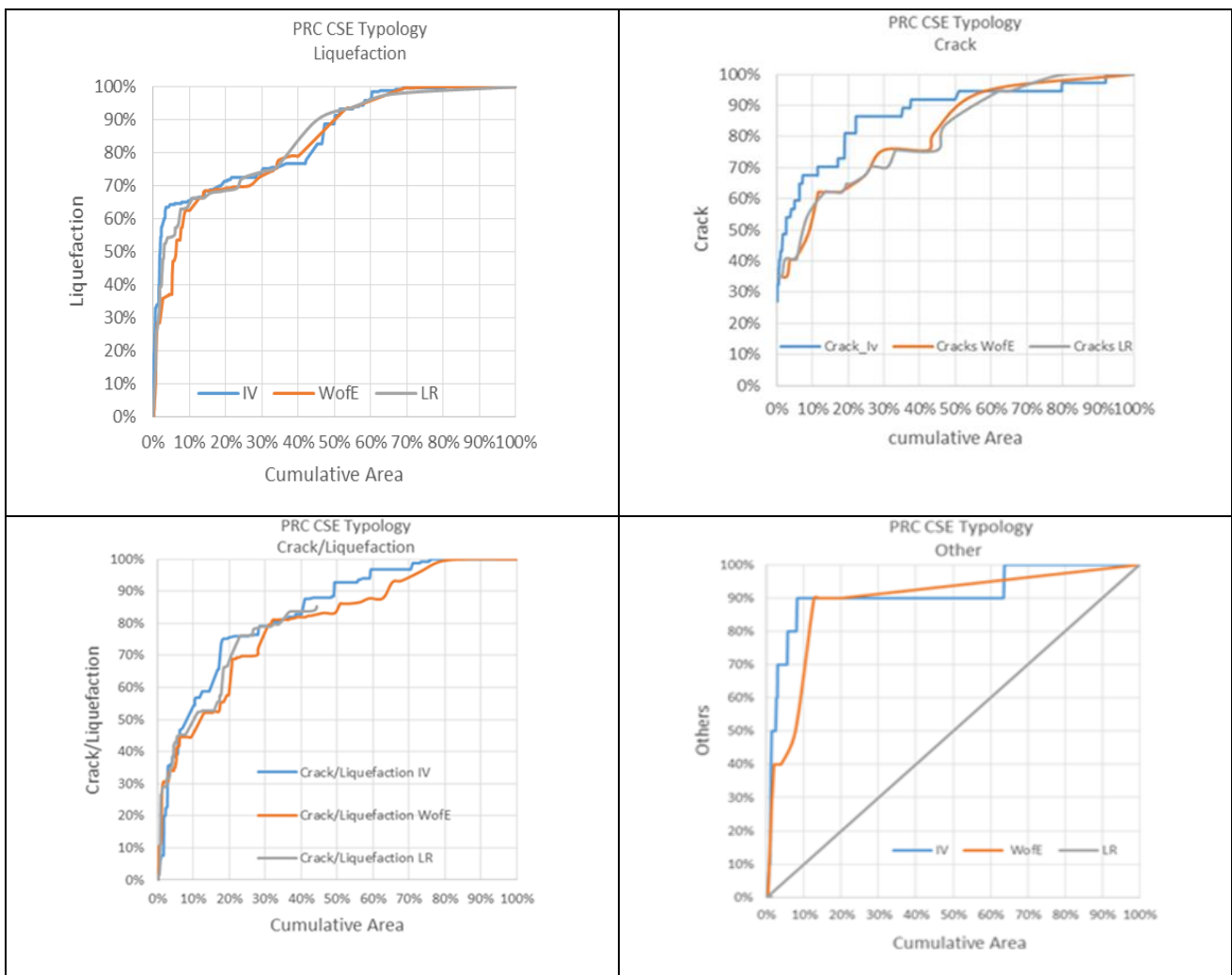


Figure 5.4.2-1 Models Prediction Rate Curve comparison for the four typologies of CSE.

Table 5.4.2-1 summarizes in a comparative way the results regarding the model prediction for of each CSE inventory run with the three models considered. Part of the analysis considering the results for the different typologies of effects have been previously done in concomitance with the susceptibility maps results presented for the whole set of CSE in order to appreciate the weight of the different casual factors (expressed by a value) and consequently their influence on the

phenomena. The classification of the susceptibilities maps has been done in a more conservative way, taking into account the first minimal inflection in the prediction curve plotted.

Looking at the effective ration that represent the real prediction ability of class, for all the CSE typology with all methods the Very High susceptibility class (that define the area extremely prone to liquefaction phenomena) seems to be the most accurate presenting value over 6 (Chung and Fabbri, 2003). Discrepancy in results are mainly associated to the effect classified as other.

liquefaction	IV			WofE			LR		
CLASSES	% of Area	%CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness
VERY HIGH	4	63	15.75	5	37	7.4	6	55	9.17
HIGH	20	71	0.5	16	67	2.73	25	72	0.95
MODERATE	45	89	0.72	40	79	0.86	45	89	0.85
LOW	63	98	0.5	69	99	0.69	66	93	0.19
VERY LOW	100	100	0.54	100	100	0.03	100	100	0.21
Crack	IV			WofE			LR		
CLASSES	% of Area	%CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness
VERY HIGH	8	67	8.38	4	40	10.00	4	40	10.00
HIGH	23	86	1.27	12	62	1.5	13	62	1.33
MODERATE	38	91	0.33	30	75	0.72	34	75	0.62
LOW	51	94	0.23	58	95	0.71	62	94	0.68
VERY LOW	100	100	0.12	10	100	0.11	100	100	0.16
Crack with I	IV			WofE			LR		
CLASSES	% of Area	%CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness
VERY HIGH	4	35	8.75	5	42	8.40	6	44	7.33
HIGH	18	74	2.79	20	69	1.80	23	75	1.71
MODERATE	41	87	0.57	33	81	0.92	53	93	0.90
LOW	65	96	0.38	65	92	0.50	73	99	0.30
VERY LOW	100	100	0.11	100	100	0.23	100	100	0.04
Other	IV			WofE			LR		
CLASSES	% of Area	%CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness	% of Area	% CSE predicted	Ratio of efectiveness
VERY HIGH	2	50	25.00	3	40	13.33	x	x	
HIGH	6	70	5.00	14	90	4.55	x	x	
MODERATE	8	90	10.00	100	100	1	x	x	
LOW	64	100	0.18	100	100	1	x	x	
VERY LOW	x	x	x	x	x	x	x	x	

Table 5.4.2-1 Class skills prediction for of each CSE inventory run with the three models considered.

ID	CSE TYPE	IV	WofE	LR
1	Liquefaction	0.84	0.79	0.84
2	Crack	0.87	0.80	0.80
3	Crack with liquefaction	0.84	0.79	0.82
4	Other	0.89	0.88	0.30

Table 5.4.2-2 values of AUC (expressed in 0-1 scale, i.e. 0.5=50% of the PRC) for the CSE susceptible models assessed through the Information value, Weight of Evidence, Logistic Regression and discriminated for each typology of effect.

From the results of the AUC comparison of table 5.4.2-2, it can be appreciated that almost all prediction rate curves show reasonably good accuracy in predicting the susceptibility for different typologies of effects in the study area. The LR AUC (0.30) for the typology of effects discriminated as “other” reveals the inability of the model to predict the particular type of phenomena in the study area. Two important assumptions may be related to this results; firstly, only 34 effects are classified in this category, moreover, the nature of these phenomena are more related to hydrological anomalies and may be less dependent to lithological or soil conditions. In fact, one important limitation for quantitative modelling is availability of inventories. Finally, the results highlight how bivariate multivariate methods can give different outputs, for the reason a comparative approach is necessary for any hazardous phenomena susceptibility evaluation.

## 5.5 Discussion

The aim of the study was to compare bivariate and multivariate analysis, precisely Information Value, Weight of Evidences and Logistic Regression methods, to evaluate liquefaction-based CSE susceptibility in the central part of the Po Plain. Here, on May 2012 the two main shocks, of a long seismic sequence, induced widespread CSE in the epicentral area. The outcomes obtained by the parallel application of IV, WofE and LR data-driven methods raise some points of discussion. The methods have provided acceptable results, expressed by Prediction Rate Curves, obtained using an independent validation dataset, showing an AUC above 80%.

Models indicated that the spatial distribution of susceptible zones is mostly controlled by fluvial landforms as crevasse splays, fluvial levees, and ancient riverbeds. This is in total agreement with more qualitative studies that indicate how the presence of paleo riverbeds, out-of channels fans were the main controlling factor for the occurrence of CSE phenomena during the 2012 seismic sequence (Papathanassiou et al. 2015). The medium to fine sandy lithology associated to these facies beside the shallow water table depth, represent the others main casual factors which are outlined in the distribution of susceptibility areas. The elevation provides a positive contribution to susceptibility prediction just in one class of altimetry that for the southern part of the study area appears associated mainly to the levees of fluvial geomorphological landforms. As shown in the output maps, the susceptible zones cover the central part of the study area, displaying two wide extremes areas (east and west zones) of low and very low susceptibility for all the maps produced. On the other hand, the central classes of susceptibility seemed to be more spatially scattered, showing also a higher degree of discrepancy between the models classification.

The existing body of research and the literature produced after the May 2012 earthquakes focused to assess the liquefaction potential at municipality level with deterministic methods. CSE-liquefaction susceptibility assessments assessed with geostatistical approach remains an open research field rarely tested.

During the last few decades, both deterministic and probabilistic conceptual understanding and procedures have remained strictly centred on liquefaction potential evaluations performed *in situ*. From site evaluations, the susceptibility assessment over large areas are generally based on interpolations methods, which contain intrinsic not liquefaction phenomena related generalization processes. In this sense, this work demonstrates that CSE susceptibility at regional scale can be assessed based on the statistical relationship between CSE evidences and a dataset of terrain variables assumed as CSE predisposing factors with good accuracy using bivariate and multivariate geostatistical data-driven approaches.

From a methodological perspective, this study has pretended to propose a contribution in the branch of CSE susceptibility evaluations at regional level. Considering the results obtained and the quality of the susceptibility maps produced within this study, IV, WofE and LR can be applied as assertive methods for susceptibility evaluations over large areas as first level of liquefaction analysis.

Beside the validated accuracy of the results that can be obtained, geostatistical data-driven methods demonstrate to be reliable, particularly for their low operational cost, and rapidity of

procedures. One of the advantages of the CSE susceptibility maps produced with the statistical approach deals with the capability to assess the susceptibility to CSE for all the study area, including also those areas that are not taken into consideration by the official microzonation cartography (areas outside urbanization planning). In addition, throughout the susceptibility maps, the approach applied allow to rapidly fulfil a synthetically overview of the phenomena at regional scale. Otherwise, the outputs consent to differentiate spatially the phenomena into different degrees of susceptibility within the municipality boundaries. Considering the degree of detail of maps, the susceptibility delineated resulted to be more precise than the first level of seismic microzonation studies (e.g. PTCP). If on the one hand by a conservative point of view cannot be directly applied to land use restrictions, it represents an useful cartographic reference during emergency or in planning long-term risk reduction strategies and should be considered as a part of the background knowledge documentation within the official seismic risk cartography.

These supporting reasons suggest testing the approach presented in this study in other seismic areas beyond Emilia, characterized by similar geological and fluvial dominated environments and potential liquefaction susceptibility proneness.



## 6 INVESTIGATION ON SEISMIC RISK PERCEPTION COMMUNICATION, AWARENESS AMONG COMMUNITIES WITH A FOCUS ON COSEISMIC SURFACE EFFECTS AND SEISMIC CARTHOGRAPHY

### 6.1 Introduction

Although risk perception research has a history of 40 years in Europe and North America, a single theory giving an integrative, empirically valid approach to understanding and explaining all the factors related to this concept is still missing.

Within the social sciences the term risk perception has become a conventional way of defining the personal and collective interpretations of hazards and risks. Cognitive, personal, emotional, situational, cultural and contextual factors have the major influence on risk perception (Sjöberg, 2000a). Because of its complexity, it is very difficult to deduce general statements or a general theory of risk perception (Wachinger & Renn, 2010). Risk perception has been examined using various methods concerning different risk levels (individual personal risk or risk for the general society), by means of different measures (magnitude of risk, overall risk rating, probability of an event, estimated fatalities per year) and dimensions such as probability of damage, personal death/injury, property loss, social disruption (Rohrmann, 1999; Sjöberg, 2000b; Lindell & Perry, 2000).

Several approaches have been formulated in research works, aiming to analyze the dimension of risk perception: the psychometric paradigm (Fischhoff et al. 1978a; Slovic, 1987, Slovic, 1992), the cultural theory of risk perception (Douglas & Wildavsky, 1983; Thompson et al., 1990; Dake, 1991, Dake, 1992), trust-oriented concepts (Slovic, 1993; Siegrist, 2000a; Siegrist, 2000b, Siegrist, 2000c), the mental models approach (Lave & Lave, 1991), concepts to including associations and affects (Peters & Slovic, 1996), demographic variables (Savage, 1993; Barke et al., 1997), gender perspectives to name a few (Gustafson, 1998; Greenberg & Schneider, 1995).

The psychometric paradigm alongside the cultural theory paradigm are the two most influential theoretical paradigms within this subject of research. The psychometric model, arising in the 1970s (Fischhoff et al., 1978), bases its actions on acquiring data through cognitive maps of risk perceptions and attitudes, relying heavily on statistics, scaling and metrics to represent a stable measurement of risk perception. Some of the most important factors which control risk perception are: fear of a certain risk, number of people affected by a risk, and if the risk is known or unknown. The psychometric paradigm seeks to bring forward a set of general properties that become the hallmarks of a risk object, which helps in building individual perception of that specific object

(Sjöberg 1996 in Oltedal et al.2004). Besides the subjective nature of risk perception, as it is influenced by a social and cultural environment, the psychometric paradigm wants to highlight the importance of survey instruments (Sjöberg, Moen and Rundmo 2004) as a means of quantifying risk perception. The cultural theory paradigm, on the other hand, stresses the anthropological elements affecting the individual, focusing on one's relationship with one's milieu (Oltedal et al. 2004). Researchers assert the fact that risk is "a social construct" and that people coming from diverse backgrounds will automatically have a different concept, judgement and tolerance of risk. Otedal et al. (2004), explore the way in which cultural biases affect individuals and how social activities shape the individual from a psychological point of view.

The approach adopted in this study can be placed within both psychometric and cultural theories of risk approach, with additional aspects related to the estimation of the importance of scientific knowledge and the significance of cartographic representation in risk understanding.

This chapter directs the attention towards the connection between risk perception and communication. Communication has a strong power in shaping collective perception of hazards and risks; on the other hand, good communication processes should consider public perception to define effective strategies and the content of messages which would be generated. Mental models and other psychological mechanisms that individuals use to judge risks (such as cognitive heuristics and risk images) are internalized through social and cultural learning and constantly moderated (reinforced, modified, amplified, or attenuated) by media reports, peer influences and other communication processes.

To understand risk perception, it is required to consider several social, psychological and cultural ambits, as well as interaction among them (Wachinger & Renn,2010); this implies a methodological approach able to translate the plurality of variables in measurable values to support the study (Crescimbene et al., 2014).

With this scope, the questionnaire represents a valid method of investigation, able to translate qualitative responses and conceptual aspects in quantitative data. The structure of the questionnaire prepared for the survey has been built with the collaboration of INGV. Indeed, items and questions of the first two sections, have been formulated based on the questionnaire about seismic risk perception promoted by INGV at national level, which is mainly constructed on the semantic differential method proposed by Osgood et al. (1957).

The main goals of section 6.3 of this chapter deal with an investigation of seismic risk perception within the Emilian population, with the aims of understanding firstly how the seismic experience

has influenced the perception of seismic risk in the Po Plain and secondly, of providing an overview of the perception of Emilian community about seismic hazard and risk with respect to other possible natural hazards of the area. The core of the analysis is directed towards the evaluation of the following three topics:

- The role of geoscience knowledge in addressing people to a correct perception of local hazards and risk;
- The importance and the request of seismic information within the public;
- The significance of seismic cartography in risk communication process.

Risk communication found out in literature is best summarized by definitions such as the following one: *“Any purposeful exchange of information about risks between interested parties”* Lang, Fewtrell and Batram (2001). The key role of mass media during emergency situations has been highlighted by several authors (e.g. Lombardi, 1993; Scanlon & Alldred, 1982; Turner et al., 1980; Wenger et la., 1980). The importance of the newspaper, radio, television and social networks in risk communication has become a central topic to appreciate the cognitive universe of meanings which influences risk perception and may direct people’s responses, decisions, and further actions.

Risk communication can be described as: *“An interactive process of exchange of information and opinion among individuals, groups and institutions. It involves multiple messages about the nature of risk and other messages not strictly about risk, that express concerns, opinions to risk messages or to legal and institutional arrangements for risk management”* (US National Research Council, 1989).

The ultimate goal of risk communication should be to keep the public risk informed, providing accurate information about hazards and risks understanding, in order to make sustainable choices and enhance resilient actions (Hance et al. 1988, Bbreakwell 2007, Atman et al., 1994). It is a crucial matter for the public to get information about risk and risk management to be fully aware during any hazardous events, for implementing strategies directed to the personal and collective safety (Veland and Aven 2012).

Furthermore, Lang, Fewtrell et.al. (2001) specify possible roles or functions concerning risk communication:

- Explanation role: to improve risk understanding among target groups.
- Right-to-know: to divulge information about hazards to those who may be exposed.
- Attitude modification role: to legitimize risk-related decisions, to improve the acceptance of a specific risk source, or to challenge such decisions and reject specific risk sources.

- Legitimate function: to explain and justify risk management routines with the intention of enhancing trust in the competence and fairness of the management process
- Risk reduction role: to enhance public protection through information about individual risk reduction measures.
- Emergency readiness role: to provide guidelines or behavioral advice for emergency situations.
- Public involvement role: aiming at educating decision-makers about public concerns and perceptions.

Indeed, risk communication represents a public reference framework for enhancing people's capacity to understand local hazards and risks. The aim should be the promotion of adaptive strategies at individual, social and organizational level for sustainable resilient behaviors among communities. This "double way" process linking information and public perception, implies that for risk mitigation measures and adjustment behavior, knowledge about potential risk perception is mandatory.

Earlier studies have discussed that risk communication can be improved between authorities and the public when fulfilling the following aspects (Sandman 2012):

- Make the risk more familiar to the public.
- Acknowledge the way that the risk is memorable and explain the bad news and mistakes made.
- Increase public's knowledge about the risk.
- Share the control and the information with the public.
- Build trust among the public.
- Respond to the public openly.

During the last decades, the media has assumed an increasing and priority role in risk information and communications, with the power of reaching a broader public. In this context, during an emergency period, media communications are the primary source of information which many people rely upon (Cowan et al., 2002; Piotrowski & Armstrong, 1998). The dissemination of information can engender important positive effects as stated above, or on the other hand, the language of the message (vocabulary) adopted by the media, can bring the intention of communication in an opposite direction, depending on the real scope of the message (in the case of

newspapers) and also on the modality of framing events (Vasterman et al, 2005). Amplification or attenuation of information associated with risks may produce social ripple effects (as with the misinterpretations associated to CSE). Usually media tends to focus on the sensational aspects of a natural disaster, drawing the attention on primary losses and damages rather than communicating the information of a specific hazard using accurate, scientific terminology. Media contents have the tendency to overemphasize the consequence on the population. News reporting often relies on eye-witness reports rather than stating the opinions and knowledge of experts, which are sometime contemplated to give greater credibility to message (Walters & Hornig, 1993). On the opposite, sometimes media report statements from scientists and experts to support their messages giving more credibility to the message.

Concerning the communication of seismic risk, the following part of the work has intended to investigate the language of the articles taken from online newspapers during the emergency period (May-September 2012) to figure out the real communicative purpose. With this intention, the research focuses on the semantic of seismic hazard and risk in local newspapers.

The goal is to assess if the information has been transferred by use of a scientific semantic, and if it was supported by scientific content with the intention to provide a communication seeking to disseminate reliable and educational content on seismic hazard and risk or whether the aim is to restate generic information about the seismic event.

## 6.2 Analysis of information sources

### 6.2.1 Methods: Online Newspapers during Emergency Period

- Newspapers

The scope of this part of research is specifically addressed to analyze the language, the “vocabulary of risk”, within the most popular online local newspapers of the provinces hit by the 2012 earthquakes and published on <http://quotidiani.gelocal.it>.

During emergency, the language adopted by communication channels is highly influential, having the power to shape the cognitive universe by translating reality into images and words. In this sense, the media has the power to select, direct and amplify information using words and pictures which, more or less consciously, are integrated into the common popular cognitive vocabulary. The interpretation of reality, far from being solely the result of subjectivity, is also based on external inputs that contribute with a semantic multiplicity to direct (or confuse) the audience. For this reason, this study has investigated precisely how the newspapers informed citizens during the emergency period of the Emilia earthquake in 2012.

The study has analyzed the online version of local newspapers from May 20 to September 20, by counting the number of citations in articles of online newspapers. The research has explored how the newspapers have reported the earthquake during the emergently period, considering the following information sources: *La Gazzetta di Modena*, *La Nuova Ferrara*, *La Gazzetta di Reggio*, *La Repubblica di Bologna*, *La Repubblica di Parma*, *La Repubblica* (as national newspaper). Tierney et al. (2006) suggested how mass media can play a significant role in promulgating erroneous beliefs during disasters. From the methodological point of view, the investigation has looked at the presence of the following terms: earthquake, seismic sequence, magnitude, fault, fold and liquefaction.

The purpose of the investigation was to detect the relevance of scientific language during the seismic event communication in 2012. Moreover, for the articles relating the occurrence of CSE-liquefaction in the area the study focused on the entire content of the article which has been discriminated in one of these three groups based on different semantic categories: scientific, emphatic, deceptive. The scope was to evaluate whether the informative content had been explained using specialized, scientifically consistent language or if more recurrent words have been used instead, describing the event in a simple, common language without considering any informative scope or involving any processes of sharing information about seismic hazards.

### 6.2.2 Results: Newspapers

The study has adopted a quantitative approach by counting the number of times that one of the six terms appeared in each newspaper articles, which have been published from the 20<sup>th</sup> May 2012 until the 20<sup>th</sup> September 2012, as illustrated in table 6.2.2-1. A total number of 20847 citations were found in the articles published, within a mean of 1.700 articles (by estimation). It is possible to assert that the generic term of earthquake is the most representative one (12.705 citations and a mean value of 2541 citations), followed by seismic sequence (7234 citations with a mean of 1446 citations). The frequency of the terms magnitude, fault, fold, liquefaction appears much lower. Indeed, the use of terms which belong to a specific scientific language have appeared less frequently in the text of articles. The chart of Figure 6.2.2-1 expresses the frequency of key terms in percentage values.

Month	Earthquake	Seismic Sequence	Magnitude	Fault	Fold	Liquefaction	Tot.	Mean
May	1.236	622	131	82	4	20	2.095	349
June	4.450	2.244	254	80	10	35	7.073	1.179
July	3.136	1.884	84	13	1	19	5.137	856
August	1.954	1.302	58	8	-	14	3.336	556
September	1.929	1.182	79	6	-	10	3.206	534
<b>Tot.</b>	<b>12.705</b>	<b>7.234</b>	<b>606</b>	<b>189</b>	<b>15</b>	<b>98</b>	<b>20.847</b>	
<b>Mean</b>	<b>2.541</b>	<b>1.447</b>	<b>121</b>	<b>38</b>	<b>3</b>	<b>20</b>	<b>4.169</b>	

Table 6.2.2-1 The table reports the number of citations related to the seismic key terms selected which appeared from May to September 2012 within all articles of the newspapers which have been chosen. Total and mean values are stated regarding the selected terms and for the months taken into consideration.

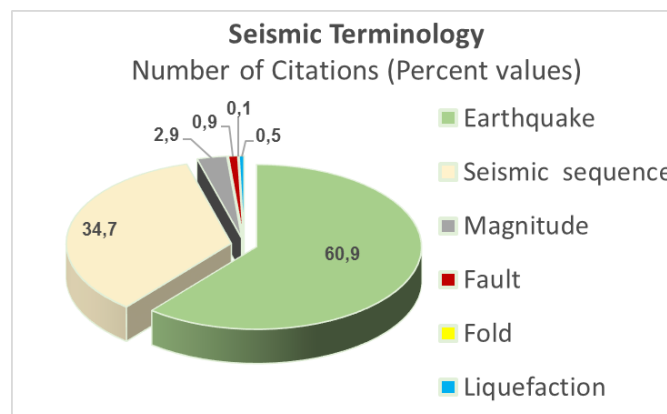


Figure 6.2.2-1 Number of citation in percent value for each type of terms investigated.

Considering each newspaper, from a total number of 20847 citations, about 46% belong to the *Gazzetta di Modena*, 45% to *La Nuova Ferrara*, with the remaining 26% belonging to the *Gazzetta di Reggio* (6.2.2.-2).

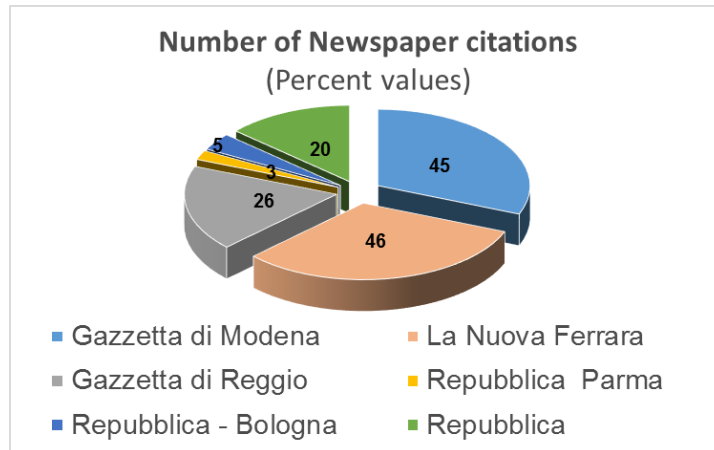


Figure 6.2.2-2 The six newspapers considered in the analysis. The chart represents the number of citations in percent values for each newspaper title.

The chart of Figure 6.2.2-3 shows the trend of citations based on the temporal variable. It is significant to note that the peak of citations, of all six aforementioned terms, is reached in the month of June 2012. To understand their distribution over time, the chart of Figure 6.2.2-4 summarizes the terms in percentage values calculated for a period of four months.

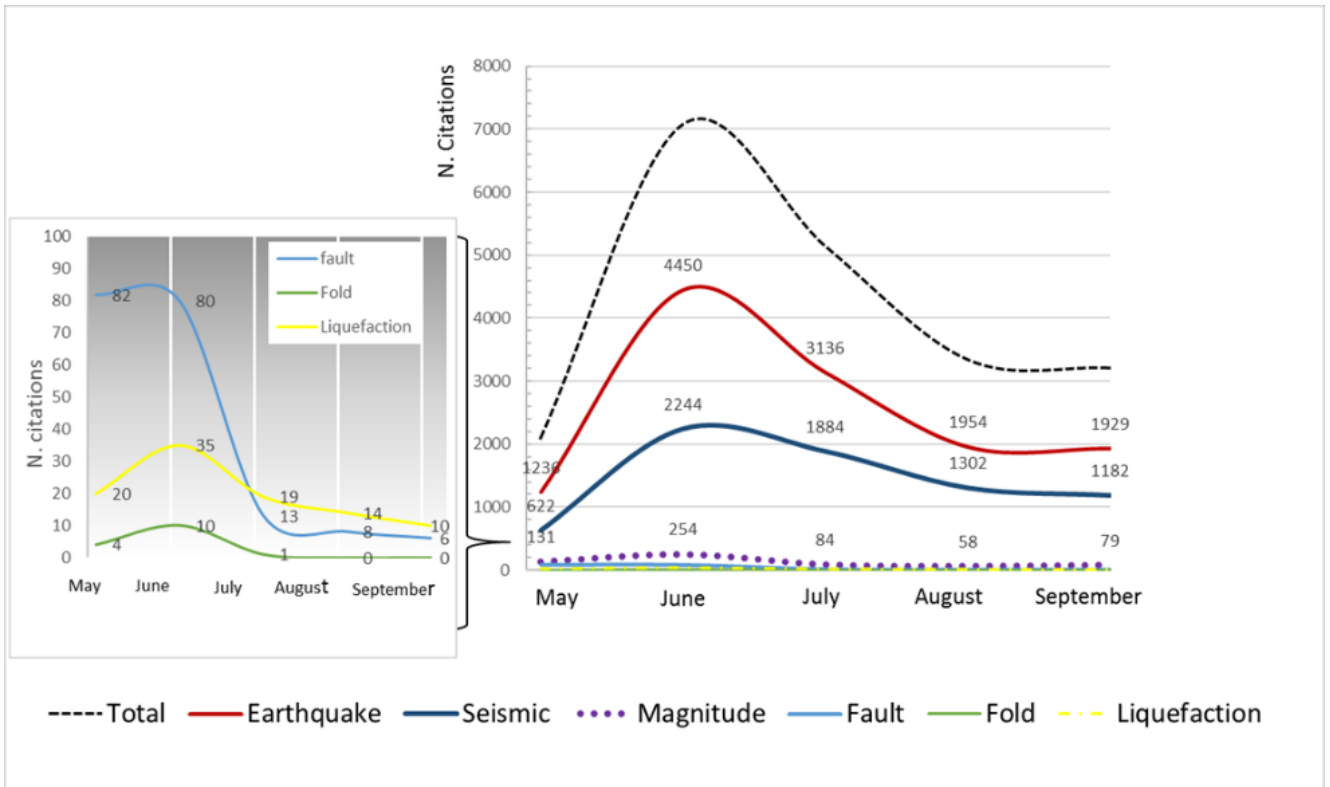


Figure 6.2.2-3 The chart displays the distribution of the seismic terminologies cited in absolute numbers along the four months.

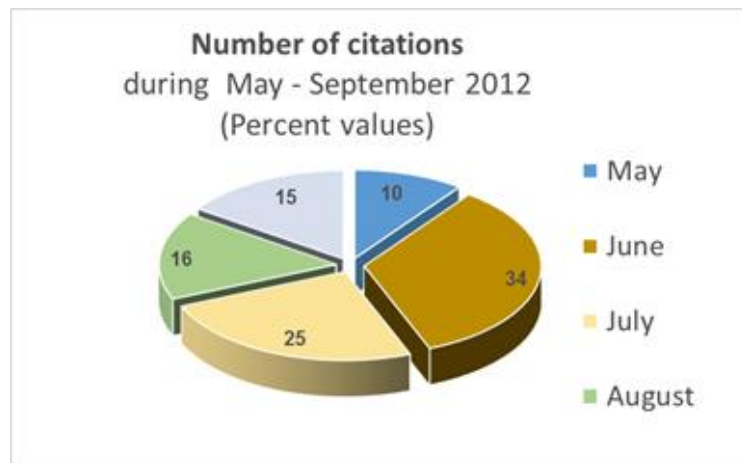


Figure 6.2.2-4 The aerogram displays the total citations in percentage values in the period between May and September 2012.

Focusing on the differences in the use of the language within the different newspapers, it is possible to state from the figure below, that the terms earthquake, seismic sequence and magnitude are the most quoted in the articles (6.2.2-5). The sharp difference with the other terms more related to the geosciences language is quite evident. The percent distributions in the chart consider the absolute frequency distribution of citations; indeed, it is influenced by the number of articles and quotations presented in the newspaper. *La Nuova Ferrara* presents the peak values for

the more general terms as earthquake and seismic sequence, then the distribution shows a more homogenous trend of values.

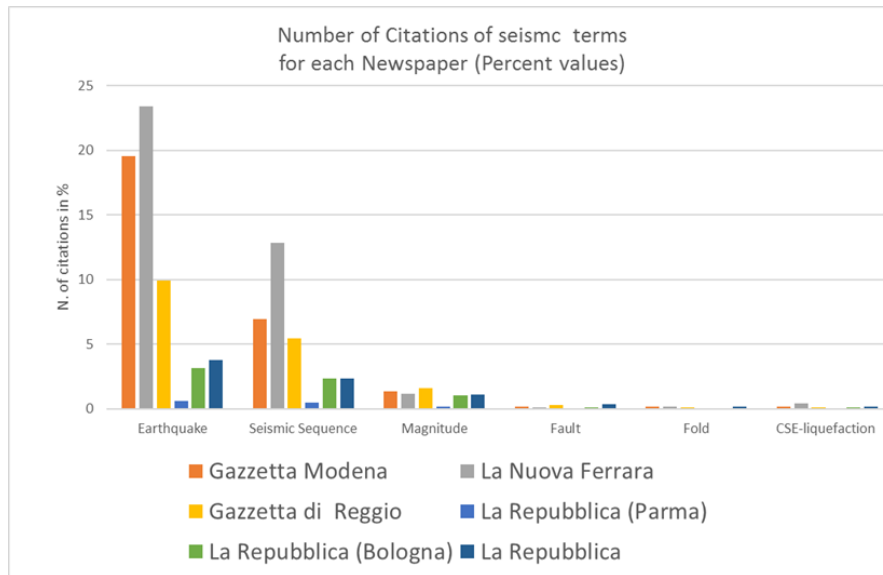


Figure 6.2.2-5 Percentage of seismic key terms quotations of the six newspapers.

Further, the study also sought to compare the relative distribution of citations per key terms within each newspaper (in percent values). From the chart of Figure 6.2.2-6 it is possible to appreciate how the newspaper with fewer citations in absolute terms, showed a more scientific language, reporting higher frequencies of terms related to the scientific semantic sphere. For instance, “magnitude” is more cited by *La Repubblica di Bologna* than by *La Repubblica* and by *Repubblica di Parma*. The terms fault and folds were more cited by *La Repubblica di Parma* and *La Repubblica*, which have displayed a highest percentage also for the CSE-liquefaction quotations. It was possible to assert that despite the highest difference in number of citations, for the scientific terminologies (fault, fold, CSE-liquefaction), all newspapers in general reported lower values and a more homogeneous trend.

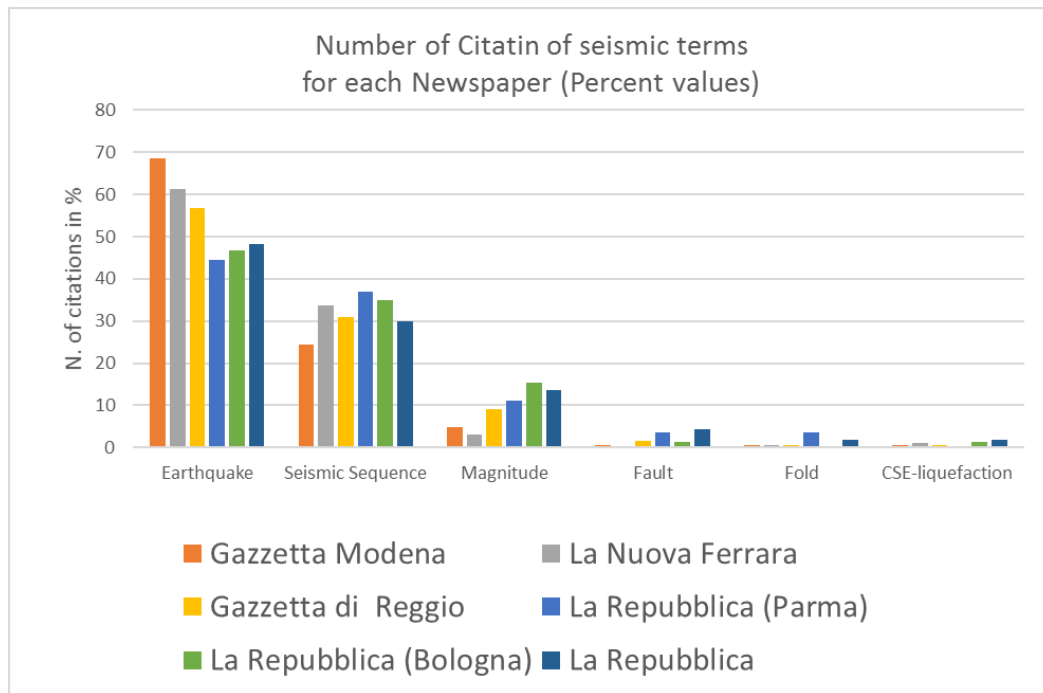


Figure 6.2.2-6 Histogram representing the distribution of citation within each newspaper in percent values.

In this context, the research has paid a specific attention to the 83 articles concerning the information on CSE- liquefaction phenomena. Changing the approach, in the second part of this chapter, the research focused on seismic risk communication analyzing the entire content of those articles concerning CSE- related liquefaction. Table 6.2.2-2 illustrates the distribution of the articles of three newspapers: *Gazzetta di Modena*, *La Nuova Ferrara*, *La Repubblica*. The analysis was performed based on the discrimination of the content of the entire article within the three semantic main categories:

- Emphatic content: the main vocabulary is functional to the amplification of aspects related to fear, uncertainty, with the intention to attract readers to look at the article.
- Deceptive content: the vocabulary is generic and within the text of the article many topics are treated approximately without giving any essential and useful information about seismic hazard or seismic risk.
- Scientific content: the subject of the article is described in scientific terms and reports direct interviews with scientists to better clarify and inform people about seismic hazard and risk with explanations of the causes of the phenomena.

	Gazzetta di Modena	La Nuova Ferrara	La Repubblica	Tot.
<b>Emphatic</b>	4	4	2	<b>10</b>
<b>Deceptive</b>	16	18	2	<b>36</b>
<b>Scientific</b>	23	10	4	<b>37</b>
<b>Tot.</b>	<b>43</b>	<b>32</b>	<b>8</b>	<b>83</b>

Table 6.2.2-2 Frequency of terms related to CSE.

As stated previously, according to the content of the articles, these have been classified within three semantic categories. As displayed in the two chart below, the number of articles in the three newspapers have shown a higher number of scientific articles for the *Gazzetta di Modena* (around 70) while the “La Nuova Ferrara” has presented a higher number of articles with a more general and mixed information. For the national newspaper, *La Repubblica*, looking the highest number of articles belonging to the semantic category the emphatic articles reach 20% of the total number of articles. In chart of Figure 6.2.2-8, the percentage values indicate the relative subdivision of the articles from each newspaper in the three semantic categories. When considering CSE-liquefaction phenomena, the *Gazzetta di Modena* presents almost 60% of articles with scientific content, while the *La Nuova Ferrara* has reported the information concerning coseismic effects in more general way. The scientific approach only touched 20% of its articles, while *La Repubblica*, being a national paper, was not so focused on these local geological surface manifestations, which arose a lot of interest within the Emilia-Romagna Region (see Figure 6.2.2-8).

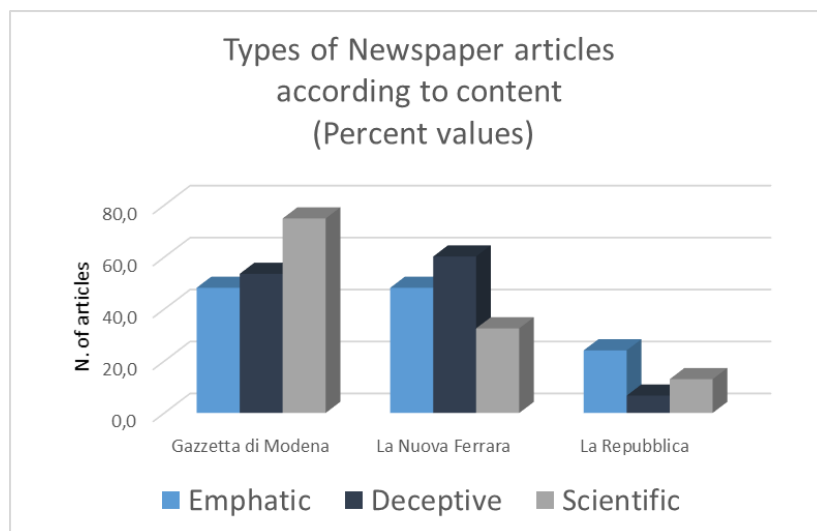


Figure 6.2.2-7 Number of newspaper articles in percentage values according to the three main categories to which their contents are ascribed.

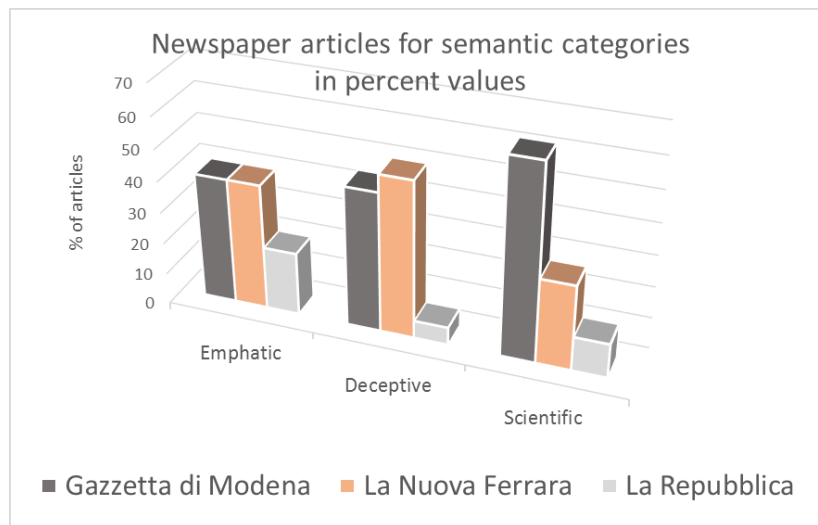


Figure 6.2.2-8 Percentage value of CSC citation for each newspaper

In this context, it was interesting to present one article (Figure 6.2.2-9) reporting the description of CSE-liquefaction occurrences. While carefully analyzing the *Gazzetta di Modena*, it is possible to recognize several terminologies used with the intention of emphasizing the phenomena. Starting from the article the expression “it is the old Panaro river that is coming up again” generates a sort of amplification of the event, ignites an emotional response by causing feelings such as fear for the huge magnitude of the seismic occurrence.

Moreover, are herein translated expressions such as:

- “sparando” (shooting),
- “viscere della terra” (bowels of the earth),
- “fenomeno preoccupante” (worrying phenomenon),
- “misteriosa collinetta” (mysterious little hill).

The expressions above mentioned in the article described the CSE phenomena inferring a sense of alarmist tone. The real risk, in this case the severity of the effects is emphasized. Although the article gave a scientific explanation of the liquefaction phenomena, also reporting the words of the experts, the “semantic of fear” prevails with strong emotional intent.

The last sentence of the article describes the 2012 seismic event through a vocabulary abundant in negative words: impossible, improbable event, moreover it describes it as a devastating earthquake without offering reassuring interpretations.

**G7 local**  
**GAZZETTA DI MODENA**

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Sei in: Archivio > Gazzetta di Modena > 2012 > 05 > 23 > I geiger? ...

## I geiger? È l'antico Panaro che riemerge

SAN FELICE Sono una ventina i geiger che stanno "sparando" sabbia dalle viscere della terra a San Felice. Un fenomeno al quale si sta dedicando una squadra di tecnici e scienziati inviata a San Felice dall'Istituto Nazionale di geofisica e Vulcanologia. «Si tratta di un fenomeno chiamato "liquefazione" - spiegano in questa prima fase - In questo sottosuolo c'è sabbia, quando la pressione dell'acqua aumenta a causa di un evento sismico, l'acqua che non è comprimibile "dirada" la terra o la sabbia che la circonda. Si tratta di un fenomeno che diventa preoccupante quando avviene in prossimità di strutture o infrastrutture, cui possono mancare così le basi di appoggio, perchè il terreno perde consistenza». Il caso di San Felice è stato notato da Ingv dalla pubblicazione on line delle immagini, che mostravano la misteriosa collinetta sorta in mezzo allo stadio comunale, oggi reso inabitabile da queste collinette di sabbia, che hanno danneggiato anche la pista di atletica. Di queste collinette, in giro per il paese, ne sono state trovate parecchie: in giardini privati, alla stazione... «Ne stiamo cercando altre, per farci una idea complessiva», spiegano gli esperti, che ieri hanno collaborato con l'archeologo, Paolo Campagnoli, per sovrapporre alla mappa dei "gaiger" quella dei paleoalvei. La sabbia "liquefatta" e sotto pressione cerca infatti vie di fuga che prediligono i pozzi, o in alcuni casi le fratture del suolo, infine i vecchi alvei del fiume. Ed è proprio pensando alla "riemersione" dell'antico alveo del fiume Panaro che è stata tracciata una linea del fenomeno, da sud ovest a nord est. I tecnici hanno chiesto ai cittadini di segnalare eventuali fenomeni analoghi non conosciuti, da repertare o documentare. In questi giorni poi si trasferiranno nelle altre zone terremotate: a Dosso di Sant'Agostino le liquefazioni hanno infatti interessato molte abitazioni private. L'istituto di geofisica peraltro ha inviato nella Bassa anche altre squadre, per chiarire e studiare con strumentazioni di rilievo lo sciami sismico. E forse anche per capire meglio un fenomeno che molti consideravano impossibile, improbabile: ovvero un terremoto devastante, ben oltre le rassicuranti interpretazioni degli ultimi tempi. (ase)

23 maggio 2012 | sez.

Figure 6.2.2-9 Example of article referring about CSE occurrences.

### 6.2.3 Discussion

Risk communication became essential during disaster occurrences, in particular during the most critical emergency period, along which the population suddenly loses daily life circumstances by experiencing a phase of rupture, which changes their reality by inducing a state of fear, uncertainty, and insecurity. Mass media reporting's play an important role in the communication of natural disasters and contributes to shaping people's perception about risk and about the emergency contest. The public dissemination of information became fundamental for a better understanding of emergency situations and it shows to be positive when it guides and orients the public to develop a feeling of trust towards institutions, enhancing their sense of belonging to the community. The public communication through media can also have negative effects. The media tends to focus on the sensational aspects of a natural risk, including the number of losses and damage to buildings and infrastructure, rather than communicating the types of distinctive messages that promote knowledge and preparation. News reporting often relies on eye-witness reports rather than stating the opinions and knowledge of experts (Walters & Hornig, 1993).

During a seismic sequence, the newspapers, as well as other actors and the media, have all carried out a double function: the first is conveyed information about the "riskscape" and then, to orient the seismic perception among readers. Considering the temporal aspect, in the study the citations have shown a peak in June 2012. This could signify that the interest for the hazard in scientific terms (earthquake and CSE) is not immediately evoked and it also arose few weeks after, probably because the media attention during the days of strongest quakes was more oriented to relate the damages and consequences of the event. In relation to the vocabulary that has been selected, the most generic terms of earthquake and seismic sequence have been more recurrent than the more specific ones concerning the geological and seismotectonic aspects of the seismic hazard (faults, folds, magnitude). The number of citations were on the other hand proportional to the number of articles dedicated to this topic. The highest frequency of quotations belonged to the local newspapers *Gazzetta di Modena* and *La Nuova Ferrara*. It can be correlated to the geographical proximity, in fact the 2012 earthquake hit principally, the districts in the provinces of Modena and Ferrara.

The geographical proximity to a hazardous event or disasters always increases a stronger echo. From the observations made in this chapter, it was possible to deduce that information tends to become more simplistic in terms of attention of terminology moving away from the time of impact and the event itself. The language used to communicate events can often exploit the uncertainty of

the situation and start a process of change in meaning, which leads to alterations in the purpose of information. It generates a privileged position for creating persuasive messages which amplify the event, thus capturing the attention of its readers (Lombardi, 2005). On the other hand, the interrelation between the media and society is iterative: society is influenced by the media, but the media is also influenced by society. The study about semantic in disaster communication turns into an interpretative filter of the emergency, which is partially created through the construction of meanings offered by media.

The frequency of certain terms (emphatic, scientific, deceptive) in the description of CSE has allowed to understand the importance of the scientific language in clarifying the triggering and predisposing factors of such phenomena, although the semantic related to the mystery, to the fear tends to prevail having a strong power of attraction within public.

The possible impacts of mass media language on the civil population wasn't enough explored during the 2012 seismic event. The semantic and use of images tend to assume a great importance on the population perception during precarious situations such as emergencies. This thesis has explored and brought into light some aspects that have not been examined closely during the 2012 earthquake.

## 6.3 Analysis of questionnaire

### 6.3.1 Method: Questionnaire structure and target groups

The study conducted in the aftermath of the 2012 seismic sequence (from July 2014 until November 2015) dealt with the investigation of the seismic risk perception and the seismic awareness in the social context of some Emilian provinces. Specifically, the research involved two different target groups reached through an online survey: the youth generations, represented by a selected sample of students of secondary and high schools, which have been discriminated based on their location inside or outside the epicentral area (see list of institutions in appendix A).

The population that has been herein identified as “sample of adult population” was resident in the Emilia municipalities of the epicentral area (the list of the 22 municipalities involved are in the appendix A of this thesis). The online questionnaire has been hosted on the municipalities’ official websites, while the online compilation for students was done during lessons in schools or at home as homework. The supporting methodology for the study has taken from the psychometric and cultural theories, then completed by some other aspects related to reading and understanding of seismic cartography.

To fulfill the purposes mentioned above in the introduction of this chapter, in order to be consistent with the main literature about this subject, this study adopted a hybrid methodology to face this part of research.

Based on the theories cited, this study on seismic perception has been conducted by means of questionnaires. Indeed, a proper questionnaire design is crucial to assess risk perception, performing quantitative statistical analysis conducive to the goals of the research. (Bulmer, 2004; Creswell, 2003; de Vaus, 2002; McGuirk and O’Neill, 2005; Oppenheim, 1992; Parfitt, 2005; Patton, 1990; Sarantakos, 2005).

In Figure 6.3.1-1 it is illustrated the first page of the questionnaire directed to the students (which was a little shorter with respect to the adult population one, but with almost identical questions). The entire questionnaire is found in appendix B.

**SEZIONE DEDICATA AGLI EFFETTI SISMOINDOTTI**

27. Sai cosa sono gli effetti cosismici o sismoindotti? \*

sì  
 no  
 non so

27.1 Se sì, descrivili in modo semplice con le tue parole

28. Hai mai sentito parlare degli effetti cosismici o sismoindotti... \*

	sì	no
prima del sisma del 2012	<input type="checkbox"/>	<input type="checkbox"/>
solo dopo il sisma del 2012	<input type="checkbox"/>	<input type="checkbox"/>
sia prima che dopo	<input type="checkbox"/>	<input type="checkbox"/>
né prima né dopo	<input type="checkbox"/>	<input type="checkbox"/>

29. Sapresti dire se il sisma che ha colpito la pianura emiliana nel maggio-giugno 2012 ha provocato tali effetti? \*

sì  
 no  
 non so

30. Hai potuto osservare direttamente, in prima persona, tali effetti nelle zone colpite dal sisma del 2012? \*

sì

Figure 6.3.1-1 Subset of the questionnaire distributed to the students. This page shows the section dedicated to the CSE.

The reliability of the social risk analysis is entrusted to a questionnaire as flexible method able to investigate complex variables and to return measurable values useful to statistical analysis.

The questionnaire has been structured in four sections, as illustrated in Table 6.3.1-1.

1. Social and demographic characteristics of the target groups, which contemplated few variables.  
 For the adult population: gender, age, presence of children, instruction level.  
 For the students' target group: gender, school level, nationality, place of residence (inside/outside the epicentral area), school location (inside/outside the epicentral area).
2. The second section has evaluated several aspects: seismic experience, the level of knowledge about the earthquake phenomenon, the perception of the population about hazard, exposure, vulnerability, the degree of confidence towards community and institutions, the comparison between seismic risk and other possible (or not) natural hazards, and the importance of risk information sources (see also Table 6.3.1-2).
3. The third section has been specifically dedicated to CSE. The scope was to understand how this phenomenon has been observed, understood and perceived by the population.
4. The last section has considered the official seismic cartography in terms of popularity, acceptance, intelligibility and usefulness as informative tool of seismic hazard and risks.

1 Social - Demographic characteristics	2 2012 Seismic Event	3 Coseismic Surface Effects (CSE)	4 Seismic Cartography
<b>1 ADULT POPULATION</b> Gender Age Family (child/not) Instruction level <b>2 STUDENTS</b> Gender School level Nationality Place of Residence School Location	<b>1. Perception of Earthquake phenomenon</b> Memorie of seismic event Feeling/ Reaction Scientific knowledge: on seismic Hazard/Risk / classification <b>2. Perception of seismic Hazard</b> <b>3. Perception of Exposure</b> <b>4. Perception of Vulnerability</b> <b>5. Perception of Institutions and Community</b> <b>6. Natural Hazards comparison</b> <b>7. Risk information and Infomation sources</b>	<b>1 CSE Memories</b>  <b>2 CSE description</b>  <b>3 CSE spatial location</b>  <b>4 CSE Scientific knowledge on:</b> CSE possible causes	<b>1 Map of Seismic Classification (2012)</b>  <b>2 Map of Seismic Hazard (2005)</b> Map information Reading and Understanding: •Clarity •Density •Reprensetativness •Usefulness

Table 6.3.1-1 Structure and content of the questionnaire

The questionnaire has been created by means of different typologies of responses or scales:

- Aspects to reveal the perception or for mapping analysis were built on the semantic differential (Osgod et al., 1975); this method considered opposite adjectives or terms based on the Likert's scale, which in this study has been used at 5 points values, as shown below.
- Closed-ended questions;
- Multiple choice;
- Open questions;
- Expression of satisfaction;
- Comparative expressions.

FACTOR	ANSWER
<b>1. Earthquake phenomenon</b>	You see the earthquake as an event...
<b>2. Hazard</b>	If yuo try to imagine an earthquake in the area where you live , how would you describe it?
<b>3. Exposure</b>	Compare to an earthquake, how would you describe the area where do you live?
<b>4. Vulnerability</b>	In case of an earthquake, how do you imagine your home/work place/school/ hospital/city center?
<b>5. Institutions and Community</b>	Compare to an earthquake, how would you describe the institutions and the people around you?

	1	2	3	4	5	
expected	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	unexpected

Table 6.3.1-2 Five factors for perception risk evaluation with the semantic differential based on five points Likert 'scale.

As stated in the theoretical framework, it is important to highlight that the research on risk perception integrates questions about a multifaceted concept, subjected to a plurality of cultural, cognitive, emotional aspects which have been intrinsically explored with questions during the analysis.

For the students' target group, the questionnaire has been modified to simplify or reduce the number of questions and items. The number of questions could have appeared excessive, nevertheless the compiling didn't require much time (7-10 minutes).

Furthermore, as stated before, the questionnaire matrix and the items of the second section replicate the *terremototest* of INGV, that is still accessible at: <http://www.terremototest.it>. This methodology allows to compare the Emilia regional seismic perception with the national level outcomes.

The statistical analysis of the questionnaire responses has been supported by two main methodological approaches:

1. Statistical analysis concerning: (i.) calculation of relative frequencies (for each variable in percentage value), (ii.) cross tabulation, where the contingency tables show the frequency distribution and the correlation between two variables. The correlation between variables was assessed by Pearson's chi-squared ( $\chi^2$ ); while the degree of significance has been tested by Cramer's V.
2. Seismic perception assessment deals with the definition of a perception score (index of seismic perception), which has considered six factors: hazard perception, risk perception, perception of the earthquake phenomena, perception of exposure and perception of vulnerability and population. The perception score was obtained from the average of individual items based on the 5-points Likert's scale (also calculated as percentage of respondents). A further step of the analysis concerned the comparison between the seismic risk perception score with respect to the "seismic risk by law" (Crescimbene et al., 2014). The latter considers the seismic risk assigned to the Italian districts with respect to the national official seismic risk classification through the official national map of seismic risk classification (Gruppo di Lavoro MPS, 2004; Stucchi et al., 2011). For instance, all the municipalities falling in the target area are classified as low seismic risk (in zone 3), consequentially the good perception for this area of Italy, corresponds to a mean value score of 3 (from 3 to 4) as displayed in table 6.3.1-3.

Seismic Zones	1	2	3	4	5
zone 1	-4	-3	-2	-1	Good Fit
zone 2	-3	-2	-1	Good Fit	1
zone 3	-2	-1	Good Fit	1	2
zone 4	Good Fit	Good Fit	1	2	3

Figure 6.3.1-3 Interpretation of Hazard Perception scores (HP) respect to Hazard by Law (HbL). The sign minus (-) signifies underestimation and sign plus (+) overestimation of perception.

Statistical computations have been performed with multiple software according to the requirements of the analysis, namely EXCEL, R, SPSS® (Statistical Package for the Social Sciences).

The analysis of questionnaire results for both targets groups followed the main sections and contents sequence of the questionnaire. The most important relative frequencies (percent value) and contingency tables obtained from the association tests ( $\chi^2$  and Cramer's V) are presented, in order to evaluate which variables influence the perception levels revealed from the responses.

### 6.3.2 Results: target group Population

A total of 153 respondents have completed the questionnaire hosted by the official municipality websites and then included in this study. Table 6.3.2-1 shows the socio-demographic characteristics of the sample in percent value. The analysis considered 153 observations, 136 variables and, from the pairwise analysis of variables, 54 significant associations were found between the independent variables (the socio-demographic characteristics) and the responses.

Age	
<35 years old	18,30%
36-45 years old	29,41%
>45 years old	52,29%
Gender	
M	47,06%
F	52,94%
Family	
With children	64,05%
Without children	35,95%
Instruction Level	
Primry school	0,65%
Secondary school	14,38%
High School	50,98%
University Degree	31,37%
Post Degree	2,61%

Table 6.3.2-1 Demographic frequencies by socio-demographic characteristics.

SECTION 1. Socio-demographic characteristic of the sample.

Considering the age of participants, around half of the sample is >45 years old, balanced in terms of gender distribution and with a preponderancy of people with children and more than 50% of the target group presents an instructional level corresponding to a high school diploma and about 34 % to a university degree.

SECTION 2. The 2012 seismic event

In Section 2, the analysis of seismic perception has considered the degree of knowledge of seismic hazard and risk, beside different experiential, cognitive, emotional dimensions. For instance, from the open answer related to seismic experience, all the respondents have clear in their memory the days and the emergency period of the 2012 event; their knowledge about the geographical extension of the phenomena and the memory of the strongest quakes corresponded to the reality. Looking at the emotional aspect related to the seismic shocks, fear was the dominant feeling, as displayed in Table 6.3.2-2.

- Seismic experience and feeling-reaction

*Question 1.b How did you react? / what was your reaction?*

The table 6.3.2.2-shows the emotional or physical reactions during the shocks and gender seems to have a slight influence on the reaction within the population investigated.

	Frequency	Percent
Fear	79	51,6
Indifference	20	13,1
Confusion	24	15,7
Physical reaction	30	19,6
Total	153	100,0

Gender  $\chi^2$  df p-value  
9 3 <0.05  
V= 0.24

Table 6.3.2-2 Emotional reaction during the main shocks

- Scientific knowledge

In general, public knowledge about earthquake causes and triggering aspects is satisfactory; 83% give the right response considering that is not possible to foresee where and when an earthquake may happen (Question 3), and 51% of the population correctly indicated that earthquakes tend to occur in the same areas (Question 4). 62% of people has affirmed to know the definition of hazard and 82% of risk, but when they were asked to explain those concepts, the percent of wrong explanation reached 80% (questions 7 and 8). Asking about the class of seismic risk in their municipality of residence, the results revealed that the responses were equally divided in being correct or incorrect. From the following question, Table 6.3.2-3 explicates the awareness of living in a seismic area.

*Question 11. Do you think Po Plain could be affected by earthquakes in future?*

	Frequency	Percent							
No	3	2,0	Instruction	$\chi^2$	df	p-value			
Yes	120	78,4					16.67	8	<0.5
Not Sure	30	19,6					V= 0.23		
Total	153	100,0							

*Table 6.3.2-3 Response to question 11.*

This response was significantly associated with the level of instruction of respondents ( $\chi^2 = 16.67$ , p-value < 0.05, cramer V = 0.23).

#### *Perception of hazard*

Table 6.3.2-4 displays the mean percent values of people who responded in the different levels, by the semantic differential based on a 5-point scale. 37.4% and the 27.7% of the sampled Emilia population have a correct perception with respect to hazard by law (which corresponds to the values between 3 and 4). About 14% of people overestimated the seismic hazard by 1 point (value5) and only 7.4% underestimate the hazard by 2 points (value 1) for the Emilia territory.

Question 9. If you try to imagine an earthquake in the area/land where you live, how do you see it?

		1	2	3	4	5	
1	Unexpected	19,6	9,2	24,8	30,7	15,7	Expected
2	Weak	2,0	27,5	47,1	23,5	0	Strong
3	Small	4,6	29,4	39,2	26,8	0	Big
4	Far	,7	2,0	19,9	35,8	41,7	Near
5	Short in time	,7	7,8	37,9	30,7	22,9	Long
6	Destructive	19,6	24,8	31,4	21,6	2,6	Not destructive
7	Far in time	4,6	13,7	40,5	24,8	16,3	Near in time
		7,4	16,3	34,4	27,7	14,2	

Table 6.3.2-4 Frequency distribution of differences in hazard perception within the respondents.

Considering the demographic and social aspects that may influence the perception of hazard, it was found that the mean score for all categories was higher than 3, with women, people with children people in the range of 36-45 years old, or having a university degree showing a higher perception of seismic hazard (see Figure 6.3.2-1).

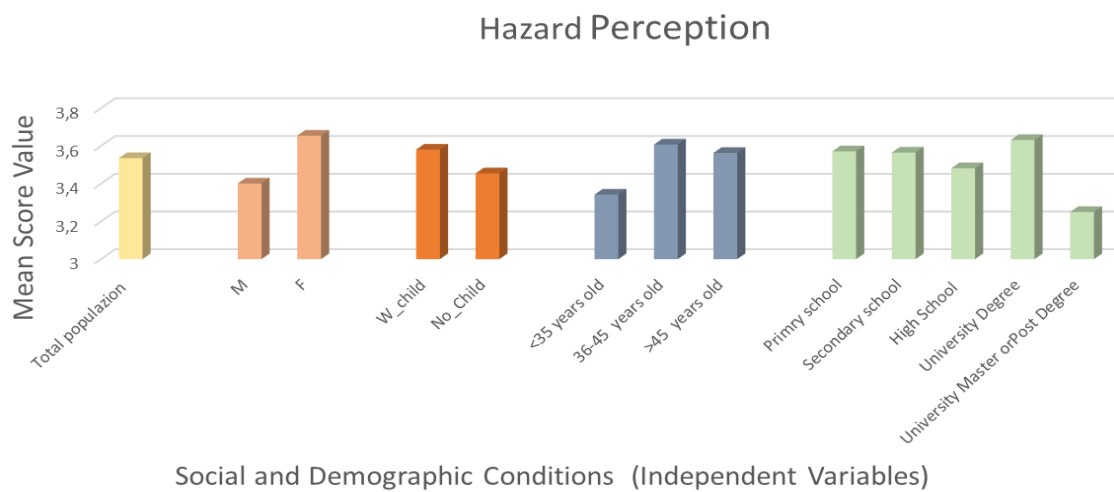


Figure 6.3.2-1 Histogram representing the degree of hazard perception by mean score value (1 to 5) for each independent variable.

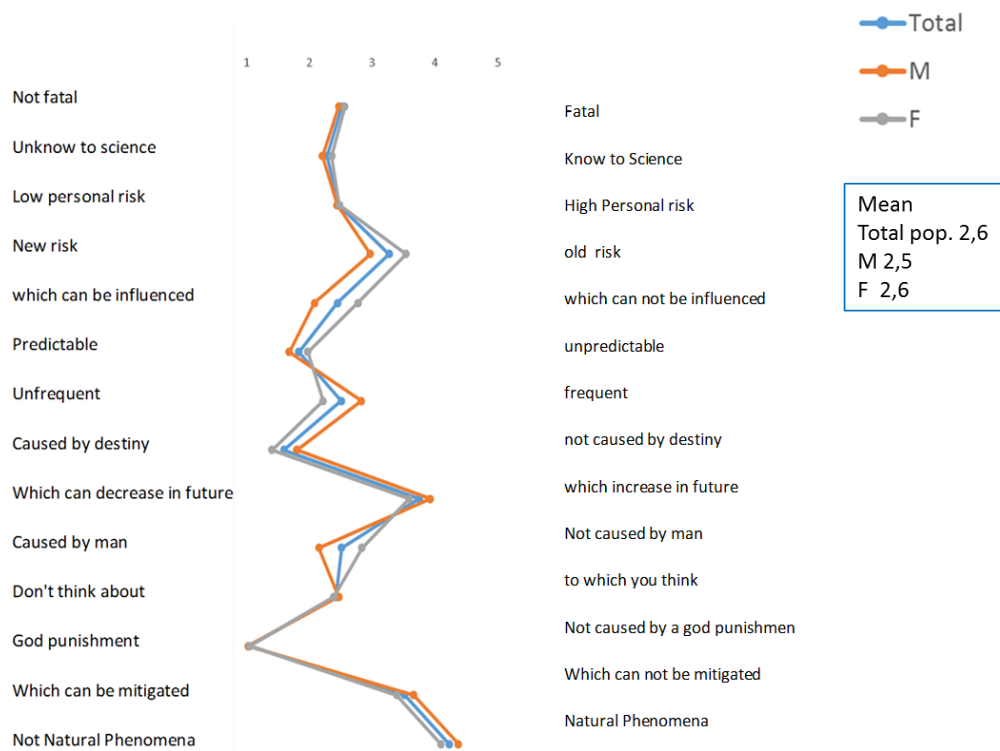


Figure 6.3.2-2 Descriptions of the earthquake phenomena, the perception scales (HP) assess the total number of respondents and discriminate the responses by gender.

The chart above of Figure 6.3.2-2 represents an example of perception scale, specific for the earthquake natural phenomenon, where the colored lines represent the trend of scales: blue for the total of surveyors, red for the male population and grey for the female one. The trend of the lines and the results in the legend put in evidence an average value below the good (the right) perception of the phenomenon for this region. In fact, the underestimation is represented by average scores of 2.6 for female and for the total sample, and of 2.5 for males. Looking at the trend of the scale and to the correspondent items, the earthquake in the area is evaluated as an old risk that could appear to be in contradiction with the previous results or with the fact that it was known that the plain was a seismic area. Moreover, it appears quite clear that religious or superstitious elements don't have any influence on the Emilia population perception.

Respondents recognized that the more probable hazards in the Po plain are floods (61%), exudation (60%) which confirm the historical and recent event affecting this area of Italy. (Question 10). These percentages seem to disagree from the study of Salvati (2014) which stated that the perception of flood risk decreased in the region. In the Emilia–Romagna region, northern Italy, the percentage of interviewees that considered an earthquake likely to occur, increased from 48% in 2012 – before May–June 2012 seismic sequence (Anzidei et al., 2012) to 73% in 2013.

Another important point of discussion deals with the perception of vulnerability, expressed in a scale of sense of security/insecurity and referred to the house, city center, work, hospital and town (question 21). The higher percentage of the mean score value (41.2%) explains a sense of security, however 37.6% of participants also considered the environment unsafe. The predominant perception of insecurity is associated to the city center, which in effect has been severely damaged during the 2012 event. The places felt as safe were the place of work, and in general the school. A plausible reason related to the fact that the public fund for the reconstruction in Emilia have been immediately directed to public buildings built conforming to anti-seismic rules.

One of the most important topics explored in this chapter was to discover and understand the relation between perception and means of communication; the few questions dedicated to this thematic revealed that the population felt to be little or just sufficiently informed on seismic risk (39.2 % and 37.3%), moreover the assumption assumes relevance looking to the source of information, because the request for more and deeper information was clearly expressed in the results (questions 22, 24 and 26). This was specifically pronounced for scientific information (85%). The latest results may be critically supported considering that the means of communication used during the emergency period have been mostly from informal sources, such as familiars and friends (34%) or internet 36%. Only 1.3% has indicated newspaper and low percent values are correlated with institutions. Table 6.3.2.5 shows the seismic perception index which translate the frequency distribution of people with respect a five-scale degree and respect to each seismic factor considered in the analysis (perception of the natural earthquake phenomenon, hazard, exposure, institution). The mean value of the total is well expressed by the following chart.

	Underestimated 2 points	Underestimated 1 point	Good Fitting	Overestimated 1 point	Overestimated 2 points
FACTORS	1	2	3	4	5
Earthquake	30	16	21	14	19
Hazard	6	9	30	33	22
Exposure	17	18	28	18	19
Institution	10	16	36	25	13
Mean Value (%)	16	15	29	23	18

Table 6.3.2-5 Seismic perception score for each one of the factors evaluated.

Figure 6.3.2-5 summarizes the perception scores as mean value of the participant distribution, for each factor considered in the analysis (perception of earthquake phenomena, perception of hazard, perception of exposure and perception related to the institution and social context). The finality was to define one single perception index corresponding to a unique mean value and which can be

compared with definitions of good perception defined by law (Figure 6.3.2-3). The vulnerability was not included in the analysis, because it has been expressed with a four-point scale of security or insecurity feeling. Higher percentage of respondents (about 27%) presents a good seismic perception with respect to the territory of the Po Plain, however values were equally distributed (from 15% to 23%) over the rest of the perception categories; about 30% of the population underestimated seismic risk, whereas about 40% overestimated the seismic risk in the Po Plain.

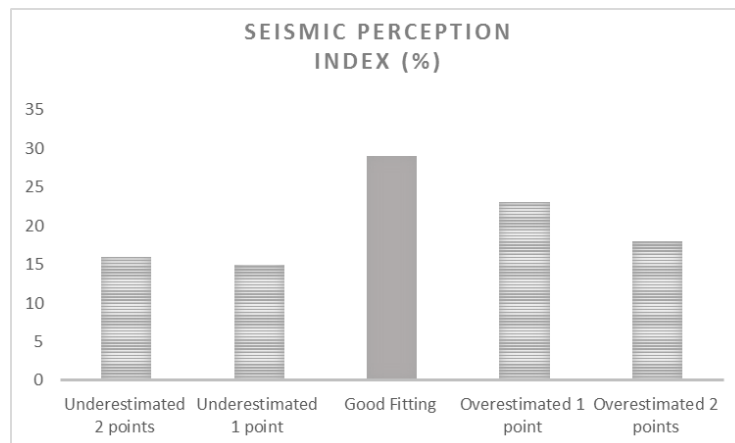


Figure 6.3.2 -3 The index of seismic perception resulted from the mean values each factor: hazard, exposure, earthquake phenomenon, trust towards institution and community.

### SECTION 3. CSE knowledge

The section of the questionnaire dedicated to CSE has revealed a general lack of information within the population on the causes and nature of the phenomena. However, when asking if they know these phenomena, almost half of the population gave a positive answer (Question 27). The contingency table below (Table 6.3.2-6) shows the relative frequency of the knowledge about triggering events of the phenomena, in relation to the different levels of instruction. People more educated seemed more conscious of the triggering factors of CSE, a significant association confirmed by the chi-square test ( $\chi^2(12) = 38, p = 0.0001$ ; Cramer's  $V = 0.3$

Question 36. Could you explain which are the possible trigger causes of these events?

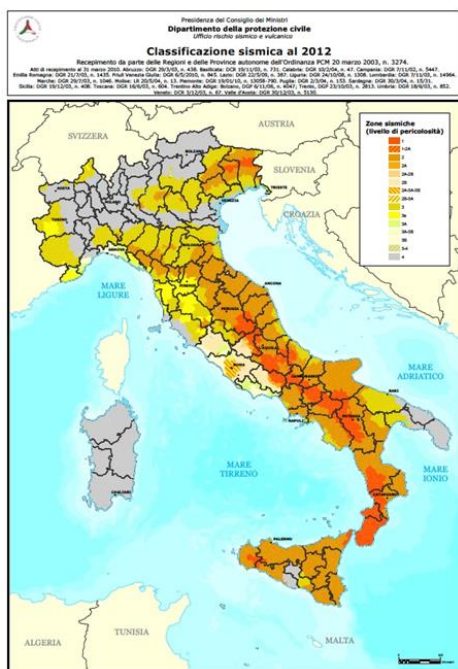
Response:	Wrong	Right	I don't Know	Other
Primary School	0,7	0,0	0,0	0,0
Secondary School	2,6	6,5	1,3	3,9
High School	2,0	28,8	3,3	17,0
University Degree	0,0	15,7	4,6	11,1
Post Degree	0,0	0,0	0,0	2,6
Tot (%)	5,2	51,0	9,2	34,6

Table 6.3.2-6 Contingency table representing the frequency distribution of answer considering the instruction level.

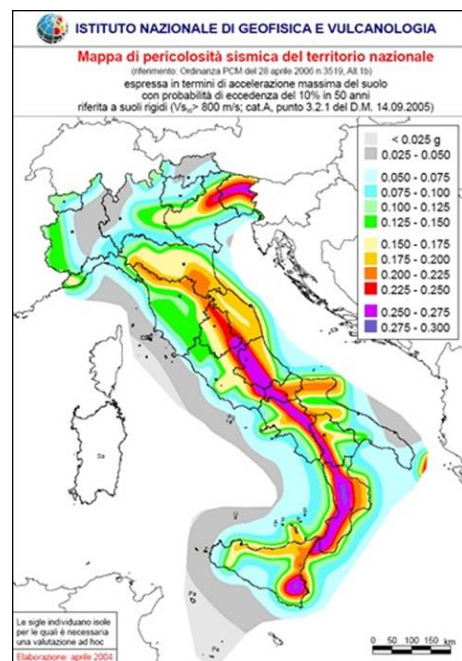
Looking at the influence of socio-demographic characteristic of the sample and level of knowledge concerning CSE, the chi-square test has statistically revealed association between these results and the presence of children in family ( $\chi^2(13) = 7.9, p = 0.04$  Cramer's V= 0.2), as well as with gender ( $\chi^2(3) = 9.2, p = 0.02$  Cramer's V= 0.2)

#### SECTION 4. Seismic Cartography (reading, understanding, opinion)

The last part of the questionnaire, dedicated to the official seismic cartography as relevant tool for seismic communication, has given interesting results, supporting one of the main issue of this thesis which considers seismic cartography as tool facilitating risk and hazard communication and understanding. The official maps of seismic classification elaborated in 2012 (Civil Protection) (Map1), and the Map of seismic hazard from 2006 (INGV)(Map2), are the most important references within seismic cartography at national scale (see Figure 6.3.2-4).



1.



2.

Figure 6.3.2 -4 Seismic Map included in the questionnaire: Map 1 Classification of Seismic Risk of Italy (from Civil Protection, 2012); map 2 Hazard seismic risk map (from Civil Protection, INGV,2006).

Evaluating the degree of dissemination of these maps, it is interesting to observe that 75.2% and 73.2% of respondents have affirmed to have already seen Map 1 and Map2, respectively, obtained from the internet within the other sources of information (85%) (Questions 40 and 40.a). Overall, the clarity, completeness and immediacy have been considered sufficient by 55.1% (map 1) and by

41% (map 2) of participants, while only 7.8% and 4.1%, respectively, expressed a very low appreciation (not at all) (Question 41). Concerning the interest and usefulness of the maps through the differential semantic (1 to 5) points scale, half of the sample is concentrated within the first two high value positive range. The judgment of people about seismic cartography is expressed by the table 6.3.2-7.

*Question 41. Additional reading incentives. In your opinion, the map is...*

<u>Map1 (Risk)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>%</u>
Interesting	26	25	34	10	5	Not Interesting
Useful	25	25	35	10	4	Useless

<u>Map2(Hazard)</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>%</u>
Interesting	26	23	33	14	4	Not Interesting
Useful	24	26	30	15	5	Useless

*Table 6.3.2-7 Appreciation of respondents in relation to the usefulness of cartography.*

On the question regarding “In your opinion the map *is reliable, and representative of the theme in a scientific way (Question 46)*” half the respondents have considered the two maps to be sufficiently scientifically representative. To better understand the maps, especially for map 2, 52% of the sample expressed the need of additional clarifications. This concern could be related to the fact that the cartographic tool does not yet represent a widespread information tool, therefore, the lack of habit of using maps in daily life affects the possibility of reading immediately its components, since it implies a cognitive interpretation in legend symbols.

Moreover, an important statement for the final objective of this thesis came from the responses of question 50, from which, despite difficulties in the immediate map interpretation, 65% of the participants have considered the cartography an appropriate tool for the dissemination of knowledge related to seismic hazard and seismic risk; 11% expressed a negative opinion, and 24% uncertainty on the issue exposed. Concluding, the analysis strictly related to questions for the adult population target group, the table 6.3.2-8 allows to estimate the frequency distribution of associations from the statistical chi-square test which has considered 136 variables over 153 observations, estimating 54 significant associations in total. Looking at the main sections and factors investigated, the higher percentage is referred to the correlation between earthquake knowledge and gender (18.5%) and seismic cartography with level of instruction (18.5%).

Questionnaire Sections	DEPENDENT VARIABLES	INDEPENDENT VARIABLES				Total (%) (Mean Values)	
		Age	Gender	Family	Instruction		
2	Memory Seismic Experience	0	1,9	0	0	1,9	0,5
2	Earthquake Knowledge	0	18,5	0,0	7,4	25,9	6,5
2	Hazard	1,9	3,7	1,9	3,7	11,1	2,8
2	Exposure	1,9	0,0	1,9	1,9	5,6	1,4
2	Vulnerability	0	0	0	0	0,0	0,0
2	Institution	2	0	0	0	1,9	0,5
2	Natural Hazard Comparison	0	0	0	1,9	1,9	0,5
2	Seismic Risk	0	0	0	0	0,0	0,0
2	Information	0	1,9	1,9	1,9	5,6	1,4
3	CSE	0,0	5,6	1,9	3,7	11,1	2,8
4	Seismic Cartography	1,9	11,1	3,7	18,5	35,2	8,8
Total (%)		7,4	42,6	11,1	38,9	100,0	
(Mean values)		0,7	3,9	1,0	3,5	9,1	2,3

153 observations - 136 variables - 54 correlation

Table 6.3.2.8 The table shows the relative frequency number of significant correlation between the main section (main issues) of the questionnaire and all the socio-demographic factors.

### 6.3.3 Results: Target group Secondary school students

315 students (from secondary and high school level) have been involved in the survey; the online questionnaire was filled directly in school or at home. Table 6.3.3-1 presents the socio-demographic variables of target group in percent relative frequency value that have been considered significant for the study: 315 observations (respondents) and 87 variables (number of answers to each respondent). From the Pearson's chi square 136 were significant correlations.

Gender	Frequency	Percent
M	217	69
F	98	31
<b>Nationality</b>		
Italian	275	87
Not Italian	40	13
<b>Municipality</b>		
Epicentral Area	229	73
Outside Epicentral Area	86	27
<b>School Level</b>		
Secondary	94	30
High School	221	70
<b>School Location</b>		
Epicenter	242	77
Outside	73	23

Tot. 315 observations

Table 6.3.3-1 Socio-demographic independent variable considered for the study: gender, nationality, municipality of residence, school level (secondary or high school), school location (inside/outside the epicentral area).

#### SECTION 1: Socio-demographic characteristic of the sample

Taking into consideration the gender, 69% of the sample corresponded to male population and 31% to female. 13 % of students were not of Italian origins. This aspect allows to explore possible cultural influences on seismic perception, and the degree of knowledge of local environmental contexts within immigrants (directly related to their social integration). A wide literature has showed that personal experience of a natural disaster reduces optimistic bias (Mileti e O'Brien, 1992; Burger and Palmer, 1992; Helweg and Laisen, 1999). In accordance with this assumption, the geographical location of the residence municipality and of schools was herein considered. As displayed in table above around 77 % of the sample was living and attending studies in schools inside the zone of epicenter while the 23% outside. The questionnaire has been divulgated especially in high schools, which justifies the 70% of high school respondents against 30% of secondary students.

## SECTION 2. The 2012 seismic experience, feeling, reaction

Over 96% of the participants affirmed to remember the main shock of 2012. From the emotional point of view, the seismic experience was associated to a feeling of fear (44%), followed by a sense of confusion (26%), less represented were the indifference and the physical reaction.

In general, after two years from the event, students' knowledge about causes still remained generic, inaccurate despite, in most of the cases, lessons were dedicated to the 2012 earthquake. Student tendency was to express with affirmative response to questions related to the seismic knowledge (when answer was yes or not), but then, when asking to explain the concept of the previous question the high percentage of people giving a wrong response confirm the lack of real knowledge. In fact, students tend to choose the central response (equal to the mean value), which doesn't express in general to a real choice. Moreover, is it important to state another general assumption, student's questionnaire filled in the classroom are more susceptible to a shared thinking, because they tend to copy to each other's.

Table 6.3.3-2 shows that 43.8% of respondents gave a wrong answer when asking if is it true that earthquakes occur always in the same areas, while 39% was giving the good response, which means an affirmative answer (Question 4).

	Frequency	Percent
Wrong Answer	138	43,8
Right answer	123	39,0
No idea	54	17,1
Total	315	100,0

Table 6.3.3-2 Statistic results of knowledge referred to earthquake phenomenon.

More than half of the students declared to know the meaning of hazard, risk, vulnerability and exposure, but looking at the wrong explanations those concepts have appeared not clear at all to them (Questions 6 and 7).

Figure 6.3.3-1 summarizes the analysis done to define the student's perception following the methodology proposed by INGV that makes possible to compare the seismic perception score in a scale from 1 to 5 to respect to the seismicity by law (Crescimbeni et al., 2016). The score for each factor (as hazard, earthquake, exposure etc.) was obtained from the total mean of the items evaluated (see questions 8, 9, 14, 15 of the questionnaire in appendix B). Results as displayed by

the histogram (Figure 6.3.3-1), presented a general low seismic perception, since most of the values are below value 3. Otherwise, the perception related to the exposure and to the trust in community and institutions are higher, touching value 3. Considering the variable related to the socio-demographic characteristics of the sample, results show the same trend. The municipality of residence within students appeared to be a discriminant factor in seismic perception; students living outside the epicentral area present lower seismic awareness. The underestimation of seismic perception (1 plus 2 values) encompass the 40% of the students, the 25 % of students had a good seismic perception, while about the 27% overestimated the seismic risk in their territory (Figure 6.3.3-2).

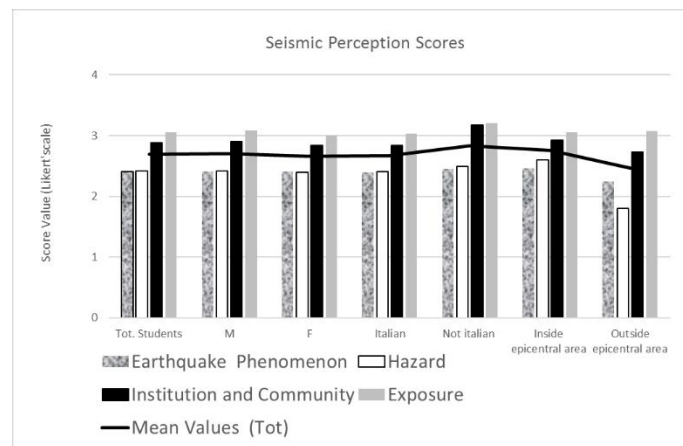


Figure 6.3.3-1 Statistic results showing differences in seismic perception for characteristic of the sample

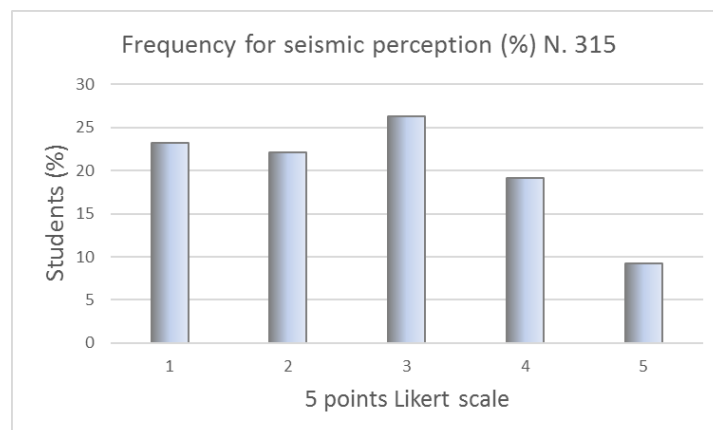


Figure 6.3.3-2 Statistic results about differences in seismic perception by student frequency distribution in percentage

Seismic awareness could be strongly influenced by appropriate and continuative information strategies. About seismic information, 60% of the respondents thought to be enough informed about regional natural hazards-risks; moreover 31% of students felt little informed and only the 3.5% well informed on local risks, the same percentages have been expressed in specific for the seismic risk. The information sources more consulted were internet (77.8%), TV (15.9%), less important were the newspaper and the formal channel of communication (4%) (Questions 22.23.24). 87% of the students have participated in seismic information programs that have been mainly promoted by INGV (Question 25). Over 80% of participants considered the importance of scientific knowledge to better understand seismic risk, against this value only 7.3 % didn't find it significant (question 26).

### SECTION 3. CSE knowledge

Taking into consideration the focus of the thesis, the section reporting the responses for CSE has revealed some associations between the socio-demographic characteristic and the degree of knowledge about CSE. It was interesting to reveal from the survey as CSE still remain unknown manifestations to the 60% of students. 21% of them were not sure about their knowledge and 18% express their ignorance about the phenomenon as it is displayed in table 6.3.3-3. Moreover, within the 8 typologies of effects mentioned, almost only crack with liquefaction were indicated as type of CSE observed in field (85%) (Question 30c). Doubts were also expressed about the triggering causes associated to the main shocks inducing CSE occurrences (see table 6.3.3-3b).

27. Do you know about coseismic surface effects?  
triggering

	Frequency	Percent
No	190	60,3
Yes	57	18,1
Don't Know	68	21,6
Total	315	100,0

(a)

31. On your opinion, what have been the triggering factors of those effects?

	Frequency	Percent
Main Shocks	128	40,6
Minor shocks	83	26,3
Don't know	104	33,0
Total	315	100,0

(b)

Table 6.3.3-3 Statistic results about student knowledge of CSE (a) and theirs causes of induction (b).

Chi-square test found significant correlations between CSE awareness and municipality of residence; in relation to their general knowledge  $\chi^2 (2) = 6.19$ ,  $p = 0.045$ , Cramer's  $V = 0.14$  and in particular for effect recognition  $\chi^2 (7) = 14.49$ ,  $p = 0.04$ , Cramer's  $V = 0.27$ . Gender seemed also to be correlated with the CSE understanding  $\chi^2 (2) =$ ,  $p 0.007 =$  Cramer's  $V = 0.17$ ; moreover, other important variable was the school level,  $\chi^2 (2) = 8.9$ ,  $p 0.01 =$  Cramer's  $V = 0.16$ , and the location of the school  $\chi^2 (2) = 7.8$ ,  $p 0.01 =$  Cramer's  $V = 0.15$ .

#### Section 4. Seismic cartography (reading, understanding, opinion)

Question 40 revealed the degree of knowledge of risk and hazard map. Within student's cartography representation should be more familiar, the target group are more frequent exposed to this kind of informative tool. Questioning about the degree of maps knowledge, 74.9 % of students were confident in affirming they know the official risk map of Italy while the 59% asserted to have already seen the hazard map. One part of the questionnaire was directed to guide the map reading and understanding (question 41). For instance, results related to the general comprehension of maps based on the following adjectives: clear, complete, immediate, complex, understandable, have shown in Table 6.3.3-4 a moderate-satisfactory appreciation by 48.7 % and 44.4% of students, while little appreciation corresponds to the 26% and 29%. Great appreciation corresponds to the 18.9% and 17.5% of respondents. The 64.8% of students has recognized the importance of cartography in seismic risk communication with respect to 10.5 % of them that hasn't attributed any relevance to cartography.

Table 6.3.3-6 summarizes the significant correlations (%), using Pearson Chi Square test, between the characteristics of the sample and the main aspects investigated within this thesis: seismic memory, seismic knowledge, factors (e.g. hazard, exposure, vulnerability). School level appeared to be the most influent variable in student's seismic perception, while awareness related to earthquake phenomena is the aspect more conditioned by the socio-demographic variables.

The school level seems to affect the degree of knowledge and the appreciation of seismic cartography, specifically, high school students gave more importance to the cartographic instrument. CSE knowledge have been more significant correlated to municipality of residence and to school level.

Question 40. Do you know this map?

1			2		
Frequency	Percent		Frequency	Percent	
No	38	12,1	No	65	20,6
Yes	236	74,9	Yes	188	59,7
May Be	41	13,0	May Be	62	19,7
Total	315	100,0	Total	315	100,0

Table 6.3.3-4 Evaluation concerning seismic Maps Knowledge

41. From a general overview do you consider the cartographic information ...

Map 1	Not at all	Little	Enough	A lot
clear	5,4	17,8	53,3	23,5
complete	2,9	13,7	63,2	20,3
Immediate	6,0	36,2	42,2	15,6
Complex	13,0	43,8	33,0	10,2
Understandable	5,1	18,4	51,7	24,8
Mean (%)	6,5	26,0	48,7	18,9

Map 2	Not at all	Little	Enough	A lot
clear	10,5	29,8	42,5	17,1
complete	4,1	17,1	59,7	19,0
Immediate	10,8	38,1	38,4	12,7
Complex	11,7	32,4	36,8	19,0
Understandable	8,6	27,3	44,4	19,7
Mean (%)	9,1	29,0	44,4	17,5

Table 6.3.3-5 Evaluation concerning seismic Maps reading

Sections of Questionnaire	Municipality of Residence	Gender	Nationality	School Level	School Location	Total
Memory Seismic Experience	2,2	0,7	0,7	1,5	1,5	6,6
Earthquake Knowledge	<b>4,4</b>	0,7	<b>2,2</b>	<b>4,4</b>	<b>5,1</b>	<b>16,9</b>
Hazard	0,7	0,0	0,7	1,5	0,7	3,7
Exposure	0,7	0,0	0,0	1,5	2,2	4,4
Vulnerability	2,9	0,0	1,5	3,7	2,9	11,0
Institution	0,0	0,0	0,7	2,9	0,0	3,7
Natural Hazard Comparison	1,5	<b>2,2</b>	<b>2,2</b>	3,7	1,5	11,0
Seismic Risk	2,9	0,0	1,5	2,9	2,9	10,3
Information	0,0	0,7	0,0	1,5	0,0	2,2
CSE	<b>4,4</b>	1,5	0,0	<b>4,4</b>	3,7	14,0
Seismic Cartography	2,9	1,5	0,7	6,6	4,4	16,2
Total	22,8	7,4	10,3	<b>34,6</b>	25,0	100,0

Total correlation n. 136 (315 cases 81 variable)

Table 6.3.3-6.

Table showing the relative frequency number of significant correlation between the main section (main issues) of the questionnaire and all the socio-demographic factors.

#### 6.3.4 Results and Discussion

Within researchers dedicated to risks is arising the consensus that technical or technological solutions alone are not enough to decrease the risk of hazards, rather a wider consideration of the interaction between societies, territories and related hazards allow a deep understanding of the multilateral implications of environmental geological risks. Analysis of risk perception data consent to produce useful indications to better define the social and cultural context in order then to design risk reduction and risk prevention strategies. Concerning risk perception, the debate is between the psychometric paradigm claiming that people's risk perception is the result of hazard peculiarities and personal aspects and the cultural theory paradigm, claiming that the social context is the most important to understand people's perception of risks. A single theory of risk perception able to offer an integrative, as well as empirically valid, approach to understanding and explaining risk perception is still missing. The complexity of the topic can be faced only integrating different perspectives of analysis as it was done in this chapter of the research. Personal characteristic seems to influence seismic perception: age, gender, educational level, personal knowledge, personal disaster experience, but also religiousness, trust in authorities, trust in experts, social cohesion, confidence in different risk reduction measures seem to be influent in shaping risk perception. Some studies have found that age and gender have an influence on risk perception, others saw no or little influence. In this study, some social-characteristics of the two specific target groups have been considered to better define the reasons behind the general lack of awareness within the Emilia population. Indeed, results from this study indicate that perception of risk should consider both social situations as well as the peculiar context of endogenous forces and characteristics of the natural environment as pointed out by Sjöberg et al. (2004). The survey directed to the population and to the students produced an important feedback of the degree of seismic perception among the sampled target groups.

Beside to recognize the importance of scientific knowledge for hazard understanding, in general terms the questionnaire has revealed a low seismic awareness, particularly within students; otherwise, the 2012 seismic experience increased knowledge and interest on seismic risk. This assumption is also confirmed by Ruin *et al.* (2007), that asserts that individuals without direct hazard experience tend to underestimate dangers and risks.

Looking at the results, the methods implemented by INGV (Crescimbene et al., 2014) based on the comparison of seismic perception and seismic by law has consented to summarize by mean values of the different factors in one index. From the sample, it was possible to assess the higher

perception for the vulnerability of city centers. The 2012 earthquake had in fact severe impacts on the city center; the collapses of historical or religious buildings have been well reported and emphasized by media. Information related to CSE widespread by media did not enhance knowledge and awareness about these phenomena, within students. One of the main achievement of this chapter was the possibility to prove the importance of cartography in seismic risk communication. From the results was encouraging to state that cartography have been designated from both target groups as a valuable tool of seismic risk understanding.

Visualizing land natural hazards and uncertainties through cartographic information allows to explicit and to synthesize the complexity of natural hazard events. According to Gahegan (2000), visual representations of risks may take over others, given that vision is the dominant sense. For this reason, visual representations may also bring out stronger affective responses than other representations. Maps vary significantly depending primarily to its main scope. 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. Considering earthquake risk features and factors influencing cartographic 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 risk analysis based on the information and the authority of different information sources. Cartographic thematic design implies graphic and sociological considerations to represent and to return the severity and spatial distribution of hazards and risks dimension (Gaspar-Escribano, 2011). The correct understanding of the seismological message will depend also on the design of this cartography. The improvement of this understanding must, therefore, attempt cartography from the perspective of visual communication and pay special attention to map design. This perspective of cartography as a communication medium is well recognize in the cartographic literature (Dent, 1972; Robinson and Petchenik, 1977; MacEachren, 1995; Slocum et al., 2005), since Bertin (1967) first elaborated the template for graphic semiology. 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 should 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.

According to public risk perception and attitude, effective risk communication can have deepened our knowledge of risk and danger, enhance safety consciousness and help people establish rational behavior patterns of risk perception. Individual risk perception appears influenced by variables as: sex, age, culture, experience and other factors. More investigations and studies should be carried out to further identify the risk factors to provide useful suggestions to effective risk communication.



## 7 CONCLUSIONS

The earthquakes that struck the southern-central part of the Po Plain in May 2012 caused deaths, injuries, considerable damages to the cultural heritage and to the economic activities, crumbling “social certainties and references”. An earthquake of a similar magnitude in the Po Plain was considered unlikely to reoccur and CSE were unknown manifestations to the population. Mentioned only in historical chronicles, during the 2012 seismic sequence CSE have been mistaken for anomalous or even suspicious phenomena. Moreover, the 2012 earthquakes hit the Emilia communities causing collapses and severe damages reported to religious or monumental buildings of historical centers, have generated a sense of collective loss. Community heritage represents the references of a shared identity, the “icomena” of a territory (Turri, 1998). On the one hand, the solid economy, the social cohesion coming from a tradition of associations and cooperatives, definitely helped to generate widespread resilient responses in Emilia during the emergency period; on the other hand, the low perception of the seismic potential of this area still continues to be entrenched despite the seismic experience of 2012 especially in this plain of northern Italy, where local dangers are historically associated with floods. Moreover, in common beliefs, the Po Plain was conceived as a static and homogenous landscape where seismic waves could be reduced by the alluvial sand sediments (Bertacchini et al., 2012).

Risk perception is influenced by several factors and cultural reasons, often related to popular beliefs, traditions and not only to a real scientific response. In the Emilia local context, despite other Italian regional realities, the religious believes had little significance, while the lack of seismic awareness it was unquestionably associated to other aspects resulting from a seismic “information gap” (Guidoboni and Valensise, 2013). The occurrence of a major earthquake has developed a social interest towards the nature of the seismic hazard and its related risks, which was also expressed in a request for more information and access to knowledge, as revealed by the findings of this research. Mileti and Darlington (1995) highlighted the relationship between lack of knowledge and sense of precariousness and insecurity; in fact, terms as hazard and risk are associated to uncertainty and fear shared at community level. The scientific knowledge of the earth sciences can have a pivotal role in the processes of knowledge and risk awareness. In the complex dimension of seismic hazard, for which, unlike other dangers, the triggering and predisposing factors are often abstract entities, forces (e.g. magnitude), or less geographically observable phenomena, geosciences must disclose and find the way to transfer vital data, evidence, and information, since

the responsibility to define concepts such as hazard, exposure and vulnerability cannot be delegated only to the media. Certainly, geological studies need to encompass specialized knowledge and highly technical terminology when describing the endogenous nature of seismic hazard variables and dynamics to the wider public. Alexander (2007) also summarizes what strategies earth sciences can put in place to reveal contents and methods to the plurality of stakeholders in the territory. To identify and map the areas susceptible to hazards; to clarify the relationship between hazards and geophysical processes that cause them; to explicit values of magnitude and frequency within the notion of dangerousness, are all relevant actions in the processes of knowledge construction and risk perception among the population (Alexander, 2007). The passage between scientific to popular culture can only be facilitated through the identification of appropriate communication tools. The transfer of knowledge indicated by this study is a compulsory step to scientifically sustain and shape the perception of people facing risks.

As previously stated, the subjective perception is both a vision strongly influenced by contextual factors (Sjöberg, 2000). With this purpose in mind, only an interdisciplinary approach allows the creation of a methodological paradigm which first and foremost is used to analyze the perception of risks in its complexity within its behavioral manifestations. Alexander (2007) highlights the extreme importance of this concept with the phrase "democratization of the disaster," referring to the need for inclusion of the population in prevention and mitigation of natural hazards strategies.

The achievement of the initial research objectives has been supported by a disciplinary transversal investigation. These concluding remarks serve for a better clarification of the connections between the three main sections of the dissertation.

The first part of this work, corresponding to chapter four, has described the data and phases required to implement a comprehensive catalogue concerning the CSE induced by the Emilia earthquake, through the integration and homogenization of data from different databases and inventories. The importance of this finding is based on the possibility of its free online access within ArcGIS online. The disclosure of important information beyond the technical-scientific community amplifies their potential, particularly when the open source methods of access easily allow their online consultation. The databases have a central role and increasing importance over time in the study of the territory. Access to already coded and organized data facilitates scientific research, the development of methodologies and new projects. Considering risk studies, the availability of catalogs related to historical events (Guidoboni et al., 2007) and usability of geo-referenced data

are a valuable source of information to know local hazards and to develop scenarios and predictive models for the definition of susceptibility to CSE, as in this context. The catalogue implemented during the PhD has integrated the highest number of occurrences induced by the main quakes of the 2012 seismic sequence; further the descriptive sheets and the photos complete the information.

In the second part, corresponding to chapter 5, susceptibility to CSE has been assessed and mapped with good accuracy using bivariate and multivariate geostatistical data-driven approaches, in a GIS environment. Information Value, Weights of Evidence and Logistic Regression methods, which are widely used in susceptibility assessment in other fields, have been applied for the first time to predict CSE-liquefaction susceptibility at regional scale, without considering any seismic parameters (triggering factors), but only based on spatial correlations between past occurrences and conditioning factors related to local terrain conditions. This achievement embodies an important advancement in the domain of liquefaction studies, presenting assertive and validated methods which have allowed to predict and map CSE susceptibility at regional scale with the advantages of: (i) to be an approach replicable in other contexts; (ii) to be a suitable method in terms of reliability, rapidity and low operational costs. In addition, the CSE susceptibility maps produced give a synoptic overview of the phenomena, which have been classified into five categories which are easier to interpret, where red color shows the most critical zones, prone to future liquefaction occurrences. The easily understandable output cartography, thus, proved to be an important instrument for enhancing seismic knowledge and awareness, not only directed to a specialized public, but also for a wider audience, especially common citizens. They are conceived as useful information tools for CSE risk assessment that can be supportive during emergency to different stakeholders, in future preliminary land use planning, also for part of the territory that is not taken into consideration by the official seismic Microzonation mapping.

The third section of this thesis (chapter six) was dedicated to the analysis of risk perception within the Emilia population after two years of the seismic sequence. The findings have partly confirmed the outcome of previous investigations, such as the national survey done by the INGV (terremototest), contributing with additional evidences and more detailed information about the peculiar context of the 2012 earthquake in Emilia. The investigation was based on a survey through a questionnaire on seismic risk perception, directed towards two different segments of the population, the youth generation of students (secondary and high school) and the “adult” residents reached through the websites of the municipalities. Outcomes from both samples suggest that the

2012 seismic sequence resulted on a general enhancement of risk perception. By interpreting the scores relating to the degree of perceived risk in respect to the real risk for this area of Italy (classified in zone 3: low seismic risk) the survey participants have generally demonstrated a good perception or a light underestimation in the limit of the appropriate range. Significant statistical bivariate associations proved the importance of social and demographic variables (e.g. gender, place of residence or school location inside/outside the epicentral area, level of education) in shaping hazard or risk perception.

This PhD research gives several noteworthy contributions leading to a better understanding of the alteration of seismic perception (beliefs, knowledge, behaviors) in its regional context. Moreover, the results from survey analysis have confirmed the most important initial assumptions and hypothesis, which conceptually indicated the importance of a scientific background in shaping a correspondent seismic perception of risk. Knowledge, in particular from geosciences, allows the public to understand the causes and dynamics of the dangerous phenomena, which is paramount to develop resilient responses at the potentially-affected communities. On the one hand, the analysis highlighted an overall knowledge on the seismic risk in the area; on the other hand, the demand for more information, and the important role attributed to earth sciences were also emphasized, supporting the theoretical framework of this research. Despite its exploratory nature, chapter six has offered some important insights into the key role of the cartographic representation as a relevant medium facilitating the transfer and public understanding of scientific information about CSE susceptibility and in general seismic hazard and risk. Cartography within geographic information systems became a dynamic powerful tool able to rapidly transfer information during the contingency of hazards and disasters, allowing to reach via web a wider, more diverse public.

The visualization of natural hazards and uncertainties through cartographic information allows a cohesive explanation, which can synthesize the complexity of natural hazard events/ geological phenomena and their variables. The three related parts of the research made it possible to show that there is a clear relationship between geosciences, dissemination tools, and construction of perception of risk in the population. The correct information, supported not only by an ethical and scientific justification, but also from adequate tools for information and disclosure, such as the mapping tool, can therefore make a difference in risk management, with regards to prevention and to the post-event management. Disasters can assume alarming proportions in size and effects, with direct and indirect costs for the communities involved, such as loss, trauma, and levy on the

medium and long term. The scientific message, when extended to the civil society, must be clear and unambiguous, as it has important repercussions on the local governance decisions.

In this sense, tools such as the dissemination of online catalogs or maps, can constructively influence prevention and risk mitigation actions. Scientific knowledge should be promoted in any hazardous context and, from a scientific perspective, geosciences must apply a deeper holistic approach in hazard and risk communication, to overcome disciplinary boundaries, and respond to the heterogeneous dimensions of risks.

The inclusiveness should also be directed towards the population. Scientific information has the purpose to create knowledge, deep critical thinking, active citizenship and community responsibility in local sustainable land use and land planning actions. Landscape reading skills enables the possibility of intervention in the processes of participatory construction of the territories. I hope this work has contributed, at least in part, to this ambitious and valuable goal.

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## Appendix A

- Schools that have participated in the risk perception survey

Ist. Galilei Mirandola  
Ist. F. Corni Modena  
Ist. A. Volta Sassuolo  
Ist..A. Tassoni Modena

- Municipalities of residence of the participants in the risk perception survey

Bondeno  
Camposanto  
Carpi  
Cavezzo  
Cento  
Concordia sulla Secchia  
Fianale Emilia  
Guastalla  
Medicina  
Medolla  
Mirabello  
Mirandola  
Modena  
Novellara  
Novi di Modena  
Quistello  
Reggiolo  
Revere  
San Felice sul Panaro  
San Possidonio  
Sant'Agostino  
Soliera

## Appendix B

The questionnaire used for the seismic risk perception survey

### IL TERREMOTO EMILIANO DEL 2012

#### 1. Ha vissuto in prima persona l'esperienza del terremoto che ha colpito l'Emilia nel 2012? \*

*Did you experienced the earthquake that hit Emilia in 2012?*

- Sì
- No

#### 1.a Se sì, ricorda dove si trovava durante le scosse di terremoto del 2012?

*If you did, do you remember where you were during the main quakes in 2012?*

- all'aperto
- in casa
- all'interno di un altro edificio
- Altro: ...

#### 1.b Che reazione ha avuto?

*How did you react? / what was your reaction?*

*Indichi anche più di una risposta*

- paura
- confusione
- indifferenza
- mi sono precipitato fuori
- sono rimasto immobile
- Altro: ...

#### 2. Ricorda quando sono avvenute le scosse più forti?

*Do you remember when the strongest tremors happen/occurred?*

- sì
- no

#### 2.a Se ha risposto sì, potrebbe indicare in quale mese e giorno sono avvenute?

*If you do, could you please tell in which day and month they happened?*

...

#### 2.b Quali sono stati i comuni maggiormente colpiti dal sisma emiliano? \*

*Which municipalities have been most damaged?*

*Indichi anche più risposte*

- Luzzara
- Mirandola
- San Felice Sul Panaro
- Medolla
- Ferrara
- Altro:

#### 3. Secondo la sua opinione è possibile prevedere dove e quando si verifica un terremoto? \*

*On your opinion is it possible to foresee where and when an earthquake may happen?*

*Indichi anche più risposte*

- sì, attraverso il sismografo
- sì, osservando gli animali, perché avvertono il pericolo in anticipo
- no, si può solo determinare la pericolosità di una zona
- non so
- Altro:

**4. È vero che i terremoti avvengono sempre nelle stesse zone? \***

*Is it true that earthquakes occur always in the same areas?*

- Sì, i terremoti tendono a colpire sempre le stesse zone ma non si può sapere con precisione quando e con che intensità
- no, i terremoti colpiscono sempre zone diverse
- tutto è legato al caso, possono interessare nuove zone o zone già colpite
- non so
- Altro:

**5. Qual è il pericolo più frequente in caso di terremoti? \***

*Which is the most recurring danger/risk in case of earthquakes?*

indichi anche più risposte

- finire in una voragine del terreno
- essere colpiti da oggetti che cadono
- essere coinvolti nel crollo della casa
- sprofondare nel terreno e fango
- Altro:

**6. Conosce il significato di pericolosità sismica? \***

*Do you know the meaning of seismic hazard?*

- sì
- no
- forse

**6.1 Se sì, provi a definire questo concetto**

*If you do, try to define this concept*

**7. Conosce il significato di rischio sismico? \***

*Do you know the meaning of seismic risk?*

- sì
- no
- forse

**7.1 Se sì, provi a definire questo concetto**

*If you do, please try to explain this concept/idea*

**8. Considerando la Regione Emilia Romagna, vede il terremoto come un evento... \***

*Concerning Emilia Romagna land, you consider the earthquake as an event...*

*Da 1 a 5 il valore più alto è 5*

	1	2	3	4	5
Fatale	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sconosciuto alla scienza	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
A basso rischio personale	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Un nuovo rischio	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Che è possibile influenzare	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Prevedibile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Che si verifica spesso	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Che si verifica molto raramente	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Causato dal fato	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Che si verificherà in futuro	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Causato dall'uomo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Un evento a cui non pensi	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Una punizione divina o del destino	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Che si può mitigare con la pianificazione	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Un evento naturale	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**9. Se prova ad immaginare un terremoto nell'area/regione in cui vive, come lo descriverebbe? \*If you try to imagine an earthquake in the area/land where you live:**

	1	2	3	4	5	
Inatteso	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Atteso
Debole	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Forte
Piccolo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Grande
Lontano	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Vicino
Corto	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Lungo
Distruttivo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Non distruttivo
Lontano nel tempo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Vicino nel tempo

**10. Quali altri pericoli naturali pensa siano più meno probabili nella sua provincia rispetto ad un terremoto? \***

*Which other natural risks do you think are more or less likely in your province compared to an earthquake?*

	Meno Probabile	Stessa Probabilità	Più probabile
Alluvioni	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Frane	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Eruzioni vulcaniche	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Esondazioni	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Uragani o trombe d'aria	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Maremoti	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**11. Crede che la Pianura Padana possa in futuro essere interessata da terremoti di entità considerevoli? \***

*Do you think Po Plain could be affected by big extent earthquakes? \**

- sì
- no
- non so

*11.a Se sì, perché... If you do, why?*

...

*11.b Se no, perché...If you don't, why?*

...

**12. Conosce le cause geologiche che hanno determinato la sequenza sismica emiliana del 2012? \***

Do you know the geologic causes originating the 2012 Emilian seismic sequence?

- sì
- no
- non so

12.a Se sì, quali sono?

If you do, which are they?

12.b Se sì, possedeva queste conoscenze anche prima del sisma del 2012?

If you do, were you aware of them before 2012 earthquake?

- sì
- no

**13. Ricorda se in passato zone della Regione Emilia Romagna sono state colpite da forti terremoti? \***

Do you remember if in the past, other areas of Emilia Romagna land have been affected by big earthquakes?

- sì
- no
- non so

13.a Se sì, ricorda quando (indicativamente in quale secolo/decennio) e dove sono avvenuti questi terremoti?

If you do, do you remember when (in which century and decade approximately) and where they happen?

**14. Rispetto ad un terremoto, come descriverebbe le istituzioni e le persone intorno a lei? \***

With reference to an earthquake, how would you describe Institutions and people around you?

	1	2	3	4	5	
Preparate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Impreparate
Fataliste	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Concrete
Sicure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Insicure
Vicine	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Lontane
Organizzate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Disorganizzate
Solidali	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Non solidali
Interessate	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Disinteressate

**15. Come descriverebbe il territorio dove vive? \***

How would you describe the territory/area where you live?

	1	2	3	4	5	
Rurale	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Urbanizzato
Non Industrializzato	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Industrializzato
Moderno	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Storico
Povero	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Ricco
Organizzato	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Disorganizzato
Isolato	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Ben collegato

**16. Saprebbe spiegare i significati dei seguenti termini... \***

Could you explain the meaning of the following words...?

	Sì	No	Non so
Vulnerabilità	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Rischio	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pericolosità	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

16.a Se sì, definisca i termini elencati: 1 rischio 2 vulnerabilità 3 pericolosità  
 If you can, please define the listed words: 1. Risk 2. vulnerability 3. hazard

**17. Per classificazione sismica s'intende..... \***

*Seismic classification means....*

- la divisione in 4 zone del territorio sulla base della frequenza e della intensità dei terremoti che l'hanno colpito
- un elenco di tutti i terremoti più disastrosi avvenuti nel nostro paese
- non so

Altro: ...

**18. Sa in quale zona sismica rientra il tuo Comune? \***

*Do you know which seismic area your Municipality belongs to?*

- sì
- no
- non so

**18.a Il comune in cui vive, in base alla riclassificazione sismica, in quale classe si trova?**

*The Municipality where you live, based on the seismic reclassification, in which class/category is placed?*

- 1
- 2
- 3
- 4
- non so
- Altro: ...

**19. Sa se nel suo Comune esiste un piano di emergenza?**

*Do you know if there's any emergency plan in your Municipality?*

- sì
- no
- non so

**20. Sa chi deve predisporre il piano di emergenza per il suo Comune? \***

*Do you know who is in charge of arranging the emergency plan in your Municipality?*

- vigili del fuoco
- comune
- protezione civile
- prefettura

**21. Per quanto riguarda la sicurezza, dal punto di vista del rischio sismico considera... \***

*Concerning the safety, from the standpoint of the seismic hazard you consider*

	molto sicuro	sicuro	poco sicuro	per nulla sicuro
la sua casa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
il luogo in cui lavora	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
il centro storico del suo paese/città	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
la scuola del suo paese/città	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
l'ospedale del suo paese/città	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**22. Considera di essere informato sui rischi naturali che possono interessare il territorio dove vive?**

*Do you think to be informed about the natural risks that can affect the area where you live?*

- molto poco
- poco
- abbastanza
- molto

**23. Considera di essere informato sul rischio sismico del territorio in cui vive?**

*Do you think to be informed about the seismic hazard of the area where you live?*

- molto poco
- poco
- abbastanza
- molto

**24. Quali sono le sue principali fonti d'informazione sul terremoto?**

*Which are your main information sources about the earthquake?*

indichi anche più risposte

- Televisione
- Internet
- Giornali
- Passaparola delle persone
- Regione
- Comune
- Amici, familiari
- Protezione civile
- Provincia
- Enti di ricerca
- Scuola
- Altro: ...

**25. Ha partecipato a progetti, iniziative o campagne informative sulla riduzione del rischio sismico?**

*Did you take part in projects, initiatives or information campaigns about seismic risk decrease?*

- sì
- no

\*

25.a Se sì, a quale/i iniziative ha partecipato? (indichi anche più risposte )

*If you did, which initiatives did you take part to?*

- edurisk
- terremoto io non rischio
- sisifo
- Altro:

25.b Se sì, quale è stato il suo livello di partecipazione/coinvolgimento?

*If you did, which has been your participation/involvement degree?*

	1	2	3	4	5	
attivo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	passivo

25.c Se sì, quanto considera sia stato utile?

	1	2	3	4	5	
poco	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	molto

**26. Crede che una maggior conoscenza scientifica sul terremoto potrebbe essere utile per comprendere meglio questo fenomeno e il rischio sismico? \***

*Do you think that a greater scientific knowledge about earthquake could be useful to better understand this event and the seismic risk?*

- sì
- no
- non so

#### SEZIONE DEDICATA AGLI EFFETTI SISMOINDOTTI

**27. Sa cosa sono gli effetti cosismici o sismoindotti? \*** *Do you know about coseismic surface effects?*

- sì
- no
- non so

27.1 Se sì, li definisca con parole sue  
If you do, please try to define them ...

28. Ha mai sentito parlare degli effetti cosismici o sismoindotti...

*Have you ever heard about coseismic surface effects?*

	Sì	No
prima del sisma del 2012	<input type="radio"/>	<input type="radio"/>
solo dopo il sisma del 2012	<input type="radio"/>	<input type="radio"/>
sia prima che dopo	<input type="radio"/>	<input type="radio"/>
né prima né dopo	<input type="radio"/>	<input type="radio"/>

**29. Saprebbe dire se il sisma che ha colpito la pianura emiliana nel maggio-giugno 2012 ha provocato tali effetti? \*** *Could you tell if the earthquake that hit the Emilia Po Plain on May/June 2012 caused such kind of effects?*

- no
- non so

**30. Ha potuto osservare direttamente, in prima persona, tali effetti nelle zone colpite dal sisma del 2012? \*** *Could you directly, at first-hand, observe those effects in the areas hit by 2012 earthquake?*

- sì
- no
- non ricordo
- Altro...

30.a Se sì, in quale comune/località ha osservato tali effetti? *If you did, in which Municipality did you observe those effects?*

30.b Se sì, dove ha osservato gli effetti sismoindotti? (indichi anche più di una risposta) *If you did, where did you observe the seismic-induced effects? (you can flag more than one answer)*

- zona urbana
- area rurale
- Altro: ...

30.c Quali effetti ha osservato? (indichi anche più risposte)

*Which kind of effects did you observe?*

- Fratture del terreno
- Fratture del terreno con fuoriuscita di sabbia
- Vulcanelli di sabbia
- Sprofondamenti del terreno
- Rigonfiamenti del terreno
- Variazione del livello d'acqua nei pozzi
- Fuoriuscita di acqua e sabbia dai pozzi
- Variazione del livello d'acqua nei fossi o canali
- Fuoriuscita di acqua e getti d'acqua
- Apertura di voragini nel terreno
- Variazioni di temperatura dell'acqua nei pozzi
- Franamenti di argini o sponde di canale
- Altro:

30.d I fenomeni geologici superficiali che ha osservato hanno interessato (indichi anche più risposte)

*The superficial geologic phenomena you observed affected:*

- strutture abitative
- campi coltivati
- strade
- ponti
- edifici pubblici
- edifici storici
- chiese e altri monumenti
- Altro...

**31. Secondo la sua opinione, durante il sisma del 2012, i fenomeni cosismici o geologici di superficie sono stati prodotti... \***

*On your opinion, during 2012 earthquake, co-seismic or surface geologic phenomena have been caused:*

- dallo sciame di scosse di minor entità
- principalmente dalle scosse più forti del 20 - 29 maggio 2012
- non saprei
- Altro: ...

**32. Quando si sono manifestati questi fenomeni ?**  
*when these events/phenomena did take place?*

Indichi anche più risposte

- molto prima delle scosse di terremoto
- poco prima delle scosse di terremoto
- durante le scosse di terremoto
- poco dopo le scosse di terremoto
- molto dopo le scosse di terremoto
- Altro: ...

**33. Se non ha direttamente osservato nessun fenomeno sismoindotto/cosismico durante il sisma che ha colpito la sua regione nel 2012, ne ha sentito parlare?**

*If you didn't directly observe any seismic-induced/co-seismic event during the earthquake that hit your land/region in 2012, have you heard about it?*

- sì
- no

33.a Se sì, da chi?

*If you did, from whom?*

**34. Ha sentito raccontare l'accadimento di questi fenomeni da testimoni oculari?**

*Did you hear tell about these phenomena from eye witnesses?*

- sì
- no
- non so

**35. Secondo la sua opinione, dopo un terremoto questi fenomeni sono....** \* *On your opininon, after an earthquake, these events are...*

	1	2	3	4	5	
normali <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	anomali
provocati <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	non provocati
dall'uomo <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	dall'uomo
naturali <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	non naturali
usuali <input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	rari

**36. Saprebbe indicare quali sono le possibili cause scatenanti di questi fenomeni? \***

*Could you tell which are the possible trigger causes of these events?*

- sì
- no
- non so

36.a Se sì, potrebbe indicarle?

*If you can, would you indicate them?*

**37. Saprebbe indicare quali sono i possibili fattori predisponenti di questi effetti? \*** *Could you tell which are the possible predisposing factors of these events?*

- sì
- no
- non so

37.a Se sì, potrebbe elencarli?

*If you can, would you list them?*

...

38. Secondo la sua opinione perché il terremoto nella Pianura avrebbe indotto fenomeni geologici superficiali?  
*On your opinion, why the earthquake in Po Plain would have caused surface geologic phenomena?*

39. Secondo la sua opinione i fenomeni sismodotti avrebbero una correlazione con l'idrologia, la geologia, la geomorfologia, la litologia della Pianura Padana? \* *On your opinion, do the seismic-induced phenomena, have a correlation with Po Plain Hydrology, geology, geomorphology and lithology?*

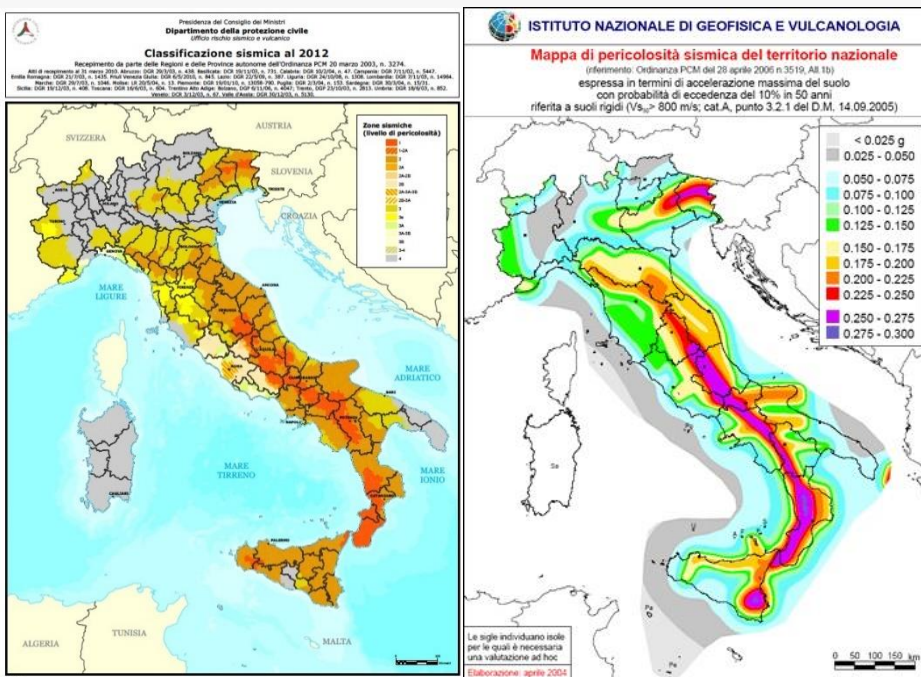
<input type="radio"/>	sì
<input type="radio"/>	no
<input type="radio"/>	non so

39.a Se sì, provi a spiegare il perché If they do, please try to explain why?

**SEZIONE DEDICATA ALLA CARTOGRAFIA -PERICOLOSITA'- RISCHIO SISMICO**

Dopo aver osservato con attenzione le mappe, la invitiamo a rispondere ad alcune domande. Si ricorda che per Mappa s'intende l'intero documento in ogni sua parte: titolo, corpo della carta (fondo cartografico e tematica), legenda, scala, testo, uso dei colori etc.

**MAPPA 1 and MAP 2**



40. Ha già visto, conosce questa mappa? \* *Do you know this map?*

	sì	no	forse
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

40.a Se sì, dove l'ha già vista (in che occasione o contesto)? *If you do, where have you seen it (in which occasion or context?)*

	internet	giornali/riviste	comune	luogo di lavoro/scuola	TV
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Altro contesto

**41. Nella visione d'insieme, l'informazione cartografica rappresentata è:** \* *From a general overview, do you consider the cartographic information*

Mappa 1

	per nulla	poco	abbastanza	molto
chiara	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
completa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
immediata	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
complessa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
comprensibile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

\*

Mappa 2

	per nulla	poco	abbastanza	molto
chiara	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
completa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
immediata	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
complessa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
comprensibile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**42. Leggibilità della mappa: formulazione iconografica- linguistica**

*Readability of the map: linguistic – iconographic information*

Mappa 1

	per nulla	poco	abbastanza	molto
chiari i simboli in legenda	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
uso dei colori appropriato al tema	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
linguaggio conosciuto	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
termini tecnici chiari	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

\*

Mappa 2

	per nulla	poco	abbastanza	molto
chiari i simboli in legenda	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
uso dei colori appropriato al tema	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
linguaggio conosciuto	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
termini tecnici chiari	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**43. Chiarezza dell'informazione**

*Information Clear*

Mappa 1

	per nulla	poco	abbastanza	molto
informazione ordinata	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
informazione coerente	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
informazione di difficile lettura	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Mappa 2

	per nulla	poco	abbastanza	molto
informazione ordinata	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
informazione coerente	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
informazione di difficile lettura	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**44. Densità delle informazioni \***

*Information Density*

Mappa 1

	1	2	3	4	5	
* troppe informazioni	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	limitata all'essenziale

Mappa 2

	1	2	3	4	5	
* troppe informazioni	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	limitata all'essenziale

Mappa 1

	1	2	3	4	5	
distoglie l'attenzione dallo scopo informativo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	concentrata sullo scopo informativo

Mappa 2

	1	2	3	4	5	
distoglie l'attenzione dallo scopo informativo	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	concentrata sullo scopo informativo

**45. Stimoli aggiuntivi alla lettura. La carta per lei è ... \***

*Additional reading incentives. In your opinion the map is...*

Mappa 1

	1	2	3	4	5	
interessante	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	insignificante
utile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	inutile

\*

Mappa 2

	1	2	3	4	5	
interessante	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	insignificante
* utile	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	inutile

**46. Ritiene che la carta sia attendibile, che rappresenti cioè il tema trattato in modo scientifico? \***

*In your opinion the paper is reliable, and representative the theme in a scientific way?*

	per nulla	poco	abbastanza	molto
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**47. Avrebbe bisogno di chiarimenti aggiuntivi per poter comprendere meglio la carta?**

*Would need additional clarifications in order to better understand the map?*

	sì	no	forse
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**48. Ritiene che la popolazione possa facilmente comprendere la mappa? \***

*In your opinion people can easily understand the map?*

	per nulla	poco	abbastanza	molto
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**49. Considerando il sisma che ha colpito l'Emilia nel 2012, crede che la carta rappresenti in modo realistico la pericolosità/classificazione sismica della sua regione? \***

*Considering the earthquake that hit the Emilia in 2012 in your opinion the map represents a realistic seismic hazard / classification of the region? \**

	per nulla	poco	abbastanza	molto
Mappa 1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mappa 2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**50. Considera che la cartografia sia uno strumento appropriato per la divulgazione della pericolosità e/o rischio sismico? \***

*In your opinion cartography is an appropriate tool for the dissemination of knowledge in relation to seismic hazard and / or risk?*

- si
- no
- forse