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LUP and Multi-risk: the Mutual Influence of Natural and Anthropic Impacts

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In Italy, the different territorial risks are managed through completely separate plans, that the Municipalities (local scale) should apply on their territory with direct interventions; anyway, the current approach, which does not consider the interactions between risks, could decrease the efficiency of the planning and emergency actions. Therefore, the research here exposed, deriving from a PhD thesis, aimed at developing a quick and easy to use methodology, able to identify and rate the main risks which characterize a territory, and to simulate the possible effects of their interaction on the territorial and environmental vulnerabilities. The methodology was tested on the case study of Mantua, where both industrial, seismic and hydrogeological risks are present. Each step of the methodology proceeds simultaneously with a GIS Map, which helps to spatially understand the extension and gravity of each risk.

1. Shortcomings of the current Land Use Planning related to risks

In 2010, the European Commission (2010) recommended that "National risk assessments should attempt to also consider multi-risk scenarios", but nowadays many European countries still face the different territorial risks within a sectorial perspective; also, EU directives related to risk still do not include multi-risk methodologies.

In Italy, the main risk sectorial plans are: 1) for Industrial Risk: Technical Document for Major Risk Accidents (ERIR), deriving from the Legislative Decree 105/2015 and the Ministerial Decree (implementation of the EU Directive 2012/18/EU – Seveso III). ERIR regulates safe Land Use Planning (LUP) around Seveso plants; 2) for hydrogeological Risk: Plans for the Hydrogeological arrangement (PAI), recently revised in compliance to EU Directive 2007/60/CE, implemented in Italy with the Legislative Decree 49/2010. PAI identify the zones potentially subjected to floods, together with the return times; 3) for seismic risk: since 2008, each new building or reconstruction should be made in compliance with the "Norme Tecniche per le Costruzioni" (Technical legislation for structures). After L'Aquila earthquake in 2009, it was introduced the "Piano nazionale per la prevenzione del rischio sismico" (National plan for the seismic risk prevention), which committed the Municipalities interested by major seismic risk to draft the so-called "Seismic micro-zoning" plans; they analyse the amplification effects produced by different types of soils.

Risk strategic plans and indications are usually developed by Supra-regional, Regional and Provincial authorities, and the Municipalities have to implement these studies and indications in their City plans, by establishing bindings on their territories. However, the direct application of the requested measures, or the development of dedicated studies can be sometimes affected by a severe lack of technical and financial resources. Furthermore, even if the City Plan is the final collector in which all the sectorial plans are contained, no mutual influences and interactions between the risks are developed (Pilone et al., 2017).

Another criticality is related to the probabilistic approach adopted by the sectorial plans; besides of the problems related to its reliability, especially for hazards influenced by climate, it was demonstrated that the events connoted by low probabilities and high impact, as the risk interactions are, tend to be considered neglectable, and the priority for interventions is given to the most frequent but low impact events, so that in the end there could an insufficient preparation towards extreme events (Menoni et al, 2006).

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1.1 Multi-risk and Na-tech approaches

Many projects in the last years tried to face the problem of the Multi-risks analysis and risk interaction; an appropriate and detailed resume is provided by the European project MATRIX (2010-2013). In particular, Garcia-Aristizabal and Marzocchi (2011) operated the review of the existing methodologies, concluding that the main portion of projects related to multi-hazard analysis dealt with different independent hazards which threat a common area or exposed elements, without considering triggering effects or any kind of interaction at vulnerability level. On the contrary, the analysis of possible interactions resulted less common because of the kind of input data needed, and of the complexity of hazard chains.
A particular type of multi-risk analysis could be identified in Na-tech procedures; even if they are focused on the industrial risk, these approaches try to assess and prevent the effects of external events on dangerous industrial items, therefore defining the possible interactions. I.e. Antonioni et al (2010) and Salzano et. al (2009) proposed an integrated Quantitative Risk Analyse able to take into account the risks provoked by floods, earthquakes and lightning. However, even if many approaches were proposed for Multi-risk assessment, no one became a regulation yet, neither at European or Italian level; furthermore, they often require the employment of multidisciplinary experts, tools and time that could be out of reach for local authorities' capacities.

2. Proposal for a methodology

The Municipalities result in front line both for land use planning and emergency management; they have to directly face the risks on the territory and often to decide about the most urgent interventions related to preventive and protective measures. Nevertheless, they cannot evaluate the possible risk interactions, and in some cases, they do not have enough technical or financial resources to extend their knowledge of the territory, or adopt the correct protection measures.
Considered the key role of the Municipalities in the risk management, the present research aimed at defining an expeditious methodology built for a direct use from the local planners and technicians, able to identify the most dangerous areas and the risks interactions in an easy way. The proposed approach is not a replacement of the existing plans, but is intended as an all-inclusive "Rapid guide to the risk", whose objective is to help the Municipalities in addressing studies and interventions to the areas with major risks. The choice of a simplified approach entailed a series of assumptions: the most important was related to the probability. Indeed, even if the probability could orient the decision-makers' actions, the harmonization of the different risk probabilities used for each risk, and the calculation of the probability related to the interactions would have introduced an excessive complexity in a methodology explicitly constructed for non-expert users. Furthermore, as reminded before, sometimes extreme events can slip through the probabilistic approach assessment.
Another assumption was related to the analysed risks: it was chosen to focus only on the main risks which characterize a territory, according to the principle of spatial filter adopted in the ESPON project (Schmidt-Thomé, 2006): spatially non-relevant hazards, that can occur everywhere (i.e. meteorite), were not considered, while the risks analysed were only those that regularly or irregularly interested the same areas. In our research, also the climate risk factor, even if it is not properly spatially relevant, was taken into account, because it could be particularly influent in case of interaction; anyway, since the studies are still at a beginning point on this theme, the parameters adopted for the analysis remained quite general (see the explanations given in Table 1).
In the end, we chose to develop a methodology based on a rating scale common to all the main hazards identified on the territory, and at the same time able to measure the interactions; the use of the scale was inspired by ESPON project (Schmidt-Thomé, 2006), which classified all the risks analysed on the basis of the hazard intensity, measured in five classes, from very low to very high. In our case, the scale was not related to hazard intensity, but to the influence of elements that could increase or decrease the impact of the risk: the scores go from 1 to 1,99 "Low", from 2 to 2,99 "Moderate", from 3 onwards "High". The following paragraphs go in-depth in the methodology, explaining it through the direct application on a case study: Mantua. This city, located in the middle of the Po valley, on the Mincio river, and very close to Po river, resulted simultaneously affected by at least three main risks: the hydrogeological one, the seismic one and the industrial one.

2.1 Hazard characterization

In order to rate the hazards, the Municipality technicians should first of all proceed with the hazard characterization. The hazards are described through three macro-categories, which aim at pointing out the aspects that could majorly influence the final impact: 1) Category *Strengthening Effects (S.E.)*; identifies the local characteristics of the hazard that can amplify its dangerousness, also in case of interactions; 2) Category *Historical and recent events (.H.E.)*; takes into account the recurring events correlated to the hazard analyzed, verifying the reliability of the return times 3) Category *Protection measures (P.M.)*; describes the existing protection and preventive measure that can control and reduce the impact of the hazard analyzed. The characterization of the hazards in macro-categories allow to carry out an in-depth analysis of the territory, that go beyond the sectorial plans to identify also neglected aspects which could influence the impact.

After the hazard characterization, the scores of the previous mentioned rating scale have to be assigned to each macro-category of each hazard: a dedicated table, developed on the basis of literature review and experts' judges, provides a series of parameters to support the assignation. Table 1 below reports the parameters related to the macro-category Strengthening effects for Flood, Seismic Hazard, Industry and Climate related events.

Table 1: Guideline for score assigning – Macro-category Strengthening effects

	Hazard	1 to 1,99 (low)	2 to 2,99 (moderate)	3 to 4 (high)
[SE] Elements which could produce strengthening effects	Seismic	Rigid soils, without local amplification effects	Soils with local amplification effects, classes Z3 - Z5	Soils with local amplification effects, classes Z1 - Z2
	Flood	The interaction between the different elements of the water network, and the hydraulic control devices show low or reduced criticalities	The interaction between the different elements of the water network, and the hydraulic control devices show moderate criticalities; or: the part of river /creek / etc. is a key element for the general safety of the system	Presence of zones with high criticality, reported in P.A.I., Urban Plans, or which have provoked criticalities in past events i.e. throttling points, areas interested by erosion etc.
	Industry	Only few items present Na-tech risks; the scenarios are related to flammable substances, with a reduced area of impact.	There are items with NA-TECH risk; the potential scenarios are related to flammable and environmental substances	There are huge quantities of hazardous substances and many items with NA-TECH risk. Domino effects are possible. The scenarios are related to toxic substances and / or have a great extension.
	Climate	A general value = 2 was adopted for Mantua case study to express the general European trend and the phaenomena of topicalization which is interesting Po valley. In general application, if more detailed local data on climate trends are available, they could be used to better defined the score.		

Table 2 provides an example of hazard characterization based on the three macro-categories, together with the scores assignation: the analysis for Mantua seismic hazard is reported. In this case, the macro-categories H.E. and P.M. have the same values on the entire Municipal territory, but S.E. varies in function of the type of soil encountered, which produce different effects of amplification: in fact, seismic micro-zoning studies evidenced the presence of soils characterized by lithologic amplification and instability.

Tables similar to table 2 shall be prepared for the other hazards present on the territory: for the industrial hazard, in the macro-category *Strengthening effects*, the assets with potential risk (atmospheric tanks with floating roof / pipelines / distillation towers), the hazardous substances, and the credible events / scenarios have to be analysed, while the *Protection measures* are those adopted by the company to face potential dangerous events or Na-tech events. For the hydrogeological risk, the *Strengthening effects* can be identified in the criticalities of the hydraulic artefacts and interactions with other elements of the water network, and by eventual; the Protection measures are constituted by water regulation systems, hydraulic artefacts etc.

The process of hazard characterization and rating proceeds in parallel with the draft of thematic G.I.S. (Geographic Information system) maps, aimed at showing the spatial distribution of the elements analysed. In order to produce the maps, it has to be considered that the characteristics of the hazards are not uniform on the Municipal territory, and a single hazard will receive different evaluations in different areas (see Table 1).

Table 2: Mantua seismic risk characterization

Areas prone to seismic hazard.	[SE] *Strengthening Effects*	[HE] *Historical Events*	[PM] *Protection Measures*
Municipal territory	The territory is classified as: Z4a soils - valley bottoms and plain composed of by alluvial/glacial sediments, producing lithologic amplifications, as proved by the surveys carried out in 4 sample areas.	Po valley is interested by the subduction of the Adria tectonic plate (NE) under the European tectonic plate (SW). In 2012, the Ferrara fault lines generated multiple shakes with an unforeseen intensity, but in Mantua, the registered peak ground acceleration remained low, provoking limited damages.	-
SCORE	2		
Lake banks, Paiolo paleochannel Basso drain	These areas are interested by Z2a soils: particularly poor saturated foundation soils (noti.e. highly compressible sediments).		
SCORE	3	1	0

Each hazard is represented in GIS by a layer, which is composed by different polygons; they allow to express the variations in the ratings assignation, thanks to the GIS instrument “Attribute table” that can associate precise parameters to each polygon. Figure 1 shows i.e. one of the polygon of the seismic hazard and its Attribute table, containing the scores assigned to the macro-categories S.E., H.E. and P.M. The polygons are easily identifiable both for seismic hazard and for the industrial hazard, for which they coincide with the plant boundaries, while for flood hazard is more complex, because all the macro-categories can have great variations. In any case, the flood polygons could be identified on the basis of: 1) hydraulic artefacts which introduce discontinuities in the hydraulic asset (i.e. underground sections, sections with levees etc.); 2) Altitude discontinuity natural / artificial falls or change of level); 3) other local characteristics.

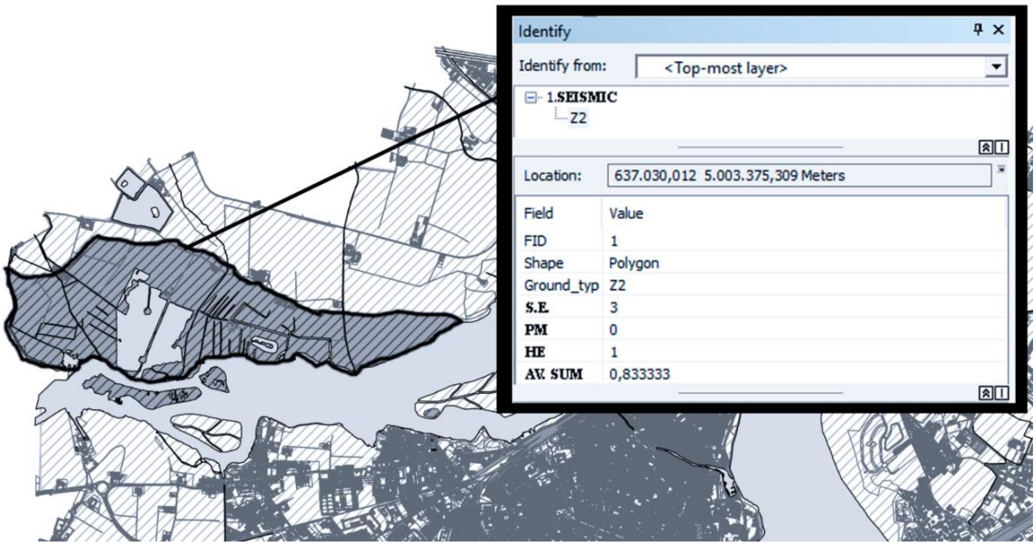

Figure1: Thematic GIS map of the seismic hazard, Attribute table of a polygon (Mantua case study)

2.2 Hazard interaction

Once assigned the ratings, it is possible to evaluate the impact of the interactions through a simple weighted average of the values assumed by the macro-categories in the areas of interaction.

The mechanism of weight attribution was already employed in several Multi-risk projects, but the weights were usually attributed to each kind of risk to establish the reciprocal importance, as in the project PRIM of Lombardy Region, 2010; in our research, the weights were used to represent the capacity of each macro-category to actually influence the dangerousness, and therefore the interaction. The following weights were assigned: *Historical Events* (H.E.) = 2. This category received the maximum weight because a good analysis of all the past and recent events could return the most reliable idea of the potential future events; *Strengthening effects* (S.E.) = 1. The weight in this case does not significantly change the scores attributed during the Hazard Characterization phase. In fact, this category is the most innovative one, whose aim is to

explicit possible elements intrinsic to the analysed hazard, that could enhance the final impact. Because of the possible uncertainties that could arise i.e. for the definition and consequent rating of these elements, it was considered more opportune to maintain the scores assigned as they were, in order to not excessively influence the final interaction value; *Protection measures* (P.M.) = 0,5. Unfortunately, many past accidents demonstrated that even huge protection measures could unexpectedly fail, or have unforeseen malfunctions, therefore we chose to assign a limited weight to this macro-category.
The scores assigned to each hazard macro-category are weighted, and then summed up to obtain the possible values of binary interactions, according to the following Eq.(1):

$$[(\boldsymbol{H.E}_{\cdot haz1} + \boldsymbol{H.E}_{\cdot haz2}) * \mathbf{2} + (\boldsymbol{S.E}_{\cdot haz1} + \boldsymbol{S.E}_{\cdot haz2}) * \mathbf{1} + (\boldsymbol{P.M}_{\cdot haz1} + \boldsymbol{P.M}_{\cdot haz2}) * \mathbf{0,5}] / \mathbf{6} \quad (1)$$

The interactions can be estimated in the areas where hazards overlay, or where many vulnerable elements are present; for each area, a dedicated excel Interaction table is elaborated. As it is possible to observe in Table 3 below, the Table contains all the hazard present and calculate their interactions two by two, by applying the formula reported in Eq. 1. In the end, the Interaction tables return the value of the interactions in a determined point: the values are measured according to the scale mentioned in Paragraph 2.
Table 3 is an example of Interaction table related to one of the Seveso plants analysed in Mantua: starting from the values assumed by the macro-categories of each hazard in the area of overlaying, the interaction is assessed; the values obtained are quite low, and reflect the moderate initial values of the natural hazards that could affect the industrial plant..

Table 3: example of interaction table for an industrial area in Mantua

Impact on →			Seismic risk			Hydrogeological risk			Industrial risk (Factory 1)			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM	SE	HE	PM
			2	1	0	1,5	1	-3	3	2	-1	2	1	0
Seismic risk	SE	2	No interaction			1,00			1,75			No interaction		
	HE	1												
	PM	0												
Hydrogeological risk	SE	1,5	No interaction			No interaction			1,42			No interaction		
	HE	1												
	PM	-3												
Industrial risk (Factory 2)	SE	3	No interaction			No interaction			No interaction			No interaction		
	HE	2												
	PM	-1												
Climate	SE	2	No interaction			1,00			1,75			No interaction		
	HE	1												
	PM	0												

The Interaction tables can be also automatically calculated using GIS, through a procedure based on the tool "Intersect", which allows to create a new layer containing only the zones of overlaying. Applying a "Field calculator" to the Attribute table of this new layer, it is possible to obtain exactly the same values of the Interaction table calculated with Excel. As far as it concerns the spatial distribution of the effects of the interaction, for the combinations of floods / earthquake / climate hazards it was decided to maintain the perimeters of the areas assessed by the sectorial plans and/or through direct surveys: indeed, for earthquake, the amplification provoked by the quality of the ground have a strict local effect, while for floods the damage areas should already represent also the extreme conditions. On the contrary, for interactions involving industries, it was not possible to assume the plant boundaries as limit of the interaction effects; both for the values assigned to the macro-categories and to the interaction, it was chosen to project them into a buffer zone around the plant of 500 m., which therefore represents the area where possible damages could occur. The extension of the buffer zone is the same required by the external Emergency plant of the companies.

2.3 Compatibility assessment

The Interaction tables, together with values assigned to the macro-categories S.E. and H.E., are the key element to proceed with the compatibility assessment of the hazard analysed: thanks to GIS, is it possible to cross the hazard and interaction maps with the vulnerable environmental and territorial elements, to point out possible points of incompatibility. The framework adopted for the vulnerability compatibility analysis partly reproduces that indicated in the Ministerial decree 09/05/2001, which defined the basic principles for a safe planning around Seveso plants. In compliance with the Ministerial decree, the vulnerable territorial and environmental elements are identified through an easy approach, mainly based on the exposure: the first ones are chosen on the basis of urban density or, for punctual buildings, of the frequentation; for the latter, detailed lists for the identification are provided, i.e. by Piedmont Region ERIR Guidelines (for further details, see Camuncoli et al. 2012). However, while the Ministerial decree 09/05/2001 bases the compatibility assessment on the probability of occurrence of the industrial damage areas, and defines compatible categories on the basis of the presence of people, in the proposed approach the compatibility assessment starts from the definition of a threshold. The value of 2,5, indicating a medium riskiness tending to high, was chosen as the dividing line which highlights possible incompatibilities: in case the macro-categories or the interactions of hazard prone areas assume this value, the included areal vulnerabilities and punctual vulnerabilities, or areas destined to the emergency and the strategic infrastructures, can be interested by a potential incompatibility. In this case, the Municipality should first of all carry out more in-depth investigations about the vulnerabilities and hazards of the area, and then, in case the incompatibility is confirmed, possible preventive and protective solutions can be implemented. As far as it concerns industrial risk, a further step in the methodology, able to give more precise indications for LUP, was developed: three possible damage states, derived from the studies by Renni et al., 2010, were associated to the values of Interaction "low", medium" and High". Then, the software HSSM and ALOHA, released by the US Environmental Protection Agency, were employed to simulate the potential consequences in terms of toxic release, environmental pollution etc, on the basis of the severity of the damage.

3. Conclusions

The choice of the local scale for the proposed approach aimed at strengthen the role of the Italian Municipalities, giving them a tool to better manage the challenges of urban planning and emergency management in relation to risk. Our methodology could be read as a first step towards the adoption of more complex multi-risk approaches: thanks to its simplicity, it can be autonomously developed and managed by the Municipality technicians, helping them to identify the points in which critical events could take place, and allowing to better address the resources for in-depth studies and interventions. The proposed methodology, even if expeditious and based on unavoidable simplification, demonstrated for the analysed case study of Mantua city to be able to identify the most problematic areas, and to highlight some unforeseen situations related to risk interactions; however, more case studies are advocated to test the methodology and we are currently working on this.

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