THE CONTRIBUTION OF OPEN-SOURCE GIS SOFTWARE AND OPEN SPATIAL DATA FOR THE RE-EVALUATION OF LANDSLIDE RISK AND HAZARD IN VIEW OF CLIMATE CHANGE

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ABSTRACT :
Recent events, including the floods in central Europe in May 2021, have highlighted how climate change is giving rise to scenarios that were neither foreseen nor predictable. One problem this poses is the need to rethink the logic of various environmental constraints that are often based on return times of 20-50 years or 100-200. A single event does not change the statistical expectations for the recurrence of the event itself, but the recurrence of several extraordinary events in a few years is a clear indication of a changing trend. The prevention of the effects of such events is based on the definition of the areas at greater or lesser risk specifically based on the return times of the exceptional events, so it is foreseeable that a series of territorial plans, mostly carried out a few decades ago, will have to be updated or re-executed from scratch. These reworkings will be able to take advantage of the open-source software and open spatial data that have become available in the meantime, facilitating the entire process, and making it more open and shareable. In this paper we tested on a real case (the May 1999 pyroclastic flows in Campania, southern Italy) the actual possibility of implementing a model for forecasting such events using only open-source software and open data.
It has been demonstrated that the entire process can be carried out using only open-source resources and it has been verified that the predictions of the hazard and risk model obtained with only input data prior to the event, give an output prediction that is significantly coincident with the events that actually occurred as documented by the authorities.

Key-words: *climate change, Campania, landslide risk, landslide hazard, pyroclastic flows, Sarno, GIS*

1. INTRODUCTION

The climate changes in progress cause undeniably new weather and precipitation situations for which we are not prepared as the recent events in Central Europe demonstrate (**Fig.1**). In particular, events characterized by high rainfall concentrated in short time intervals can trigger various events with high hazard and risk in time intervals even very short among which one of the most damaging is the liquefaction of soils (**Fig.1** again). It is easy to understand that the most efficient and effective strategy is prevention trying to evaluate a priori the major risks due to meteorological scenarios, not predictable until a few years ago. In fact, the study of hazard and risk from landslides has been dealt with geomatic methods for several years and many countries (including most European countries) have equipped themselves with digital maps that grade the various risks involved (Vallelongo, 2020; Papathoma-Köhle et al., 2011). It is clear, however, that the new scenarios require the redesign and remapping of a whole series of risks including, for example, that of the potential movement of loose materials (Chen et al., 2011; Canovas et al., 2016; Bernardini et al. 2021). One of the current advantages over a few years ago, when many of these mappings were performed, is the greater availability of open software and data that can significantly facilitate these operations. In fact, in the last years, open software and data have been used for geomatic applications to various fields such as

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speleology (Troisi et al., 2017), archaeology (Alessandri et al., 2019; Costantino et al., 2010; Dominici et al., 2013), agriculture (Aguilar et al. 2016), cultural heritage (Bitelli et al., 2019; Brigante et al., 2014), geodesy and positioning (Dardanelli et al., 2020), structural monitoring (Radicioni et al., 2017; Nerilli et al., 2020) or for emergency management (Baiocchi et al. 2014) but also for spatial and/or geographical studies (Lupia et al., 2017; Baiocchi et al. 2017; Maglione et al. 2014; Costantino et al., 2011).

About the availability of open-source software, it is undeniable that in recent years even complex functions once available in high-level commercial software are now available in environments such as QGIS and toolboxes within it such as GRASS or SAGA. At the same time, initiatives such as the European INSPIRE (European commission, 2021) have stimulated and encouraged the dissemination of spatial data by facilitating the retrieval of updated and consistent databases by the various agencies. These two factors together provide new possibilities and potential for the reworking of the perimeter of the areas at risk using complex algorithms in an efficient and effective way by all stakeholders (Waiyasusri et al., 2021; Eslaminezhad et al., 2021).

In the following a model for the prediction of the liquefaction of pyroclastic materials in the area that was affected by similar phenomena in 1998 in Campania is shown and it’s verified using open data and software.

Fig. 1. Effects of climate change in central Europe (summer 2021).

2. STUDY AREA

The landslides referred to are those that occurred in Campania in 1998 because of high meteoric events that were particularly concentrated in terms of temporal duration.

The May 1998 landslides affected a large area, mainly in the municipalities of Bracigliano, Episcopio, Quindici, Sarno, and Siano (**Fig. 2**).

This part of the Campanian Apennines is characterized by Mesozoic carbonate sequences, consisting of limestones, dolomitic limestones, and platform dolomites, in layers and banks, with variously oriented layering and inclination. The state of tectonization is variable from area to area; equally variable are the thicknesses of the most superficial portion of fractured, degraded and altered rock (Brancaccio et al., 1995; Lizárraga et al. 2017). The aforementioned carbonate sequences are covered by a layer of loose pyroclastic deposits with gradually decreasing thicknesses from the *Piana*

Campana towards the interior of the chain. The covers are represented by loose materials of volcanic origin, consisting of a generally irregular alternation of pumice, lapilli, slag and ash. The pyroclastic materials are referable, almost exclusively, to the apparatus of Somma-Vesuvius and, in particular to the eruption of Plinian type of 79 A.D. and to the following volcanic activity until the last phase of 1944. The deposits of 79 A.D. are, however, by far preponderant (Santacroce, 1987; Sigurdson et al., 1985; Calcaterra et al., 2003). Because of their particular characteristics, the loose pyroclastites have intensely suffered the effects of exogenous dynamics with consequent modifications of the original situations that have led to reworking and washouts that have modified the granulometric composition, physical properties, resistance characters, hydrogeological aspects, giacitural conditions and topographic position. Consequently, one can distinguish pyroclastites in situ and others fluctuated by tractive transport and in mass (Rolandi et al. 1993, Lirer et al., 1973).

The materials of pyroclastic origin covering the carbonate massifs present, in general, variable technical characteristics as a consequence of the volcanic phenomena of formation and, above all, of the subsequent reworking processes that have substantially modified the original depositional, granulometric and hydrogeological characteristics. The permeability of pyroclastic materials varies from very high values in the pumiceous levels, up to values around 10-5 cm/sec in the reworked pyroclastites. In carbonate rocks the permeability coefficient presents considerable variations not only in the horizontal sense but also along the same vertical (Celico et al., 1986).

The area affected by the landslides of May 1998 is (**Fig. 2**) made up of the slopes of Monte Torrenone which, from some maps as the one of the National Geological Service, is covered with pyroclastites (yellow color) only at the base and in its summit, near the base are, moreover, cartographed of the debris of stratum (white with blue dots); the remaining zones green areas are limestone and dolostone.

Fig. 2. May 1998 Campania landslides (image acquired in 1999).

The causes of the triggering of these landslides have been debated in the scientific field, for this study has been considered one of the most accredited theories. From the hydrogeological point of view these rocky masses can be divided into three parts that, from top to bottom, include: the loose pyroclastic cover; a layer of a few tens of meters of very fractured and degraded carbonate rock; the underlying less fractured carbonate rock. In dry period, the scarce rainwater, generally well distributed in time, are easily absorbed and retained by the pyroclastic layer as it has a very high porosity. During the flood period, a band of saturated fractures can be created in the transition zone between the fractured carbonates and the less fractured carbonates below. Since in this case the base of the fractured limestone must be considered as an impermeable formation, an aquifer circulation is created with a sub-parallel trend to the lines of maximum slope gradient. In case of very intense precipitations concentrated in a short period of time, this saturated layer can rise up to the level of the pyroclasts, thus determining conditions of confined or semi-confined water table and under pressure of the pyroclastic layer.

3. DATA AND METHODS

3.1 Materials needed for model development

As stated in the introduction, a focus of this contribution is to verify whether the availability of open data allows the updating of the layers of risk and landslide hazard that will be necessary as a function of the effects of climate change now evident. The situation, at least in Europe, has changed a lot in recent years, in fact only a few years ago the realization of such a model required the not always easy research and obtaining data, often in paper form, from the bodies responsible for environmental protection. This constraint, actually only logistical/bureaucratic, however, heavily influenced the actual feasibility of a series of plans. In Italy, probably thanks to the stimulus provided by the INSPIRE directive of the European Commission, a whole series of spatial data whose accessibility was previously limited and partial have become directly and freely available. Many territorial bodies have released web pages generally called geoportals from which data can always be consulted through web viewers but also within GIS using protocols such as WMS and WFS as, for example, for cadastral coverages (Agenzia delle Entrate, 2021). In some cases, the data are even downloadable such as some of those made available by the Ministry of Environment on the most consulted geoportal at national level: the "National Geoportal" (Ministry of Environment, 2021). Other data at a larger scale, such as base maps at 1:5000 scale, are available on the geoportals of local authorities such as the provincial administration of Salerno (Campania Region, 2021).

Below are the open data that you can freely use for the realization of the model of hazard and risk for movements:

From the National Geoportal of the Ministry of Environment (www.pcn.minambiente.it/mattm/):

- “Catalogo delle frane, poligoni” (Catalogue of landslide, polygons) (scale 1:5000), year 2009
- “Carta geologica” (Geological map), scale 1:500000, year 2009
- “Carta geolitologica” (Geolithological map), scale 1:500000, year 2009
- “Tavole dei grigliati Lidar 1*1” (Lidar Grids) resolution 1 metre, year 2008

From ISPRA (Istituto superiore per la protezione e la ricerca ambientale, Superior Institute for Environmental Protection and Research) Geoportal (ISPRA, 2021), (http://sgi.isprambiente.it/)

- Carta Geologica (Geological Map), scale 1:100000, year 1971

From Campania Region Geoportal (https://sit2.regione.campania.it/servizio/carta-tecnica-regionale):

- Carta tecnica regionale (Regional technical map), scale 1:5000, year 1998
- Carta tecnica regionale (Regional technical map), scale 1:5000, year 2004- 2005

3.2 Possible model implementation in open-source GIS

The most immediate model for landslide hazard is to relate a slope map with a geolithological map: by assigning a certain hazard score to the various slope classes and to the various lithologies, it is possible to obtain a derived map obtained simply by adding the values corresponding to a given area in the two maps. Areas with steep slopes and lithologies subject to movements will obtain the maximum hazard values, flat areas with lithologies not subject will obtain the minimum values. The software that allows this kind of elaborations normally work on raster files because the discretized format of these files allows an easier calculation. It must be underlined that these cartographies constitute only a cognitive instrument for the individuation of zones to high dangerousness, to this first phase must always follow an accurate geological survey of detail.

Anyway, to implement any model of landslide hazard it is necessary to have a digital elevation model of the area we want to study; from the DEM it is in fact possible to derive themes that are essential for any study of movements. Using GIS raster functions, it is quite easy to derive precise information on the inclination and direction of slopes, preferential drainage lines and on these to estimate distances. These are some of the functions were very useful in implementing the described model.

The algorithms present in the toolboxes that we could define of "Map Algebra" allow to use several more complex functions such as the calculation of a grid of preferential drainage directions from the DTM or the possibility to measure distances on the same grid once defined, this allows to implement and test a simple model of hazard a bit more complex already described in the literature (Baiocchi, 1998). The model can be considered as a development of other models: starting from a hazard map (obtained perhaps with the simple procedure just described) that already indicates the "dangerous" areas. Are considered "dangerous" also all the areas that are located in correspondence of drainage lines, downstream of a hazard area within a certain distance measured in the drainage network. This model derives from the observation that the material moved in the landslides of loose materials, in many cases acquires a fluid consistency or practically liquid, for this reason the material is channelled in the preferential lines of drainage scavenging everything that meets on its way for a few hundred meters (in some cases for kilometres). For this reason, the model considers risky not only the zones in which the movement of material could happen, but also the zones, often distant, in which the material, so moved, could arrive. What was more interesting to experiment, were the possibilities of the algorithms to identify and follow the preferential drainage lines comparing them with those along which the landslides developed.

The application of data to the model starts from the elaboration of the slope map that can be obtained for example with the "classic" command contained in QGIS under the path "Raster > Analysis > Slope".

The layer thus obtained must be resampled into dangerous zones and non-dangerous zones according to the degree of acclivity; deciding which is the inclination that separates dangerous zones from non-dangerous zones is a particularly delicate choice. For local studies in geotechnics this angle is chosen based on the angle of internal friction of the material, but in the case of the drafting of a study of this extension the materials involved may be very variable and present variable states of aggregation, for this reason introducing a single angle for the entire mapped area is in any case an approximation. The inclination value to be inserted is, together with the distance to be calculated along the drainage lines, one of the two variables of the model that must be experimentally tested to calibrate the model itself. However, good agreement was observed with the areas that could be estimated at risk from an initial morphological examination of the cartography, using an inclination value of 25 degrees.

4. RESULTS AND DISCUSSIONS

4.1. Derivation of maps of preferential drainage directions

A further refinement of the cartography can derive from the intersection with the geological cartography, but in this case, since the most "dangerous" formations (the volcanites) are located in the valley floors, areas that will be considered dangerous by the program as preferential drainage lines, in this first test have not been included. Further considerations of the necessary geolithological data are discussed in more detail later. The main purpose of this first step is to evaluate mainly the possibilities of identifying drainage lines.

To obtain the grid of the drainage lines and study the diffusion along the drainage can be used various algorithms including, for example, the one contained in the plugin "FlowPathDown_BB" (Valentinotti, 2013). The plugin starting from the areas considered dangerous or trigger areas follows the drainage lines for a certain distance, this distance is the second parameter that must be chosen to calibrate the model. The distance that the handled loose materials can travel inside the drainage lines varies mainly according to the consistency of the material (which in case, for example, of mudflows is practically liquid). Also, in this case various values have been tried and it has been finally decided to start with a value of 100 meters that is surely insufficient for the events then regularly happened in the area but it allows to quickly carry out evaluations; in fact, the elaboration times of such an algorithm can also be long.

It is necessary to remember that, for how the model has been thought, in this phase of test, what must be verified is above all the correspondence with the real event in the low part of the landslide, where the moved material is channeled in the preferential drainage lines. The most interesting result was obtained on the landslide east of Episcopio: here it was possible to compare the results obtained from the model with the perimeter available on the "Geoportale Nazionale" (**Fig. 3a**).

4.2. Estimation of the importance of the input DEM resolution

We wanted to verify in particular if these models could also be used with DEM of lower resolution such as those available freely as ASTER and SRTM but also very interesting is the possibility of using the model Tinitaly (Tarquini et al., 2012) produced by the National Institute of Geophysics and Volcanology (INGV) with a resolution of 10 meters. To this end, an intentional degradation of the resolution of the original DEM has been made to evaluate the effects at various resolutions, but unfortunately converting from the original resolution of 1 meter to that of 5 meters, the results are yet unsatisfactory significantly degrading the final result compared to the polygons of comparison reported on the “Geoportale nazionale” web site (**Fig. 3b**).

4.3. Characteristics of available geolitological maps in input

Considering these first results we wanted to verify if it was possible to further refine the model by inserting information on geolithology according to the simple criterion exposed previously or consider unstable areas with high slopes and that present a lithology that can easily be subject to landslides. Actually, this test must be considered almost as a provocative in the sense that, as already anticipated, the available geological and geolithological maps cannot be of valid help in this specific case because the material shifted by this type of event is actually a layer of some meters of thickness of pyroclastic soil that conventionally is not reported on the same geological maps. For this reason, since the date of the events under study (1998), research and surveys have been carried out to map the thickness of these soils in the area, but their validation is still a debated issue in the literature (Del Soldato et al., 2016) and therefore an official model of these thicknesses has not been released and therefore could not be tested.

It is already evident that the introduction of these data in the model will not improve the model performance because the lower part considered at risk will remain unchanged, while the upper part (where the movement started and from where most of the moved materials detached) will be not at risk (**Fig. 3c**). The lack of representation of the pyroclastic covers of the upper part of the slopes is not to be considered an error of the surveyor, in fact at very small scales like these, what we want to map are the large tectonic structures, a cover of a few meters of pyroclasts is not relevant for these purposes. The inclusion of geolithology data will therefore be useful only if data are available at an appropriate scale and surveyed for such a use: some experiments in this sense (survey of only quaternary cover at large scale) in Sacramento County (California, USA) have, already in the past, obtained satisfactory results (Howell et al., 1999; Brabb, 1985).

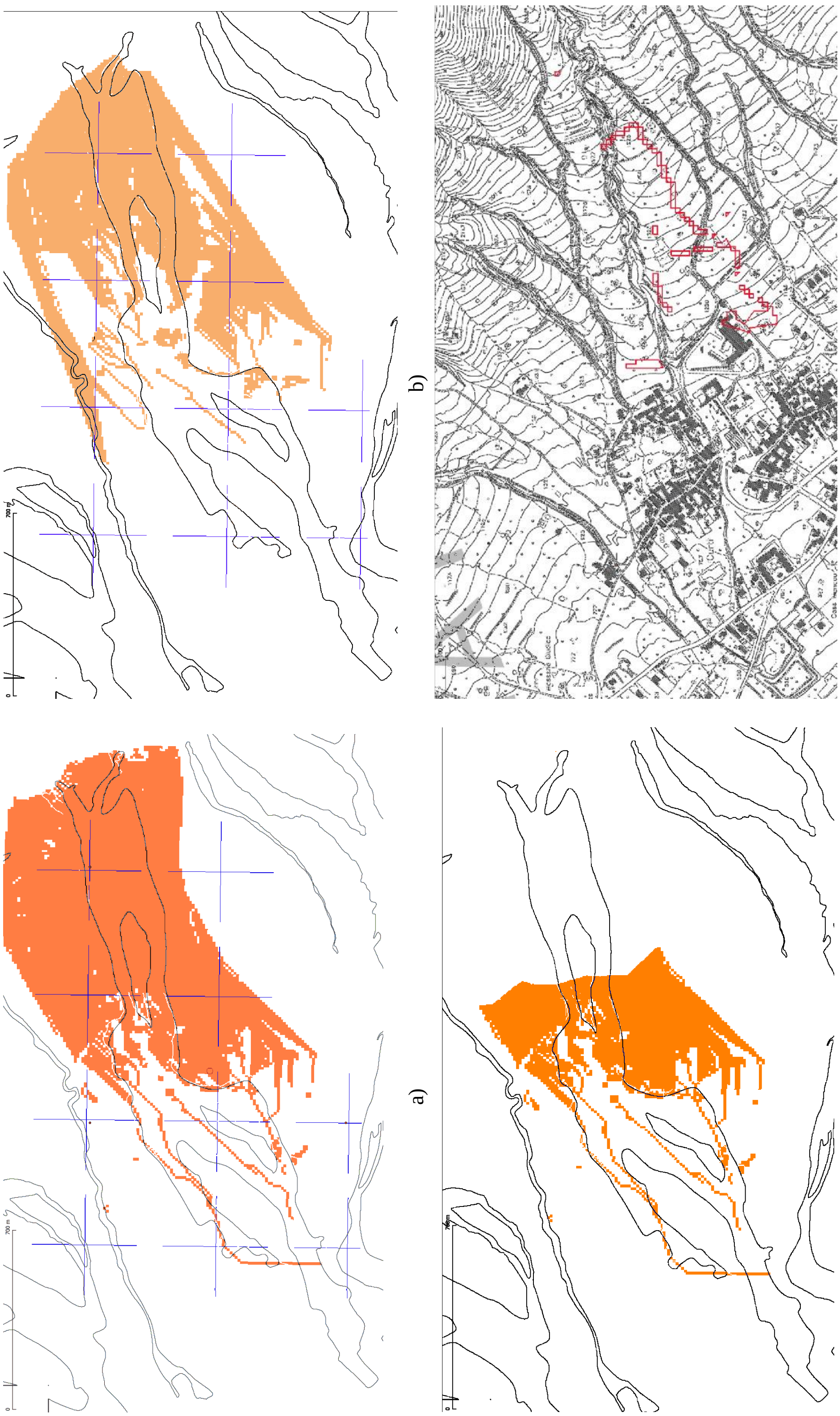

Fig. 3. Results of the model implemented: a) the first test with full resolution DEM, b) the same model with degraded DEM, c) the original model with the geological map data and d) the population risk map.

4.3. Layers for population risk assessment

The overlapping of hazard layers thus created with vector layers of the built-up area and transport infrastructures (areas in which it is more likely that the population is concentrated during the 24 hours) allows to identify the areas at greater risk for the population itself. The building and infrastructure layer were extracted from 1:5000 base maps from Campania Region. In this case we have added a buffer of ten meters around the areas evaluated "dangerous" from the model because the building or the infrastructure involved also in part from the event must obviously consider all to risk.

The result of this evaluation of risk has effectively identified all and only the areas that have then been really interested from the event as then happened (**Fig. 3d**).

5. CONCLUSIONS

This paper demonstrates how even complex studies on land vulnerability can be effectively carried out by implementing advanced models using open-source software and open data. This possibility is even more interesting given the need to rethink and redesign several environmental constraints due to the evident climate changes as the recent events in Central Europe have shown. This is made possible by the recent availability of open-source software which now has functions that are absolutely comparable with those of commercial software and, in some cases, even more sophisticated. It can be said that this availability of software has developed completely over the last two decades. Moreover, the even more recent availability of open data, stimulated in Europe by the INSPIRE directive, has been very important, in a certain sense revolutionizing the policy of dissemination of spatial data by public administrations, which until a few years ago kept all spatial information as confidential material, with few exceptions, and now publish it all, with few exceptions. This "revolution" has taken place completely in the last two to three years and, in fact, many of the data mentioned in this contribution have only just become available. The specific web diffusion protocols for spatial data, such as WMS and WFS, have also contributed greatly. These allow us all to work on the same layer update and to load locally only the part of the data that is of interest, as for example in the case of the landslide catalogue used in this study, which covered the entire national territory but of which only a few polygons were of interest here. This new possibility of working with open data and open software is a great advantage for the scientific community, which has more and more possibilities to elaborate and develop new models by testing them on real data. It is also a great advantage for public administrations, which can immediately adopt the suggestions of the research world, and it can be a great help for developing countries, where the costs of commercial software often limit the possibilities of complex spatial studies. Unfortunately, there is often not yet such a wide dissemination of data in these countries, and this is a gap that more developed countries should help overcome.

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