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Multi-Risk Assessment: a Sensitivity Test for a Local-Scale Semi-Quantitative Methodology

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A semi-quantitative methodology at a local scale is presented, aimed at increasing the efficacy of Land Use Planning related to the Management of risks, in particular for multiple risks impinging on the same territory (Multi-risks). At the moment, each risk is managed through a dedicated sectorial plan, having its proper procedures and scale, and the only "meeting point" for these plans – at least in Italy - are the Municipal city plans. The Municipalities have to implement the contents related to the various risks and directly intervene on the territory, but the lack of linkage and coordination between the plans and the authorities in charge often makes the emergency management and LUP less effective towards the achievement of a real safety of territories. A semi-quantitative approach, based on an index scale from 0 to 3 onwards was developed for a direct use from Municipal technicians; the proposed scale is applied to measure both the impact of the risks and risk interaction. The methodology is composed by 4 steps: 1) characterization of the risks; 2) assignation of the ratings to the risks; 3) assessment of binary risk interactions; 4) assessment of the compatibility and planning phase. Each step is accompanied by GIS mapping. The methodology was tested on two Italian case-studies, two Municipalities affected by multiple types of risks which could interact; the proposed approach demonstrated to be able in identifying and bring multi-risks aspects to the attention of the decision makers, constituting a guide to risk that can be integrated with the existing planning instruments to improve the quality of decisions related to risks.
The paper presents a further step in the research related to the methodology, investigating the influence on the interaction values provoked by the discretion in the assignation of the rating operated by the users. A sensitivity test was developed on one of the case studies analysed with the methodology; the interaction values demonstrated to be sensitive to the variations of the ratings, in particular in the zones near the change of scale intervals.

1. Introduction

The authors developed a semi-quantitative methodology aimed at helping Italian local authorities in facing multi-risk aspects inside their Land Use Planning practices. The methodology was experimented and tested on two different Italian case-studies, two towns with different dimensions interested by natural and industrial risks, whose possible interactions were not adequately considered by the existing sectorial risk plans. The methodology was extensively presented in two previous CET papers (Pilone et al., 2017) and (Pilone et al., 2018), and in (Pilone & Demichela, 2018) therefore this paper provides only a quick overview of the proposed method and then focuses on a sensitivity analysis of the outputs (risk interaction values). In fact, the methodology was conceived for a direct use by the Municipal technicians, so that the risk interaction values are directly connected to the ratings assigned to territorial and industrial risks by the users. In order to improve and refine the methodology, it was necessary to verify the specific influence of possible uncertainties and mistakes during the assignation of the ratings. The present paper presents the sensitivity tests executed on one of the case studies, a small city nearby Turin that was interested by two different risks, (flood and industrial risk).

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2. Methodology

The methodology is composed by 4 different steps: 1) Rating assignation; 2) Assessment of the binary interaction; 3) Assessment of the compatibility and 4) Planning phase; it is here presented in parallel with the explanation of the case study. The methodology was developed to take into account the interactions between 4 types of risk: Seismic risk, Flood risk, Industrial risk and Climate related events (the latter were rated with a simplified approach). The Municipality technicians are required to rate the possible impact of the risks on the basis of a scale from 0 to 3 onwards, inspired to those used for the projects ESPON and MATRIX (Nadim & Liu, 2013), (Schmidt-Thomè, 2006): $0 < I \leq 0.99$: Negligible impact; $1 < I \leq 1.99$: from Low to Moderate impact; $2 < I \leq 2.99$: from Moderate to High; $I \geq 3$ onwards: from High to very high impact.
The values of the binary interactions (impact of one risk on another one) are calculated starting from the ratings assigned to the risks. Finally, the compatibility of risks and risk interactions with territorial and environmental vulnerable elements is assessed, in order to program further studies and interventions.

2.1 Risk rating

The municipal technicians rate the risks of their territory on the basis of three macro-categories that describe different aspects of each specific risk. Historical events (HE) and Strengthening effects (SE) macro-categories return an esteem of the possible risk impact of the risk with reference to previous events, and aspects that could enhance the dangerousness; the macro-category Protection Measures (PM) keeps into account the structural measures adopted to contain the risk. (PM) receives only negative rates because it compensates (HE) and (SE). Dedicated tables to guide the rating assignation were drafted for each type of risk: the table below reports the elements that allow the users to rate the macro-category (SE) of Flood, Industrial risk and Climate events.

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

	Risk	1 to 1.99 (low)	2 to 2.99 (moderate)	3 to 4 (high)
[SE] Strengthening effects	Flood	The interaction between the elements of the water network, and the hydraulic control devices show low or reduced criticalities	The interaction between the elements, and the hydraulic control devices show moderate criticalities; or: key element for the general safety of the system	Presence of zones with high criticality, reported in sectorial Plans, or 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.	Items with NA-TECH risk; the potential scenarios are related to flammable and environmental substances	Huge quantities of hazardous substances and many items with NA-TECH risk. Domino effects are possible. Scenarios related to toxic substances, great extension.
	Climate events	A general value = 2 is adopted to express the general trend of tropicalization.		

For the case study mentioned in Par. 1, the following risks were identified and rated:

1) FLOOD RISK: According to the Flood sectorial risk Plan, a creek located in the northern portion of the Municipality could generate flood with low return time and moderate water depth. However, flood events in the last 30 years interested wider areas and had higher return times than those indicated by the Plan. In addition, the Plan did not consider that the floods were not only provoked by the creek, but also by a secondary water network, lacking of any protective measure.
   Ratings → Creek: (SE) 3; (HE) 2; (PM) – 0.5. Secondary water network: (SE) 3; (HE) 2; (PM) 0
2) INDUSTRIAL RISK: Two plants were identified; a former galvanic Seveso plant in state of abandon (Plant X), whose closure in safe conditions could never be proved, and a plant detaining a quantitative of hazardous substances overcoming the Seveso lower-tier threshold (plant Z), not signalled by the Authorities in charge. Both the plants were included in areas flooded during the las 30 years (see Figure 1 in the following page).
   Ratings → Plant X: (SE) 3; (HE) 1.5; (PM) 0. Plant Z: (SE) 2,8; (HE) 1.5; (PM) -1.8

N.B. (HE) received a fixed value of 1.5 = low impact, because of the unavailability of information on the accident case histories of the two plants and on the effects provoked by the floods.

Figure 1: Areas of superimposition of flood risk and industrial risk (Plants X and Z)

2.2 Binary risk interactions

The impact of one risk on another one (binary interaction) is calculated summing up the values assumed by the macro-categories in the area of risk superimposition, according to the following equation:

$$I = \left[(HE_{R1} + HE_{R2}) * 2 + (SE_{R1} + SE_{R2}) * 1 + (PM_{R1} + PM_{R2}) * 0.5\right] / 6 \qquad (1)$$

R1 and R2 represent the risks superimposed; HE, SE and PM are the ratings assigned to their macro-categories in the specific point of risk overlaying. Specific weights were introduced in Eq. (1) for the Macro-categories, to consider their different reliability in terms of available data and different capacity to influence the final interaction value: 2 for (HE); 1 for (SE), 0.5 for (PM). The assigned weights were validated through experts' judge. An excel table called Interaction table allows the users to assess the binary interaction values for all the possible risk interactions, repeatedly applying Eq. (1). Tables 2 and 3 show the Interaction tables for Plant X and Plant Z:

Table 2: Binary interaction table for Plant X

PLANT X			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	-0.5	3	1.5	0	2	1	0
Flood	SE	3									
	HE	2		No interaction			2.13			No interaction	
	PM	-0.5									
Industrial	SE	3									
	HE	1.5		No interaction			-			No interaction	
	PM	0									
Climate events	SE	2									
	HE	1		1.79			1.67			No interaction	
	PM	0									

Table 3: Binary interaction table for Plant Z

PLANT Z			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	0	2.8	1.5	-1.8	2	1	0
Flood	SE	3									
	HE	2		No interaction			1.98			No interaction	
	PM	0									
Industrial	SE	2.8									
	HE	1.5		No interaction			-			No interaction	
	PM	-1.8									
Climate events	SE	2									
	HE	1		1.83			1.48			No interaction	
	PM	0									

2.3 Compatibility and planning phase

The compatibility of the risks and their interactions with the vulnerable urban and environmental elements is assessed on the basis of a fixed threshold of 2.5, corresponding to a medium-high impact. The threshold is evaluated both for the rating of (HE) and (SE) risk macro-categories and for the interaction values; if the threshold value is overcome in areas where highly vulnerable elements are present, it provides an alert to the Municipalities about possible incompatibilities. Further studies will be needed to confirm or not the incompatibility, and to carry out possible preventive and protective measures. The authors defined dedicated tables both for the identification of the vulnerable elements and for the further measures (see Pilone & Demichela, 2018).

For the case study, the interaction values did not overcome the threshold; however, for both the plants analysed possible incompatibilities were identified because of the ratings of the risk macro-categories (SE = 3 in areas of high vulnerability). Both for plant X and plant Z, an environmental incompatibility was detected, due to the presence of a vulnerable aquifer with scarce depth and to high quality agricultural soil; the exposure to flood events could trigger or worsen a possible pollution. For plant Z, a potential urban incompatibility was detected too, because of the presence of two buildings with high people frequency nearby the plant.

3. Sensitivity test

As explained in Paragraph 2, the assessment of the risk interactions derives from the values attributed by the Municipality technicians to the macro-categories that describe the risk. Despite of the Guiding tables, the rating procedure is still interested by a certain degree of discretion, depending on the availability, quality and quantity of the information related to the risks, on the scientific preparedness of the technicians, on possible external influences etc. In order to verify the possible variations of the outputs (interaction values) in function of the assignation of ratings, a sensitivity test was executed on the case study previously presented. Several variations were introduced in the ratings assigned to Flood, Industrial and Climate risk.

Some specifications have to be provided in relation to the original ratings: as previously mentioned, (HE) for Industrial risk had a fixed value = 1.5, corresponding to a low-medium impact; for the Climate related events, the values for (HE) = 1, (SE) = 2, (PM) = 0 were fixed, expressing the type of climate and the increasing tropicalization.

3.1 Sensitivity test on the case study

The maximum variation related to the discretion in the assignation of the rating was assumed equal to 1.00 in absolute value, that means a variation of ± 0.5 on the assigned rating value. The variations were applied to the Interaction tables of Plant X and Plant Z (see Tables 2 and 3), verifying the variations of the interaction values in function of the variations applied to the ratings. The following tests were executed:

a) “Worst case condition”: an increment of + 0.5 was introduced for each macro-category of the 3 risks analysed. If (PM) = 0, the value remains 0 because the macro-category can have exclusively negative ratings (Table 4).
b) “Best case condition”: a decrement of - 0.5 was introduced for each macro-category of the 3 risks analysed (Table 5).
c) Variation applied to only one risk: the fluctuation of ± 0.5 was applied alternatively to the Industrial risk (Table 6 and 7), and to the Flood risk, whilst the ratings for the other risks remained unchanged
d) Increment of the rating + 1 for the macro-category (SE) of Climate related events to better represent the increasing tropicalization.

Not all the output tables of the sensitivity test are reported in this paper for reasons of space.

Table 4: Binary interaction table: ‘Worst condition’ + 0.5 all risks

PLANT X			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3.5	2.5	0	3.5	2	0	2.5	1.5	0
Flood	SE	3.5	No interaction			2.67			No interaction		
	HE	2.5									
	PM	0									
Industrial	SE	3.5	No interaction			-			No interaction		
	HE	2									
	PM	0									
Climate events	SE	2.5	2.33			2.17			No interaction		
	HE	1.5									
	PM	0									

Table 5: Binary interaction table: 'Best condition' -0.5 all risks

PLANT X			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			2.5	1.5	-1	2.5	1	-0.5	1.5	1	0
Flood	SE	2.5									
	HE	1.5		No interaction			1.54			No interaction	
	PM	-1									
Industrial	SE	2.5									
	HE	1		No interaction			-			No interaction	
	PM	-0.5									
Climate events	SE	1.5									
	HE	1		1.42			1.29			No interaction	
	PM	0									

Table 6: Binary interaction table: + 0.5 Industrial risk

PLANT X			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	-0.5	3.5	2	0	2	1	0
Flood	SE	3									
	HE	2		No interaction			2.38			No interaction	
	PM	-0.5									
Industrial	SE	3.5									
	HE	2		No interaction			-			No interaction	
	PM	0									
Climate events	SE	2									
	HE	1		1.79			1.92			No interaction	
	PM	0									

Table 7: Binary interaction table: - 0.5 Industrial risk

PLANT X			Flood			Industrial			Climate events		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	-0.5	2.5	1	-0.5	2	1	0
Flood	SE	3									
	HE	2		No interaction			1.83			No interaction	
	PM	-0.5									
Industrial	SE	2.5									
	HE	1		No interaction			-			No interaction	
	PM	-0.5									
Climate events	SE	2									
	HE	1		1.79			1.38			No interaction	
	PM	0									

3.2 Discussion of the results

The variations of the interaction values consequent to the variations of the ratings were observed to verify the solidity of the proposed methodology. An Italian case study was analyzed for the test, taking into account the possible interactions in the area of two plants (X and Z).

Firstly, the variation of the ratings was tested on two 'extreme' cases, hypothesizing that the discretion of the ratings interested all the risks (this situation is not so probable, also because i.e. Climate related events has a fixed rating):

- for the 'Worst condition' case (+ 0.5), the variation produced for the interactions Climate → Flood and Climate → Industry an increase in the level of the interaction, that passed from 'Low' impact to 'Medium' impact, thus not overcoming the alert threshold of 2.5 (see Paragraph 2.3). The value of the binary interaction Flood → Industry remained in the same interval ('Medium') but overcame the alert threshold of 2.5.
- For the 'Best condition' case (-0.5), the variation of the ratings produced a negligible decrease of the values for the interactions Climate → Flood and Climate → Industry. The value of the binary interaction Flood → Industry passed from a 'Medium' level to a 'Low' one.

The variations of the rating applied to one single risk produced less substantial variations with respect to the initial values showed in Tables 2 and 3; some of the interactions were subjected to modification of the impact level, however, the values remained quite in line with the initial ones, and in particular did not overcome the alert threshold of 2.5. Finally, as far as it concerns the variation of the macro-category (SE) for the Climate related events, it produced a modest variation with respect to the initial values.
The sensitivity test applied on the case study made clear, both for the ‘extreme conditions’ and for the single risk variation, that the interactions values more susceptible towards variations in the assignation of the rating are those that are closer to the limits between the intervals of the scale adopted (‘Low’, ‘Medium’, High’). In fact, in these cases, the variation of only one parameter of the risk macro-categories can determine an interval change; therefore, it can be said that these interaction values are those more exposed to discretion risks.
In order to compensate this result, a variation could be introduced in the application of the methodology: in case of Interaction values near to the limit of the intervals, an attention threshold of ± 0.25 could be adopted. This means that i.e. if the Interaction value is 1.75, or 2.25, the user should know that this value could be particularly sensitive to uncertainties and discretion occurred during the rating phase. Therefore, the ratings assigned shall be carefully checked, in particular when the risk level results particularly low. In fact, an underestimation in the risk ratings could bring to an underestimation of the values of the interaction, so that the users could erroneously consider their territory as ‘safe’. On the contrary, a super-estimation of the risk and risk interactions values can at best produce conservative actions, enhancing the knowledge of the territory and the possible threats.

4. Conclusions

A semi-quantitative methodology for the estimation of the risk interactions was proposed and developed for a direct use from Municipality technicians and other stakeholders. The paper presents a further step in the research related to the methodology, investigating the influence on the interaction values provoked by the discretion in the assignation of the rating operated by the users. A sensitivity test was developed on one of the case studies analysed; the interaction values demonstrated to be sensitive to the variations of the ratings, in particular for values close to the change of scale intervals.
A certain degree of discretion is obviously incorporated in the methodology, since the judgment about the risks is entrusted to the Municipality technicians; actually, one of the major advantages of the methodology is that it can exploit the major knowledge of the territory that local authorities have. However, the test helped in identifying the specific areas more exposed to uncertainty and discretion and in designing possible solutions, thus improving the application of the methodology and its results.

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