

Free and Open Source GIS Technologies for the Assessment of Tsunami Hazards in the Ionic Sea

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Abstract. It has been largely proven that Geographic Information Systems (GIS) provide a valuable tool as Decision Support System (DDS) for the assessment and management of environmental hazards. In this work we used the GIS technologies to simulate scenarios associated to possible tsunamis in the Ionian Sea, involving the territory of Acireale (Catania), in East Sicily (Italy). In particular, we implemented a literature model for the propagation of tsunamis using free and open source GIS technologies. Our GIS modelling has been used to identify the inhabited areas and the loose of efficiency of roads possibly interested by the tsunami. For this reasons, the approach can be an efficient DSS for civil protection purposes, providing a prompt answer for the identification and management of people's risk condition.

Keywords: GIS technology · Tsunami hazard · DSS

1 Introduction

The Italian territory is particularly affected by calamitous events, such as earthquakes, landslides or forest fires, etc. The triggering causes of most events can be considered of anthropic nature, linked to a not careful use of the environment, but also due to the geomorphological characteristic of the Italian territory which is characterized by a great variability of geological, geomorphological, tectonic and climatic features. The element at risk include people, the environment (air, soil, water) and goods (movable and immovable property).

In view of the possible disaster scenarios that can affect Italy, the National Civil Protection Service was established by law 225 of 24 February 1992.

The primary purpose of this law is, in fact, to defend people and to guarantee, by all means, the maintenance of a "civil" level of life. In second instance, it serves the purpose of safeguarding the other elements of risk, such as cultural heritage or property. This is done through forecasting, prevention, rescue and emergency relief activities.

The Department of Civil Protection gives guidelines for the preparation of forecasting and prevention programs, then local authorities, in particular the Provinces and Municipalities, put them into practice with forecasting activities and prevention

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interventions. Each institution should have a Civil Protection Plan whose purpose is to safeguard people and elements at risk, through the use of strategies and resources aimed at minimizing the presumed damage.

In order to prepare and integrate in an effective and functional way the different activities that can intervene in risk reduction, it is necessary to prearrange a general methodological framework able to explain the effect on risk reduction. In the literature, however, there are different definitions of risk depending on the specific field of analysis, with different aims and purposes that are difficult to direct towards Civil Protection activities. Furthermore, at present, neither a uniform conceptual-scientific model is available for all risk classes, nor quantitative evaluation criteria, especially due to the objective difficulty in identifying some factors that contribute to the definition of risk. It is therefore important to deepen the concept of risk and understand the factors it depends on.

For civil protection purposes, the risk is represented by the possibility that a natural phenomenon or one induced by human activities may cause harmful effects on the population, housing and productive settlements and infrastructure, within a particular area, in a given period of time.

The risk can be therefore translatable into the formula:

$$\boldsymbol{R} = \boldsymbol{H} \times \boldsymbol{V} \times \boldsymbol{E}$$

where

H = Hazard, i.e. the probability that a phenomenon of a certain intensity occurs in a certain period of time, in a given area.
V = Vulnerability, i.e. the propensity of an element (people, buildings, infrastructures, economic activities) to suffer damage as a result of the stresses induced by an event of a certain intensity.
E = Exposure or Exposed Value; i.e. the number of units or "value" of each element at risk present in a given area, such as human lives or settlements.

Therefore, to concretely assess a risk, it is not sufficient to estimate the degree of danger, but it is also necessary to carefully estimate the value of the exposure, that is the assets present in the territory that may be involved in an event and their vulnerability (Fig. 1).

GIS is a consolidated technology for risk analysis. Indeed GIS tools have been developed for different kind of environmental applications, including flooding [3] and volcanic eruptions [4]. Moreover, GIS have been also used within integrated software applications that, thanks to the direct connection with a spatial database, allow real-time emergency management in case of natural disasters [5–8].

In this work a GIS application was developed for the management of tsunami risk in the eastern part of Sicily and in particular in the coastal coast of the territory of the municipality of Acireale.

The GIS application was developed using free and open source software and considering historical data in order to provide accurate risk scenarios.

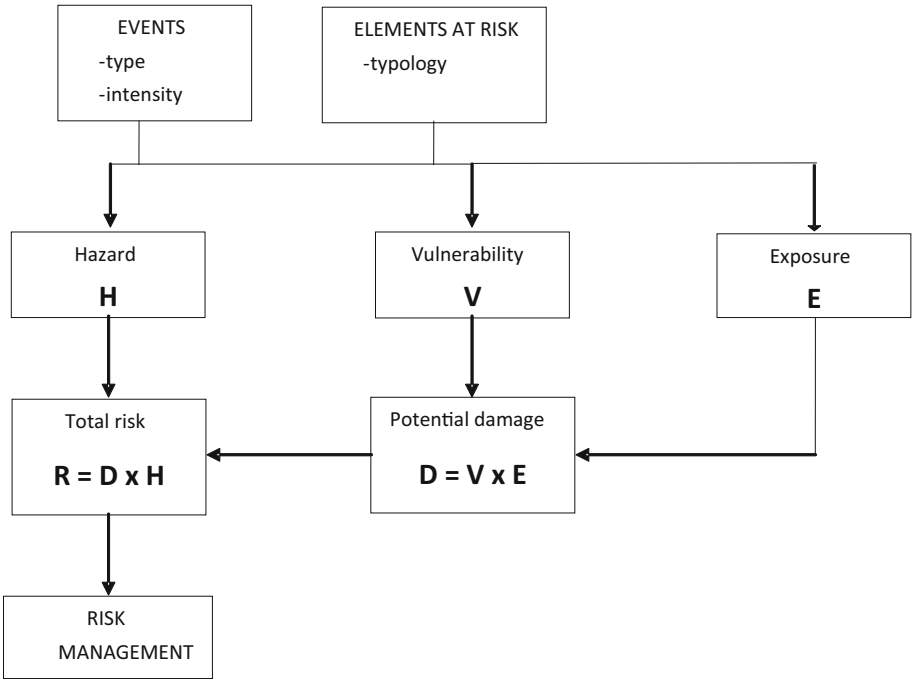


Fig. 1. Methodological scheme proposed for risk analysis

2 Tsunami Risk in Italy

Tsunamis are natural phenomena that can be caused by various environmental factors, such as underwater landslides, strong earthquakes with epicenter in the sea, etc. When earthquakes occur at sea, large masses of water are shifted violently from the bottom upwards, in correspondence with the friction zone or subduction of the tectonic plates. Tsunamis are in fact characterized by very long wave sequences in which the distance between one wave and the other can reach even a hundred kilometers.

In general the speed of a wave decreases rapidly as the depth of the water decreases. However, while in the shallow waters the first wave slows down, the second, which is even a hundred kilometers from the first, still travels at the initial speed. The result is that the distance between the waves decreases rapidly and the displaced water mass accumulates, forming waves that rise dramatically. The wave of the tsunami that was only a few centimeters high in the ocean can rise, reaching in some cases 30–40 m. The waves destroy everything in front of them causing death and destruction.

The Mediterranean presents a significant risk of tsunami, not only due to the seismicity of the entire area, but also to the presence of numerous emerged and submerged volcanic buildings. The risk due to tsunamis can be assessed on the basis of historical knowledge. In the Mediterranean Sea, unlike the oceans, the masses of water involved are smaller, so if a tsunami is produced, it will not have the same strength and intensity as one that develops in an ocean. However, through simulations, it has been

noticed that the anomalous wave propagation times in the Mediterranean are very short and most of the possible tsunami source zones are very close to the coast. Consequently the main problem is that of being able to give the alarm in a very short time (e.g. within the first 10 min) and this explains why the alert system for the Mediterranean area must be faster and more effective than the one adopted in the Ocean Pacific.

The Mediterranean countries' commitment to a tsunami warning system is part of the ICG/NEAMTWS Intergovernmental Coordination Group (Intergovernmental Coordination Group/North Eastern Atlantic & Med Tsunami Warning System) coordinated by UNESCO. Italy, represented by the Department of Civil Protection, participates, along with the national scientific research institutes INGV and ISPRA, for the construction of the CAT (Tsunami Warning Centre) which operates 24 h per day. The CAT, experimentally activated in 2014 and operational since 1 January 2017, serves as an international alert node capable of alerting the Civil Protection authorities of the other Mediterranean basin states that have joined the NEAMTWS program.

In history, the tsunamis that affected the Mediterranean coasts were 127; of these, around 90 occurred in the central Mediterranean area, i.e. in Italy, eastern Greece, Albania, Croatia and Algeria.

In Italy, tsunamis have historically originated in the Tyrrhenian area and in the Ionian area. The latter was triggered by seismic events in the Greek Aegean islands and by events in the Calabrian coast and in the Crotone area.

The eastern coast of Sicily was affected by anomalous waves that affected the Val di Noto in 1693, Messina in 1908 and the Tyrrhenian coast of Sicily, with high waves up to 10.9 m in 2002 due to a landslide in Stromboli. Also the Sicilian Ionian coast has been affected by several tsunamis. Among all the documented events, the one related to the earthquake-tsunami of Messina in 1908 reports reliable data on a tsunami that has simultaneously affected the coast of Catania [1, 2].

Therefore, considering the location of the epicenter of the earthquakes prior to 1908 and especially the events generated along the Ibleo-Maltese slope (1693–1818) we can hypothesize a wave height between 3 and 15 m.

3 Case Study: Acireale (Sicily)

The City of Acireale was largely built on a plateau, characterized by rocks of lava origin and by various faults, called "Timpa", which, with its $\sim$150 m, puts it almost overlooking the Ionian sea. The Timpa represents the northern continuation of the Ibleo-Maltese Escarpment of the Etna region that in the past triggered devastating earthquakes with the consequent development of anomalous waves that affected the entire Ionian coast. In addition, the territory is characterized by the presence of numerous active faults that have caused considerable damage to things and people in history.

The coast (where different hamlets are located) is characterized by a cliff of lava origin, while the remaining part of the municipal territory falls into an hilly area. The inhabited area is essentially composed of the urban center built on the plateau and of twenty hamlets distributed partly along the coast and in the hilly areas. The hamlets are: Aciplatani, Balatelle, Guardia, Mangano, Pennisi, Piano d'Api, Pozzillo, Santa Caterina, Santa Maria La Scala, Santa Tecla, Santa Maria Ammalati, Santa Maria delle Grazie, Santa Maria La Stella, San Giovanni Bosco, Scillichenti, Stazzo, San Cosmo, Baracche, Capomulini, and Fiandaca.

The marine hamlets, that are Pozzillo, Stazzo, Santa Maria La Scala, Santa Tecla and Capo Mulini, are equipped with small ports with moorings.

The municipal territory is served not only by the State Road S.S.114, but also by provincial, municipal and local roads, and by the Messina-Catania A18 motorway. Therefore the territory can be interested by different risks: seismic, hydrogeological, geomorphological and hydraulic, volcanic, and also by tsunami events on the coast that would affect the population centers that overlook the Ionian Sea. From South to North, these are: Capo Mulini, Santa Maria La Scala, Santa Tecla, Stazzo and Pozzillo.

4 GIS for the Assessment and Management of Tsunami Hazards

GIS is a consolidated technology to dynamically manage geographic data and to obtain a real Decision Support System (DSS) to provide primary care to the affected population and to overcome emergencies. GIS are a valuable tool to manage a large amount of real time data acquired from monitoring and alerting sensors [5].

GIS applications have been used for the management of risk phenomena and e.g. the loss of efficiency of the infrastructures affected by the calamitous event [6–8].

In this work a GIS application was created to simulate risk scenarios related to a tsunami, and to develop possible intervention actions in the inundated areas, including the loss of efficiency of road infrastructures.

The bibliographical research has allowed us to hypothesize an applicative scenario characterized by a wave height measured in the shoreline of 5 and 7 m [1, 2, 9–11].

Our GIS application provides as output the areas affected by a possible anomalous wave propagation phenomenon with the hypothesized characteristics.

The workflow includes:

- Choosing of a geo-referenced Digital Elevation Model (DEM) with a good geometric resolution;
- Creating a grid with the same geometric resolution as the DEM for the two wave heights assumed by the literature data;

- Executing the difference between the DEM raster and the hypothesized height grids in order to obtain a raster where the negative pixels represent portions of the territory that will surely be flooded by a possible wave propagation;
- Converting the obtained raster data to a vector in order to compare a possible flooding area with the existing anthropic elements.

For this purpose, a WGS84 geo-referenced orthophoto and a 20-m DEM were loaded as a WMS service and used as basic cartography in the GIS environment.

Two raster grids were created, with a square mesh and a 20 m side, comparable with the DEM in terms of radiometric resolution. To each pixel of the two grids we associated the two assumed values of wave height, 5 and 7 m (Fig. 2). Subsequently, using the raster calculator tool in the GIS environment, the raster grids with the wave heights were removed from the DEM obtaining the portions of the territory that will surely be flooded.

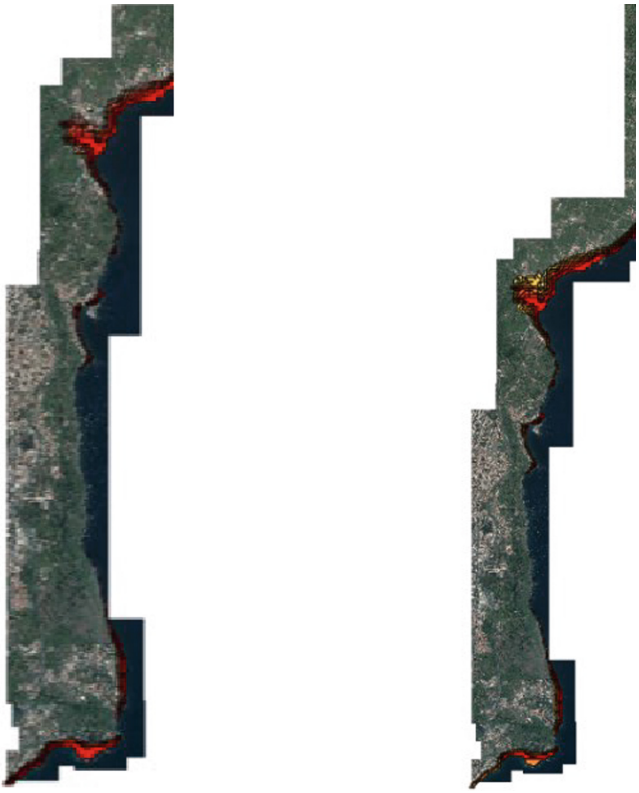


Fig. 2. Areas affected by a tsunami with a wave of 5 (left) and 7 (right) meters along the Acese coast

Through the raster to vector tool, we converted the resulting raster of the wave into a vector to analyze the possible consequences on the territory due to the propagation of the hypothesized waves.

Then, through the intersect function, the vector relative to the simulated wave was intersected to the vector of building.

The resulting vector reported the potential structures affected by the anomalous wave propagation (Fig. 3).

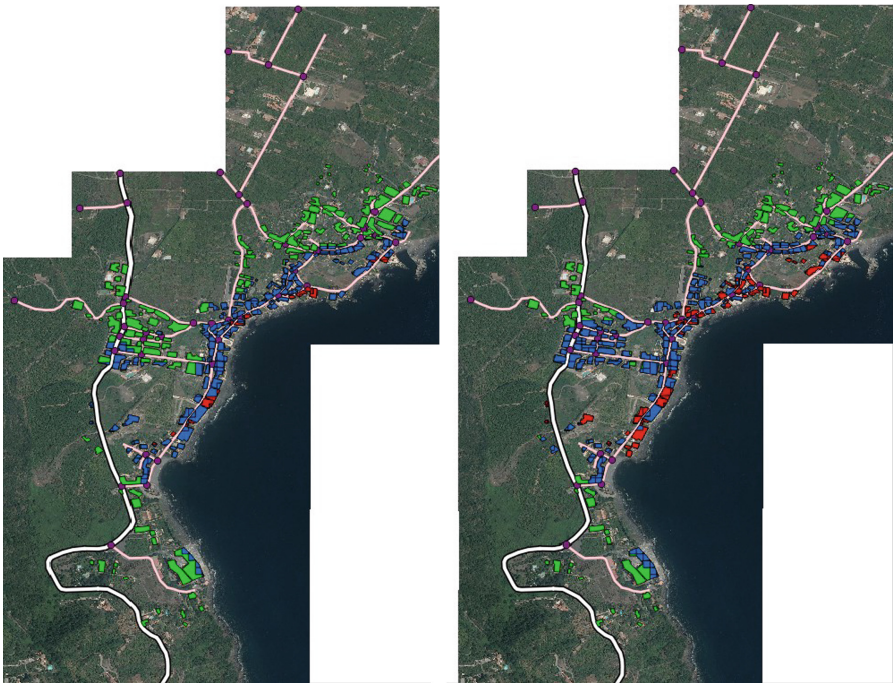


Fig. 3. (left) Potential structures involved by an anomalous wave equal to 5 (left) and 7 (right) meters: buildings completely submerged (in red); buildings damaged, but not completely submerged (in blue); buildings not affected by the anomalous waves (in green). (Color figure online)

The same procedure was used to analyze the road infrastructures inundated by the tsunamis. So the vector layer of the road graph was intersected with the vector layers related to wave propagation with a height of 5 and 7 m (Fig. 4).

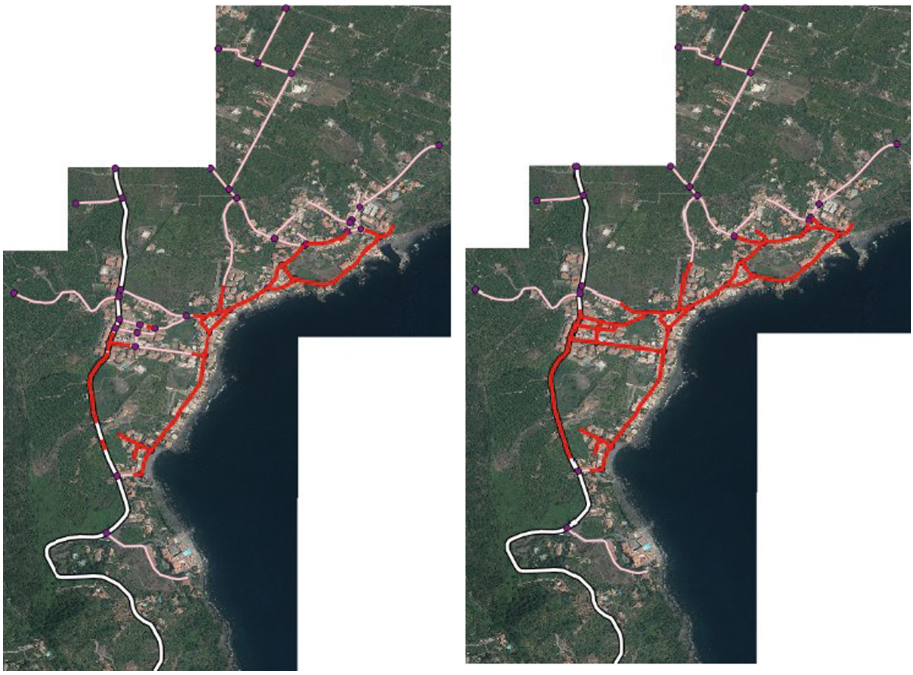


Fig. 4. Road arches (in red) made non-trafficable by an anomalous wave equal to 5 (left) and 7 (right) meters. (Color figure online)

5 Conclusions

In this work a GIS application for tsunami risk assessment was presented, providing a valid simulation tool for identifying possible areas flooded by an anomalous wave.

The area under study was the city of Acireale (Catania, Italy), in the Ionian Sea. Thanks to data obtained from bibliographic research, two possible wave heights have been identified, e.g. 5 and 7 m.

The results of the GIS simulations have highlighted how the Acireale-Stazzo and Acireale-Scillichenti vehicular flow on the SP2 would be interrupted due to the propagation of anomalous waves both of 5 m and 7 m. Furthermore, the completely submerged buildings in which it would be impossible to take refuge were highlighted in the two cases.

The GIS application developed represents a valid Decision Support System (DSS) that could be used by public institutions to plan the management of risk in case of tsunami emergencies.

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