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The ANDROID case study; Venice and its territory: identification of hazards and impact of multi-hazard scenarios

Snjezana Knezic[a]*, Mickael Scudeller[b], Maurizio Indirli[c], Francesco Romagnoli[d], Tatjana Kuzņecova[e], Skevi Perdikou[f]

[a]*University of Split, Croatia,*
[b]*Ecole des mines d'Alès, France*
[c]*ENEA Research Centre of Bologna, Italy*
[d,e]*Riga Technical University, Latvia,*
[f]*Frederick University, Nicosia, Cyprus*

Abstract

The objective of the paper is to review already published scientific papers and other relevant documents to identify hazards, their intensities and probability of occurrence in the Venice territory. In order to achieve the objective, the authors have selected relevant research papers and state of the art documents. Since the Venice and its territory are prone to various hazards, multi-hazard scenarios have been taken into consideration. Hazard impacts are the following: earthquake, tsunami and meteotsunami, flooding/"acqua alta", subsidence, coastal erosion, salt wedge intrusion, pollution. The paper classifies potential impacts and recognises possible combinations of hazards that may occur in case study territory. A multi-hazard scenarios analysis considers impacts which, either occurring at the same time or shortly following each other, are dependent from one another or because they are caused by the same triggering event or hazard, or merely threatening the same elements at risk (vulnerable or exposed elements) without chronological coincidence (EU, 2010). The research presented in the paper serves as a support for cross-border multi-hazard assessment in other North-Eastern Adriatic Sea areas.

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Keywords: Venice, natural/anthropogenic hazards, multi-hazards

* Corresponding author. Tel.: +385-21-303-360; fax: +385-21-465-117.
E-mail address: knezic@gradst.hr

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1. Introduction

ANDROID is an Erasmus academic network that aims to promote co-operation and innovation among European Higher Education to increase society's resilience to disasters of human and natural origin. The paper is related to the one of the project's activities, namely the analysis of a capacity of European cities to address disaster risk. The paper reviews published papers and studies of disasters' impacts on a selected vulnerable area in Europe to raise awareness of the importance of disaster resilience research and education. Venice and its territory have been selected as a representative case study of a region that could be affected by cross-border disastrous events (Italy, Slovenia, Croatia). Venice and its territory are prone to many various hazards, which lead to the possibility of multi-hazards scenarios that may have strong impacts on the city of Venice and its lagoon.

Venice is located in Italy's north-eastern coast at the northern part of the Adriatic Sea. The Adriatic forms a long, narrow, semi-enclosed section of the Mediterranean Sea between the eastern coast of Italy and the Balkans (Scearce, 2007). The Lagoon of Venice, which has a surface of about 500 km^2 and an average depth of approximately 1 meter, represents the major wetland connected to the basin (Lovato et al, 2010). The lagoon is a 52 km long and 8–14 km wide shallow water body. It is linked to the northern Adriatic Sea by three inlets: Lido, Malamocco and Chioggia (Zonta et al, 2005). The lagoon of Venice, the largest of Mediterranean Sea, is not so different from many other tidal lagoons in the world and it is also subjected to similar threats due both to ''natural'' evolution and to anthropic actions (Campostrini, 2004). Many natural phenomena accentuated by anthropic actions led Venice and its Lagoon in a crisis situation. Sea-level rise, subsidence, erosion, pollution, fishery activity, and wave motion have all contributed to the general crisis of the Venice lagoon system (Deheyn and Shaffer, 2007). In a closer future, several hazard scenarios are susceptible to happen and threaten Venice and its Lagoon on several fronts (environment, society/economy, infrastructures/buildings). Thus, the lagoon is a highly complex issue, and the Venice problem is emblematic of our times, representing not just environmental complexity but also legislative, scientific, and institutional intricacy (Deheyn and Shaffer, 2007).

2. A review of potential hazardous events

This section provides a literature review of various hazards and their impacts on Venice and surrounding areas.

2.1. Tsunamis – Earthquakes

Italy is located in an active seismically zone and many earthquake events have been reported over the years causing great destructions. In many cases the earthquake activity in the sea and specifically in the Adriatic Sea that separates the Italian peninsula from the Balkan peninsula has resulted in tsunamis, in spite of the fact that the great majority of seismic tsunamis is generated in oceans. A study by Pasaric et al., (2012) has identified in the last 600 years, fifteen true tsunami events occurring in the Adriatic, one of which was characterised as very strong, six as strong or rather strong and eight were light tsunamis. A similar study by Paulatto et al., (2007) has reported 60 tsunamis in the last 2000 years on the Adriatic Sea domain while they stated that the Eastern coast of the basin seems to be most prone to tsunamis within the Adriatic Sea. Herak et al., (2005) reported that seismicity of the Adriatic Sea is mostly referred to as weak compared to the seismic activity along its coasts. However, they concluded that the Central Adriatic in the last 20 years is characterized as a seismically active region whose seismicity is comparable to or even higher than some of the well-known and recognized neighbouring epicentral areas. A study by Maramai et al. (2007) has reported that in the last decades, significant seismicity has been noticed in the Adriatic basin area. They also mention that in the Italian Tsunami Catalogue, eight tsunami events have been reported in the central Adriatic region characterized mainly as low intensity apart from one on 30th July 1627 in Gargano, which was characterized as very strong. Specifically about Venice, Pasaric et al. (2012) in their paper mention a strong impact occurred in Gulf of Venice as described in the coeval bibliographical sources: on 26th March 1511, a strong earthquake occurred in north-eastern Italy where water in the canals rose so much that the inhabitants were frightened. After the earthquake, some canals dried out, and anomalous oscillations in the canals were also observed. Tiberti et al. (2008) have reported that the northwest portion of the Adriatic basin is the most vulnerable due to its large low-topography coastal area extending over 150 km that includes the city of Venice. They also concluded the northern part of the Adriatic coast that includes Venice and Trieste is safer than the southern part.

2.2. Subsidence

For Venice, subsidence can be hazardous due to the low water level of the city and also due to the damage it can cause to the heritage of the city. As stated by Carminati et al., (2007) the problem of Venice is the combined effect of the land subsidence and the absolute sea level rise, as both contribute to increase the apparent sea level. They also concluded that post seismic subsidence associated to seismogenic movements of thrust faults located around the Po Plain, at the foothills of the eastern Alps, could be of the order of 1 cm. Human intervention can cause subsidence as is the case of the mobile barriers installed in Venice to protect the city from flooding. Strozzi et al., (2009) have detected significant local settlements of a few centimetres between March 2008 and January 2009 at the three inlets induced by the construction works. They reported that during the 1950s and 1960s groundwater withdrawals induced 9 cm of land subsidence. Another source of anthropogenic subsidence is the groundwater withdrawals as a result of the industrial boom after the 2nd World War (Carbognin et al., 2010). Today, the anthropogenic component of the land subsidence only addresses local, short-time interventions such as restoration works and inherent deformations of historical structures (Carbognin et al., 2010). Other reasons of land subsidence include geochemical subsidence. The relative subsidence of the city is associated with sea level rise (Carbognin et al., 2007).

2.3. Pollution

The levels of pollution experienced in Venice have seriously impeded the balance between nature and the unique engineering structure of the city (Wetzel and Van Vleet, 2004). The Venice Lagoon environment has been heavily affected by anthropogenic activities and uncontrolled discharge of pollutants from both diffuse and point sources (Belluci et al., 2000). Another means of pollutants transporting are the flooding events. Other sources of pollutants for the Venice Lagoon include direct discharge from the industrial area of Porto Marghera, the atmospheric depositions, the city of Venice, two wastewater treatment plants located on the lagoon border and inputs of petroleum from oil spills and motorboat traffic. Moreover, contaminants accumulated in the sediment of some shallow water areas of the lagoon can be re-mobilized by the effects of both physical and biological mechanisms (Collavini et al., 2005). A study by Frignani et al., (2005) has reported that the highest values of micro-pollutants were found in the San Giuliano Canal that is likely the major conveyor of pollutants from the industrial district to the area of Campalto. Frignani et al., (2001) have reported that the contaminated sediments of the canals of the industrial area are not mobile, and not harmful to the lagoon environment, unless they are resuspended by dredging operations or passage of ships.

The ecological status of the Venice lagoon has suffered from the economic development (e.g. chemical industry, fishing, tourism, glass manufacturing) increased anthropogenic pressure on the lagoon environment, including: chemical pollution, eutrophication, and erosion (Micheletti et al., 2011). Another cause of environmental hazard for the Venice lagoon is the fact that Venice has never maintained a main sewage system (Scearce, 2007). For this reason, a large portion of the waste generated in the historic centre of Venice has always been discharge directly into its channels. Recently, an increasing number of septic systems have been installed. A study by Guédron et. al., (2001) has reported that Venice Lagoon has been recognized as mercury (Hg) contaminated area. The two chlor-alkali plants of the industrial area of Porto Marghera were identified as the main contributors to the contamination of the lagoon. Apart from water pollution in the Venice canals, the city suffers from atmospheric pollution, too. Most of these activities take place inside the Porto Marghera industrial zone (Guerzoni et. al., 2005).

2.4. Flooding

The flooding in Venice has become more regular due to climate changes and global warming, causing great destruction to coastal surfaces and groundwater, coastal ecosystems, marine biological communities and commercial species. The ground elevation of the historical centre emerges only 90 cm above the mean sea level, while the range of an average spring tide is around + 0.5 m, thus even a moderate storm surge can cause damage if it occurs at spring high water (Vieira et al., 1993). A sea flooding of the city of Venice, which is locally named acqua alta (literally high water) is generated by the following factors (Camuffo et al., 2003):

- a pressure pattern with a low on the western or central Mediterranean, generating two winds: a Sirocco, which drags water from SE along the Adriatic Sea and Bora in the Venice area, which drags water from NE;
- the so-called barometric effect, which raises the sea level where the atmospheric pressure is lower;
- the rapid change in atmospheric pressure, which generates a free oscillation in the Adriatic sea (seiche);
- the luni-solar astronomical forces.

A study by Camuffo et al., (2003) has reported that the long history of flood surges at Venice has shown an alternation of ‘regular’ periods with one or two surges per decade, and anomalous periods with an increased flooding rate. In the period of 2000-2009 the number of events with water level above 100 cm was 141 (OCDE, 2010). A study by Melaku Canu et al., (2001) has reported that in the last 40 years, the flooding events have increased in frequency and intensity. Tomasin, (1973) has also studied the flooding events in Venice and has concluded that even a small increase in sea level, due to winds and atmospheric pressure, can occasionally flood large parts of the town, disturbing many activities. These phenomena occur five to ten times every year. The flooding events in Venice are also due to the occurrence of large sea level rises in the northern Adriatic, as a result of the strong SE winds known as Scirocco. On top of this, the tide may lead, under unfavorable conditions (high water at spring tides), to catastrophic flooding (Vieira et al., 1993). The highest Acqua Alta event that has ever been observed and measured in the city of Venice happened in November 1966, when the water level rose to 1.96 m above the local gauge reference level (LGL), with a storm surge contribution of 1.90 m (LGL) as reported by Bajo et al., (2007). The frequency of flooding has increased dramatically, with St. Mark’s Square flooding more than 50 times per year in the 1990s (Deheyn and Shaffer, 2007). Loss of land has made Venice even more vulnerable to flooding events (Scearce, 2007). A study by Bellucci et al., (2007) has found that the fundamental control on marsh accretion in the Venice Lagoon was the frequency of flooding of a marsh site by acqua alta.

2.5. Salt wedge intrusion

Venice lagoon suffers from salt contamination that involves deep Pliocene aquifers: fossil brines are noticed below the Venice Lagoon, at depths varying from 300 (Chioggia) to more than 1000 m (northern lagoon) as reported by Di Sipio et al., (2006). Salt migration is mainly caused by sea tidal oscillations and human perturbation. The groundwater withdrawals from the aquifers of Venice result in sea water intrusion into the aquifers and therefore increase in water salinity.

2.6. Erosion

As discussed by Deheyn and Shaffer, (2007) the environmental problems of Venice have been further compounded due to the increasing erosion of the lagoon. This results in the lagoon getting deeper and the disappearance of salt marshes and mud flats. A study by Scearce, (2007) showed that each year, tectonic processes lead to a loss of about 1.0 mm height relative to sea level on the Adriatic plate. The city loses an additional 0.3 mm per year due to the gradual rise in sea level associated with the process of deglaciation that has been occurring since the end of the last ice age. The combined loss of land due to these natural phenomena averages to about 1.3 mm per year.

3. A classification of the main hazardous events related to the Venice and Adriatic region

The aim of this section is to classify the main hazardous events related to the Venice and Adriatic region in a form of table summarizing their origins and their impacts on environment, society, economy, infrastructure and buildings. The classification is based on the review presented in the Section 2 and will serve as an input for resilience assessment within the ANDROID project. The classification is presented in the Table 1.

Table 1. Classification of the hazardous events in Venice

		Impact on		
Event	**Origins**	**Environment**	**Society & Economy**	**Infrastructure/Buildings**
Earth-quake	- Tectonic movements	- Land subsidence - Creation of tsunami	- Casualties	- Damages, destruction
Acqua Alta	- Low air-pressure; - Sirocco wind; - Bora wind; - Luni-solar astronomical forces; - The phenomenon of "seiche"; - A combination of the above natural phenomena;	- Flooding raises water level of salt marshes: habitats may be endangered, change of water salinity; - Increase of islands and channels erosion; - Discharge of pollutants within the lagoon and its catchment; - Change in ecological parameters;	- Flooding affects tourism; - Destroyed stocks, fish farms, supply chains; - Loss/damage of property; - Psychological impacts;	- Flooding influences: sewage system, roads, harbours, terrain and sub-terrain levels of buildings; - Damaged cultural heritage; - Walls impregnated with sea salt cause destroyed mortar, marble, limestone, brick and other building materials;
Sub-sidence	- Acqua alta; - Groundwater pumping; - Geomorphologic processes; - Geochemical processes; - Earthquake; - Compaction of the ground by buildings;	- Sea level rise	- Impact on economy: tourism; - Impact on society: loss/damage of housing and property, psychological impact;	- Damage on built environment (buildings, roads, public facilities)
Coastal erosion	- Acqua alta - Wave from the motor boats	- Loss of sediments; - Decreased surface area of salt marshes and mud flats; - Creation of tsunami;		
Salt intru-sion	- Acqua alta; - Withdrawal of ground water; - Land subsidence;	- Decline of water quality;	- Threat to human health;	- Walls impregnated with sea salt: destroys mortar, marble, limestone, brick and other building materials;
Pollu-tion	- Chemical industry; - Metallurgic industry; - Harbours - oil spills; - Sewage systems; - Discharge from Porto Marghera (heavy metals, oil, chemical products); - City waste discharge; - Drainage basins from agriculture and livestock farms; - Water treatment plants; - Aerosols; - Urban waste incineration; - Traffic emissions;	- Eutrophication of the lagoon- algal blooms and anoxic events; - Ecotoxicity; - Reduction of biodiversity; Impacts on ecosystem services; Pollution storage in sediments;	- Tourism; - Fishery; - Loss from reduction of ecosystem services; - Threats to human health;	

4. Multi-hazard scenarios for Venice

Since the Venice area is prone to various hazards the potential of multi-hazard effect is relevant. Referring to the above mentioned hazard classification, two multi-hazard scenarios are described. The scenarios are based on the past events that have been evaluated in the Section 2 and classified in Table 1. The paper does not investigate the probability of these scenarios, just try to emphasize the possibility that events could happen simultaneously or sub-sequentially, no matter if they are being triggered by one another or they are fully independent. Furthermore, the scenario evaluation approach could strongly influence the social awareness of the hazardous events and contribute to the better resilience of the society in general.

4.1. First scenario

The first scenario is based on the fact that the Venice Lagoon is situated close to the earthquake prone area in Italy and Slovenia, so a seismic event in this region may influence the Lagoon. The effects of the seismic waves may trigger some other events like land subsidence, which together with earthquake, may possibly provoke salt intrusion into groundwater. The chain of the events is described solely in the context of resilience analysis.

The scenario starts with a relevant earthquake in terms of magnitude, which occurs in the area close to Venice caused by the overall movement of tectonic plates in Europe and Africa in addition to the existence of well-defined fault-lines and geological movements crisscrossing the area may provokes earthquakes. The scenario supposes the earthquake causes a land subsidence on the Venice Lagoon, which lately provokes damages to a pollutant storage tank in the industrial area of Porto Marghera. The following hazardous event is a discharge of pollutant into the lagoon. In the same time, the earthquake / land subsidence provokes a salt intrusion in the groundwater.

The effect of these events is multifold. Presuming that the effect of the earthquake is not as strong as it is in the epicenter, the scenario excludes fatalities. Primarily, infrastructures and buildings are affected in the sense that the earthquake and land subsidence causes damage / destruction on built environment (buildings, roads, public facilities, historical monuments, etc.) in the cities of the area. Secondly, regarding the effect on society the human health is affected. In fact, on one hand there is the salt intrusion, which increases the salinity of the groundwater, which leads to a decrease of drinking water quality. On the other hand, the pollution of the lagoon contaminates fauna and flora and spreads into the cities channels, which can provoke the spread of diseases. Generally, there is a strong psychological impact for people who living in this area. Regarding economy, all the activities linked to the environment / ecosystem are affected (fishing, aquaculture, etc.). The tourism is also mainly affected. Environmental impact is mostly related to two main consequential events: the salt intrusion in groundwater increases the salinity of water, and the pollution in the lagoon provokes an eutrophication of the lagoon favouring algal blooming and anoxic events. This leads to an increasing of the ecotoxicity of the lagoon with a reduction of biodiversity. Furthermore, the pollutant will store on the sediments of the lagoon with the needs to be further removed.

4.2. Second scenario

The second scenario is based on the effect of the phenomena of acqua alta occurring in combination with a discharge of pollutant in the Venice Lagoon caused by the potential technical failure. The discharge of pollutants occurs in the industrial area of Porto Marghera. As described in Section 2, the phenomenon of acqua alta is caused by a number of factors, out of which the most important are low air pressure and Sirocco wind. The discharge of pollutants in the lagoon could be cause by a leak or a human mistake on a storage tank of pollutants. The phenomenon of acqua alta causes the flooding of the city of Venice, which provokes a salt intrusion directly affecting the quality (both structural and physical) of the walls. The pollutants in the lagoon are spread within the city carried by flooding effect caused by acqua alta.

One of the effects of the pollution in the lagoon is an increased eutrophication of the water environment. Algal blooms and anoxic events are a direct effect of such event. This also brings a higher level of ecotoxicity of the lagoon and a reduction of the overall biodiversity. Furthermore, the pollutant will store on the sediments of the lagoon. The acqua alta causes flooding which raises water level of salt marshes. It also increases islands and channels erosion and directly affecting the overall ecological parameters.

The environmental impact is also directly affecting human health. In fact, the pollutants, which will be spread all over the city, would have a direct negative feedback on the overall population. Pollutants affect storage of drinking water, spread to the ground floor of houses and contaminate the population, what is susceptible to create an epidemic. On the other hand the flooding, due to acqua alta, may provokes casualties in the city. Within this environmental-oriented damage there is also a direct connection with the social and economic spheres. In fact the acqua alta destroys stocks, fish farms, supply chains. All the activities linked to the environment / ecosystem are affected (fishing, aquaculture, etc.). The tourism is also mainly affected.

Generally, there is also a strong psychological impact for people who living in this area. Moreover, the flooding affects and may cause damage or destruction of several infrastructures: sewage system, roads, harbours, terrain and sub-terrain levels of buildings (historical monuments or private houses). The flooding also impregnate walls with sea salt, as a result the infrastructure become increasingly weak and in long term the salt intrusion may be responsible of the destruction of mortar, marble, limestone, brick and other building materials.

5. Conclusions and recommendations

The study provides a preliminary insight in multi-hazards events in terms of overall resilience implications related to the identified potential single hazards in the Venice city. The study has to be seen under the prospective on building a proper framework to specifically create increased system resilience for multi-hazards disruptive scenarios (both natural and man-made). For this reason the conclusion to build up a quantitative tool based on specific metrics (at different dimensions: physical, social, economical, technical and environmental) useful for planners, stakeholders as well as policy makers is evident.

The ability to measure resilience in order to cope with potential unpredicted disruptive event (thus decreasing the overall risk) was already a key issue within the Hyogo Framework (UNISDR, 2005), but a wider, exhaustive and universal methodology for multi hazard scenario is still lacking. The potential applicability of a specific quantitative approach focused on multi-hazard scenarios – aimed to potential evaluate increasing of resilience in the built environment – must involve different dimensions starting from the institutional but as well as societal and technical. The main difficulties within this final target are related to face with the lack of quantitative data or metrics for a potential exhaustive matrix. In the other hand the need for a more holistic approach that is enlightening resilience might also contain integrative qualitative aspects. In conclusion to potentially implement a plan for resilience increasing facing with multi-hazards scenarios the evaluation of the effects of different system must be evaluated (i.e. physical, technical, environmental, social). Methods that separately evaluate the effect of different parameters and/or criteria (i.e. costs minimization, sustainability increasing, decreasing of the environmental impact) can provide incorrect overall picture within the resilience evaluation thus misleading planners and stakeholder to incorrectly implement specific actions

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