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MULTI-RISK APPROACH FOR LAND-USE PLANNING: A SCREENING TOOL FOR RISK-BASED DECISION MAKING

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SOMMARIO

In Italy, the different territorial risks and the emergency are managed in completely separate plans, that the Municipalities (local scale) should apply on their territory with direct interventions; anyway, the current approach, which doesn't consider the interactions between risks, could decrease the efficiency of the planning and emergency actions. Therefore, the authors proposed 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 Mantova, 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.

The methodology returned reliable results in terms of possible risk interaction impact, in line with the initial risk values.

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1. Introduction

In Italy, each risk is managed through separate and dedicated sectorial plans (Menoni et al, 2006), that usually adopt different methodologies for the risk assessment, and are produced with different scales by different Planning Authorities. The direct land management is delegated to Municipalities, that are responsible both for the emergency programming and land use strategies; their operative tools are the City Plan and the Municipal Emergency Plan. The first one aims at norming urban and land functions, adapting the needs of urban development to the natural specificities of the territory (geomorphological, hydrological, etc.). The second one provides a survey on the state of conservation of the territory, based on existing risk analysis, and set up the operational activities, the materials, capacities and means to deal with possible emergencies. Both the plans implement and apply planning measures derived from the superordinate sectorial plans (seismic, flood, etc.) but, even if they share the same basic indications, they are not mutually linked in terms of long-term risk management. One is specifically related to the territory and the other to the emergency, without establishing common preventive structural measures that could contribute to reduce risk and prevent emergency (Pilone et al., 2016).

As a consequence of this planning structure, Municipalities currently deal with Multi-risks, but they merely implement contents from superior plans, without analyzing or correlating them in a systemic way. The efficacy of risk management responses could be affected by delays related to the time required for the drafting and implementation of the instruments, lack of economic / technical resources, etc. Also, this management of risks in a separate way, with different procedures, timings, methodologies, makes it difficult for the Municipalities to have a clear and up-dated concept of the actual dangers that threaten their territories, most of all for those deriving from the mutual influence and interaction between risks.

However, the main difficulty related to the adoption of Multi-risk approaches, both at local or wider levels, lies on the multi-disciplinarity that they require. On one side, the assessment of each territorial risk is usually developed through a probabilistic approach and specific competences in the field; but, on the other side, the evaluation of possible protection measures, interventions and actions relies on people experts in Land Use and Urban Planning, and on politicians, who rarely have an engineering background. As evidenced by (Menoni et al., 2006), the reasons underlying risk-management and land use actions could be influenced by parameters that are not considered by scientists: i.e. "Planners are generally reluctant to consider risk estimates expressed in probability terms […]. Especially in the case of potentially rare but very harmful events, planners often end up taking the risk, as they do not fully understand the implications of probabilities".

Therefore, currently many obstacles impede to Municipalities to actively operate an integrated analysis of the territorial risk in their City plans:

1) Land use planners and Municipality technicians could be insufficiently prepared in risks disciplines; therefore, they could find difficult to apply some of the Multi-risk methodologies developed in the last years both at a European and International level;
2) Multi-risk projects show different levels of maturity and applicability (for a complete review, see Nadim & Liu, 2013), but till now, no one was integrated in L.U.P. (Land Use Planning) or risk laws adopted in Europe and in the member states. In Italy, no mandatory rules ask Municipalities to evaluate the combined effects of risks.
3) Municipalities have scarce resources for the maintenance of territory, and probably they would not afford expenses related to a domain not interested by mandatory laws. At the same time, the scarcity of resources makes very urgent the identification of the areas more exposed to risks, to optimize and better address the use of resources.

In order to bring the Municipalities to assume a more active role towards Multi-risk aspects, and at least being able to recognize and point out the main criticalities of their territory, a simplified methodology based on a semi-quantitative approach was proposed.

2. Methodology

2.1 A semi-quantitative methodology at a local scale

The research aim was to set a quick and easy to use methodology intended for a direct use from the Municipalities' technicians; the proposed methodology tried to consider in an integrate framework the main risks on the territory and their possible interactions, highlighting possible aspects that have been neglected in the existing sectorial plans. The methodology acts as a pre-screening of the possible risks, able to orient further in-depth studies and interventions related to Land Use Planning and Emergency.

The structure of the proposed methodology at a local scale was based on the scheme adopted for the Italian plans related to the industrial risk, called E.R.I.R. – Elaborato Tecnico per il Rischio di Incidente Rilevante (Technical Plan for Major Risk accidents):

1) characterization of risks;
2) characterization of the territorial and environmental vulnerable elements;
3) assessment of the compatibility.

However, not only industrial risk was considered; the integrate analysis of other territorial risks brought to the introduction of different elements and assumptions in the above-mentioned framework.

Concerning the risks to be analysed, the concept of the "Spatial relevance" stated in ESPON project (Schmidt-Thomè, 2006) was adopted: only risks that regularly or irregularly interest the same territorial area should be considered, disregarding those that could take place everywhere. For the first stage of development of the methodology, we settled the analysis on the risks more uniformly diffused in Italy: industrial, flood and seismic risk, but each Municipality should consider its main territorial criticalities (i.e. volcanic risk, avalanches etc.). Another risk introduced in our analysis, even if not properly spatial relevant, was that related to extreme climatic events: indeed, violent rains, windstorms etc. could heavily affect a territory and influence the other risks.

The proposed methodology did not analyse the probability of occurrence of the risky events, for several reasons. On one side, multi-risk events are connoted by a very low probability, that could bring to neglect this kind of events; i.e., in some risk approaches, as i.e. industrial risk, the scenarios for events with probability > 10-6 are not even developed. In addition, some of the probabilities of occurrence calculated for risks influenced by climate, like floods or avalanches, are demonstrating a decreased reliability. Finally, calculating the probability would have introduced several problems related to the homogeneity of the risks analyzed and to the lack of data, which would have compromised the simplicity of the methodology and its employability for not expert users.

Thus, a semi-quantitative approach was introduced, based on a rating system common for all the main risks present on the territory; this type of approach, already employed in European projects (Schmidt-Thomè, 2006) or regional methodologies (Regione Lombardia, 2007) was adopted for its simplicity, which could allow its use also with low economical resources and technical skills. A simple rating scale was adopted, with different scores related to the possible impact of the element analyzed:

- $0 < I \leq 0{,}99$: Negligible
- $1 < I \leq 1{,}99$: from Low to Moderate
- $2 < I \leq 2{,}99$: from Moderate to High
- $I \geq 3$ onwards: from High to very High.

2.2 Characterization of the risks

The first step of the proposed methodology consists of an in-depth analysis of the main territorial risks that insist on the territory of the Municipality, carried out by the Municipality technicians. An in-depth data collection has to be developed on the basis of existing sectorial plans, emergency plans, and on the basis of the direct knowledge of the territory.

In order to better understand and address the description of each risk, the risk characterization was based on three macro-categories, aimed at highlighting the characteristics of the analyzed risk which could majorly influence its dangerousness and its possible interaction with other events. The categories are:

1) SE - Strengthening effects: Local characteristics able to increase the dangerousness (i.e. in case of seismic risk, the type of soil);
2) HE - Historical and recent events: all the events related to the specific risk should be considered, to evaluate if the return times expressed by the overall plans are reliable;
3) PM - Protection measures: the presence of protection and preventive measure could reduce the impact of the risk analyzed.

The ratings defined in Paragraph 2.1 are assigned to each risk on the basis of these three macro-categories; a guide-line to help the Municipal technicians in the assignation of the scores was defined (see Table 1). As already anticipated, the climate related events were introduced and rated, but they were evaluated on the basis of a simplified approach, related to the global tendencies, because an analysis of the local trends could present difficulties related to the data collection and interpretation.

Table 1 – Rating assignation guideline

Macro-category	*Rating*		
	1 < I ≤ 1,99	*2 < I ≤ 2,99*	*I ≥ 3 onwards*
	INDUSTRY		
SE Strengthening effects	Only few items with Na-tech risk; scenarios related to flammable substances, with a reduced area of impact	Items with NaTech risk; scenarios related to flammable and environ-mental sub-stances	Huge quantity of hazardous substances. Items with NaTech risk. Scenarios related to toxic substances and / or with great extension.
HE Historical events	No relevant or NaTech accidents occurred	Low impact events (NaTech and / or with effects on the territorial and environmental receptors)	High impact events (NaTech and / or with severe effects on the vulnerable receptors)
PM Protection measures	No dedicated measures for NaTech have been adopted; lack of protective measures towards the environment	Good safety level towards the environment; partially effective also towards NaTech accidents	Adoption of preventive measures adequate for avoiding NaTech risk and domino effects
	FLOOD		
SE Strengthening effects	Interaction with other rivers/creeks with low or reduced criticalities; hydraulic devices in good state; no or few critical points (crossing and bridges with insufficient flow section; eroding or sliding banks/levees; sudden section variations etc.	Interaction with other rivers/creeks and hydraulic control devices with moderate criticalities; identified critical points (see precedent column); the river /creek / etc. analysed contains key element for the safeguarding of the general safety of the system	Problematic interaction points with other rivers/creeks, recognized high critical areas, reported in Flood plans (i.e. throttling points, areas interested by erosion etc). Bad state of the hydraulic devices, with recognized criticalities
HE Historical events	Rare main flood events, return time of Flood management plans is confirmed. (zones classified as C, or Em, Cn - if recent events do not evidence different	Floods of moderate impact, and/or in areas not included in Plans, with a short return time (≥ 50 years) (zones classified as B, or Eb, Cp - if recent events do not evidence different	Events with return time > than that of the Flood management plan worst zone. (zones classified as A, or Ee, Ca - if recent events do not evidence different

Macro-category	*Rating*		
	1 < I ≤ 1,99	*2 < I ≤ 2,99*	*I ≥ 3 onwards*
	distributions / timing of the floods)	distributions / timing of the floods)	distributions / timing of the floods)
PM Protection measures	No water regulation artefacts / systems or insufficient number/way. Criticalities and inadequate safety level	Water network / river / creek is properly controlled, the artefacts do not show relevant criticalities	The management of the water network / river / creek is well coordinated, evidencing no criticalities
	EARTHQUAKE		
SE Strengthening effects	Rigid soils, without local amplification effects	Soils with local amplification effects	Soils with strong local amplification effects (i.e. liquefaction)
HE Historical events	Class 3 zone, or: no unforeseen events with peak ground acceleration P.G.A. > Class 3	Class 2 zone, or: seismic events with P.G.A. ≥ Class 3	Class 1 zone, or seismic events with P.G.A. 2 times higher than that foreseen, unexpected amplification effects, reduced return times
PM Protection measures	-	-	-
	CLIMATE EVENTS		
SE Strengthening effects	When no data on specific local trends are available, adoption of a unique value for the Strengthening effects, aimed at evidencing the increasing tropicalization, which could produce a major intensity and therefore major consequences for climate related events like i.e. raining, lightning, extreme temperatures etc		
HE Historical events	Continental climate (Plane zones)	Climate with elevate temperature and/or with relevant temperature gaps: arid continental climate / cold continental climate / Mediterranean climate / mountain climate	Climate characterized by extreme temperature conditions / raining / intense storms: Tropical climate / equatorial climate / Desert climate / Subpolar climate
PM Protection measures	-	-	-

The assignation of the scores is also reported in a GIS map. Each risk is represented as a layer, composed by different polygons; the scores are reported in the attribute tables of each layer. Therefore, it is possible to obtain thematic maps showing the values assumed by the risk for a specific macro-category, and also to evaluate the overlaying of the different risks.

2.3 Risk interactions

The macro-categories, that allow to correctly identify each feature of the risks, were employed as the basis of the risk interaction assessment. In fact, these characteristics determine the risk role in a possible risk interaction, and provide useful indications on the possible plausible effects. However, the macro-categories have different levels of influence on the interaction, and also different reliability in terms of data; as a consequence, different weights were attributed to express this variability. The weights were designed to obtain final results in line with the general scale employed in the methodology (see Par 2.1.), and were validated through experts' judge.

HE Historical events received the maximum weight (2), because the past and recent events could give an immediate clear idea for potential future events. For the category SE Strengthening effects, the weight assigned was (1); indeed, this is an innovative category, based on the observations and knowledge of the technicians, but some uncertainties could arise in the attribution of the ratings, because of the lack of data or doubts related to the methodology. Finally, the value of the weight for PM Protection measures was (0,5),

because unfortunately protection measures could unexpectedly fail, or have unforeseen malfunctions, and especially they are rarely designed to face multiple risks.

The binary risk interaction, intended as the possible impact provoke by a risk on another one, can be assessed in the area of risk overlaying, in particular when vulnerable environmental or territorial elements are present. The binary risk interaction is calculated through a weighted average of the values assigned to each category of the different risks, reported below in Equation 1.

$$I = [(H.E._{RISK1} + H.E._{RISK2}) * 2 + (S.E._{RISK1} + S.E._{RISK2}) * 1 + (P.M._{RISK1} + P.M._{RISK2}) * 0,5] / 6 \qquad [1]$$

A dedicated binary interaction table was developed in order to simplify the assessment of the possible interactions: the specific values assumed by each risk in the analysed point of the territory are reported in the table; when a possible risk correlation is encountered, the formula of Equation 1 is applied. Table 2 below shows an example of interaction table, related to one of the case studies employed for the methodology: in this case, an industrial plant (I) was exposed to multiple possible binary interactions with flood (F), earthquake (E) and extreme climate events (C).

Table 2 – Example of binary interaction table

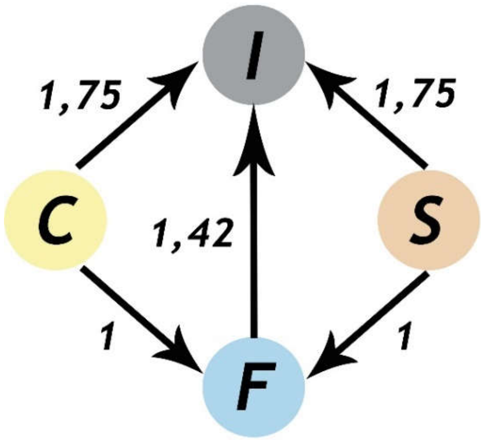
Impact →			*E*			*F*			*I*			*C*		
			SE	*HE*	*PM*	*SE*	*HE*	*PM*	*SE*	*HE*	*PM*	*SE*	*HE*	*PM*
			2	*1*	*0*	*1.5*	*1*	*-3*	*3*	*2*	*-1*	*2*	*1*	*0*
	SE	*2*												
E	*HE*	*1*		No interaction			0.92			1.75			No interaction	
	PM	*0*												
	SE	*1.5*												
F	*HE*	*1*		No interaction			No interaction			1.42			No interaction	
	PM	*-3*												
	SE	*3*												
I	*HE*	*2*		No interaction			No interaction			No interaction			No interaction	
	PM	*-1*												
	SE	*2*												
C	*HE*	*1*		No interaction			0.92			1.75			No interaction	
	PM	*0*												

The values obtained in the Interaction table can also be directly calculated through GIS, using the Intersecting instrument and operating with the calculator fields of the Attribute tables.

The presented Interaction table evaluates the impact of one risk on another one, however simultaneous manifestation of multiple risks or multiple interactions can also take place. In order to obtain a first measure of the possible impact of these rare events, we considered that the best solution was to cross the values obtained from the interaction table through a simple sum, able to return the increase of dangerousness following the interactions of multiple risks.

A dedicated scheme, showed in Figure 1 (next page), was developed to guide the assessment of multiple interaction: the possible impact can be calculated following the direction of the arrows; i.e., to calculate the effects of a climate extreme event provoking effects on Flood and on Industry, it will be necessary to sum 1 + 1,42 + 1,75.

Figure 1 – Scheme for the assessment of multiple interactions



2.4 Compatibility assessment

In order to verify the impact of risks and their possible interaction, the Municipality technicians should investigate territorial and environmental vulnerabilities. For this task, the proposed methodology recovered the indications of Ministerial Decree 09/05/2001 (minister dei Lavori Pubblici, 2001) and of (Regione Piemonte, 2010), both related to the draft of E.R.I.R. plan.

As far as it concerns the territorial vulnerability (related to people density), urban functions and buildings have to be classified in 6 different vulnerability categories, which are assigned on the basis of their building ratio index. DM 09/05/2001 defines the territorial compatibility correlating these 6 categories to the probability of occurrence of the accidental event and of its type of effects (High Lethality, Early Lethality, Irreversible Damage and Reversible Damage). Areas and buildings belonging to categories A and B (the densest ones) are considered not compatible inside the damage areas, and in a safeguard area defined by the E.R.I.R. planners.

However, the assessment of the territorial compatibility for the proposed methodology could not be based on probability; also, other risks should be considered, besides the industrial one. Therefore, the compatibility was verified on the basis of the ratings of the risk macro-categories SE and HE and of the values obtained for the binary risk interactions; when the threshold of 2.5 (medium riskiness tending to high) is overcome in areas where A and B categories are included, a potential incompatibility is signalled.

Concerning the environmental compatibility, (Regione Piemonte, 2010) provided a detailed list of vulnerable elements to be identified. However, vulnerable environmental elements have different levels of vulnerability depending on the risk analysed; therefore, before assessing the compatibility on the basis of the threshold, the Municipality should evaluate the specific characteristics of the vulnerable elements and the possible effects of the risk analyzed. A possible guide of the risk influences on the vulnerable elements was drafted by the authors on the basis of literature data (see Table 3).

Table 3 - Risk influence on environmental vulnerable elements (Extract)

Vulnerable element	*Risks*			
	Earthquake	*Flood*	*Industry*	*Climate events*
Protected natural areas (national, regional, provincial)	Reduced influence	From reduced to moderate influence	High influence (environmental /toxic/ flammable subs.)	From reduced to moderate influence (for lightning, drought)
Historical monuments, landscape archaeological areas	High influence	High influence	From moderate to high influence	Moderate influence

2.5 Planning phase

The last step of the methodology is dedicated to the studies and actions to be carried out to face possible incompatibilities. The overcoming of the threshold of 2.5. in areas with potential territorial or environmental incompatibilities, is an alert signal for the Municipalities, indicating that it is necessary to concentrate here economical and technical resources.

Two levels of actions are foreseen: the first step is an analysis in detail of the potential incompatible situation, both as far as it concerns the hazards and the vulnerabilities. If the incompatibility is confirmed, the second step, based on possible prevention and protection measures and interventions, could be prepared; in this last phase, the Municipality will have to involve and cooperate with experts of several fields.

Some existing Manuals and Guidelines, diffused by the government or other public authorities, or settled by research groups, already provide useful indications for in-depth analysis and actions, but in many cases, they do not have binding value, and therefore are little known and applied.

These indications were collected in dedicated tables, that can guide the Municipalities in the choice of a correct approach to face problems related to Multi-risk.

3. Conclusion

The proposed approach provides the Municipalities with a quick and easy to use tool that can be developed almost completely with internal resources; it analyses all the main risks present on the territory and their interactions, highlighting any potential neglected danger. The assessment of the territorial and environmental vulnerabilities and of the compatibility, inspired to that of E.R.I.R. planning, can return an immediate idea of the areas mostly subjected to the risk. The proposed methodology could represent the starting point of a path towards the increase of safety in L.U.P., allowing the Municipalities to better address further studies or interventions.

The application of the methodology to two Italian case studies returned positive results in terms of soundness and efficacy, highlighting possible problems that were not clearly signalled or neglected by the risk sectorial plans. However, a further development is advocated.

The proposed approach is already a product of multi-disciplinary competencies, since the authors are risk experts and architects; however, the focus of the attention was mainly kept on industrial risk and its interactions. A larger cooperation with other disciplines would allow to develop a framework to correctly approach other risks and risks interactions (i.e. avalanches, sea risks, fire etc.), and to strengthen the approach proposed. Finally, the future objective is testing the methodology on other case studies, in direct cooperation with the Municipalities, also through the application of participative processes.

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