

Comparative risk analysis for contaminated sites: Italian regional criteria in comparison with international standards

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Abstract

According to the Italian regulation on remediation activities (D.M. 471/99), comparative risk analysis plays a fundamental role in the evaluation of the priorities for clean-up actions on contaminated sites and gives important indications on the initial investigation strategy. Based on the US.EPA model "Hazardous Ranking System (HRS)" first developed in 1982 and successively modified, some regional comparative risk analysis criteria have been developed in Italy. A crucial point for the application of comparative risk analysis on a national scale is the development of a unique standard procedure that should include all the regional experiences, giving them a large-scale validity with the introduction of scores tested on site-specific characteristics. In this perspective, the paper presents a critical overview of the most relevant and recent Italian experiences on comparative risk analysis.

Keywords: contaminated sites, comparative risk analysis, comparative index, international standards, regional criteria, scoring method.

1 Introduction

The latest approaches to the problem of contaminated site remediation focus on the management of the greatest risks to human health and environment in a cost-effective manner. The comparative risk analysis plays a fundamental role in the development of regional remediation plans, giving a deterministic ranking approach for the evaluation of the actual risk on contaminated sites included in the regional registers.



This paper describes an evaluation of the relevant Italian criteria of comparative risk analysis, carried out by comparative indexes defined in connection with some international standards. This comparative evaluation could be a useful scientific starting point for the future development of a national criterion, as a common tool to local environmental authorities for application at regional levels.

2 Some relevant Italian criteria

2.1 Lombardia Risorse (LR) Criterion

It was originally developed with the aim of comparing contaminated sites identified in Lombardy Region [2]. LR Criterion adapted, for the first time in Italy, the international US.EPA Standard “HRS, Hazard Ranking System” (according to the original ’82 version [3]). LR Criterion takes into consideration three contaminant migration pathways (Groundwater, Surface water, and Direct Contact), characterized by the following factor categories [2]: Contamination Source, Contaminant Vehicles, and final Receptors. Each category includes a group of factors, whose scores, assigned to the investigated site and summed up, identify the category score. The corresponding three category scores are then multiplied, to finally obtain the Groundwater score (V_{hsub}), the Surface water score (V_{hsup}), and the Direct Contact score (V_{dir}). V_{hsub} and V_{hsup} scores, normalized to 0-100, contribute to the final site score (V_{site}) according to the following algorithm (similar to US.EPA “HRS” approach [3]):

$$V_{site} = \frac{\sqrt{(V_{hsub}^2 + V_{hsup}^2)}}{2} \quad (1)$$

V_{site} index expressly allows for definition of intervention priorities, whereas V_{dir} index only identifies the need for urgent measures.

2.2 CSSM Criterion

The first version of “CSSM, Contaminated Site Screening Mode” was developed focusing on Sicilian survey for contaminated sites. A new revised CSSM version was presented in [5]. According to the score-sheet of Table 1, CSSM criterion defines, for each investigated site, two different scores:

- P_{site} , calculated through an algorithm similar to (1) based on Groundwater (P_{gw}), Surface water (P_{sw}), and Air (P_a) scores. P_{site} index is used for defining a priority intervention list.
- P_{dir} , the Direct Contact score, is useful to define urgent situations of intervention (reducing the immediate risk for human health and/or the environment).

As an update of CSSM Criterion, DRASTIC parametric system (for assessment of groundwater intrinsic vulnerability) could be properly replaced in GW scoring with the more reliable SINTACS system, as expressly defined and



largely applied to the Italian hydro-geological situation [6]. Additionally, hazardous waste characteristics in Source category scoring should be certainly adapted to the current Italian legislation on solid waste management.

Table 1: Contaminated Site Screening Model (CSSM) score-sheet.

Factor categories and factors	Max value	CRW [%]	Factor categories and factors	Max value	CRW [%]
<i>GW MIGRATION PATHWAY</i>			<i>AIR (A) MIGRATION PATHWAY</i>		
<i>Source (S):</i>			<i>Source (S):</i>		
1. Toxicity / solubility	160	40	1. Toxicity	200	50
2. Waste quantity	80	20	2. Waste quantity	100	25
3. Containment	80	20	3. Containment	100	25
4. Waste physical state	80	20	4. S (lines 1 + 2 + 3)	400	-
5. S (lines 1 + 2 + 3 + 4)	400	-	<i>Trans. Vector (V):</i>		
<i>Transport Vector (V):</i>			5. Particle mobility	100	50
6. D: depth to aquifer	50	25	6. Gas mobility	100	50
7. R: net recharge	36	18	7. V (lines 5 + 6)	200	-
8. A: aquifer	30	15	<i>Targets (T):</i>		
9. S: soil	20	10	8. Land use	100	50
10. T: topography	10	5	9. Distance to town	60	30
11. I: insaturated zone	50	25	10. Dist. to sen. env.	40	20
12. C: hydraulic conductivity	30	15	11. T (lines 8 + 9 + 10)	200	-
13. V [(lines 6 + ... + 12) - 26]	200	-	<i>A score:</i>		
<i>Targets (T):</i>			Pa = (lines 4 * 7 * 11) * 100/16,000,000	100	-
14. Groundwater use	200	100	<i>DIRECT CONTACT (DC) PATH.</i>		
15. T (line 14)	200	-	<i>Source (S):</i>		
<i>GW Score:</i>			1. Toxicity	280	70
Pgw = (lines 5 * 13 * 15) * 100/16,000,000	100	-	2. Containment	120	30
<i>SW MIGRATION PATHWAY</i>			3. S (lines 1 + 2)	400	-
<i>Source (S):</i>			<i>Trans. Vector (V):</i>		
1. as in GW	400	-	4. Waste area / site accessibility	200	100
<i>Transport Vector (V):</i>			5. V (line 4)	200	-
2. Run-off potential	50	25	<i>Targets (T):</i>		
3. Site slope / run-off path slope	50	25	6. Land use	80	40
4. Distance to nearest surface water	100	50	7. Relation with public roads	40	20
5. V (lines 2 + 3 + 4)	200	-	8. Distance to town	50	25
<i>Targets (T):</i>			9. Dist. to sen. env.	30	15
6. Surface water use	140	70	10. T (lines 6 + .. 9)	200	-
7. Distance to sensitive environment	60	30	<i>DC score:</i>		
8. T (lines 6 + 7)	200	-	Pdc = (lines 3 * 5 * 10) * 100/16,000,000	100	-
<i>SW Score:</i>			<i>CSSM SITE SCORES</i>		
Psw = (lines 1 * 5 * 8) * 100/16,000,000	100	-	Psite = $\text{sqr} [(P_{\text{gw}}^2 + P_{\text{sw}}^2 + P_{\text{a}}^2) / 2]$; Pdc	100	-



Table 2: Piedmont Region (PR) Criterion score-sheet.

Factor categories and factors	Max value ¹	CRW [%]
<i>Remedy Register Site Characteristics (RRSC)</i>	8	-
<i>Site Characteristics (SC):</i>		
1. Prevalent morphology	10	13,5
2. Site area	8	10,8
3. Prevalent lithology	16	21,6
4. Impermeable layers	16	21,6
5. Depth to first aquifer	16	21,6
6. Prevalent land use	8	10,8
7. SC (lines 1 + 2 + 3 + 4 + 5 + 6)	74	-
<i>Waste Characteristics (WC):</i>		
8. Waste containment typology	8	10
9. Waste covering status	16	20
10. Waste containment conditions	14	17,5
11. Waste type classification	24	30
12. Total waste quantity	8	10
13. Waste physical status	10	12,5
14. WC (lines 8 + 9 + 10 + 11 + 12 + 13)	80	-
<i>Site Environmental-Sanitary Hazard (SESH):</i>		
15. Distance to the nearest well / spring	30	57,7
16. Distance to the nearest river	8	15,4
17. Distance to the nearest town	5	9,6
18. Distance to the nearest road	5	9,6
19. Protected area	4	7,7
20. WC (lines 15 + 16 + 17+ 18 + 19)	52	-
<i>Sanitary-Hygienic Site Condition (SHSC):</i>		
21. Soil contamination close to the site	16	17,8
22. Groundwater contamination close to the site	20	22,2
23. Surface water contamination close to the site	16	17,8
24. Leachate presence	14	15,5
25. Gas emission presence	16	17,8
26. Odor presence	8	8,9
27. SHSC (lines 21 + 22 + 23+ 24 + 25 + 26)	90	-
<i>PR Site Score:</i>		
P = [(RRSC + lines 7 + 14 + 20 + 27) - 50] * 100/230	100	-

$$^1 \text{Max value} = p_i * V_{i \text{ max}}$$

2.3 Piedmont Region (PR) Criterion

It was originally developed for the first version of the Piedmont and Sicilian Regional Plans [2]. Then, it has been recently updated, as part of the new version of the Piedmont Regional Cleanup Plan [7], according to actual Italian Technical Regulation No. 471/99 on contaminated soils [1]. PR Criterion doesn't consider the usual subdivision of hazard calculation in different migration pathways, but only defines a unique risk index P with the following expression [7]:

$$P = [\sum_{i=1}^{24} (V_i * p_i) - 50] * 100 / 230 \quad (2)$$



Table 3: Campania Region (CR) Criterion score-sheet.

Factor categories (ideal) and factors	Max value ¹	CRW [%]
<i>Source (S) (ideal):</i>		
1. Waste surface	10	9,6
2. Potential contaminated soil surface	10	9,6
3. Waste quantity	10	9,6
4. Potential contaminated soil volume	10	9,6
5. Waste classification	20	19,2
6. Waste containment	20	19,2
7. Containment / Structure conditions	16	15,4
8. Covering condition	8	7,7
9. S (lines 1 + ... + 8)	104	-
<i>Transport (T) (ideal):</i>		
10. Accessibility	8	5,1
11. Impermeable layers	20	12,8
12. Prevalent morphology	10	6,4
13. Prevalent surface lithology	16	10,3
14. Depth to the first aquifer	20	12,8
15. Soil contamination close to the site	16	10,3
16. Groundwater contamination close to the site	20	12,8
17. Surface water contamination close to the site	16	10,3
18. Leachate presence	14	9,0
19. Gas emission presence	16	10,3
20. T (lines 10 + + 19)	156	-
<i>Receptors (R) (ideal):</i>		
21. Prevalent land use	8	11,8
22. Distance to the nearest well / spring	20	29,4
23. Distance to the nearest surface water body	10	14,7
24. No. house buildings within 100 m distance	6	8,8
25. No. house buildings within 500 m distance	6	8,8
26. Groundwater use	10	14,7
27. Surface water use	8	11,8
28. T (lines 21 + + 28)	68	-
<i>CR Site Score:</i>		
$P = [(lines\ 9 + 20 + 28) - 26] * 100/328$	100	-

$$^1 \text{Max value} = p_i * V_{i \text{ max}}$$

where V_i is the numerical value assigned to twenty-four factors characterizing the investigated site, and p_i is the specific weight associated to the given factor (variable in the range 1-3). Numerical factors 50 and 100/230 are due to P index normalization (0-100). According to PR score-sheet of Table 2, the considered factors are officially subdivided into the following additive factor categories: Remedy Register Site Characteristics, Site Characteristics, Waste Characteristics, Site Environmental-Sanitary Hazard, and Sanitary-Hygienic Site Condition.

2.4 Campania Region (CR) Criterion

PR Criterion has been recently adapted too, in the so-called CR Version, for the current Campania Region situation on contaminated sites [8]. According to the specific score-sheet of Table 3, twenty-five factors are now considered. It should



be pointed out that category subdivision of Table 3 is only theoretical (according to the usual Source-Transport-Receptor route), being indeed not available a direct factor differentiation in the CR official documents.

2.5 ARPAM Study

A regional ranking model has been recently developed too by the Regional Environmental Agency of Marche Region (ARPAM), as a possible system for hazard comparison of contaminated sites located in this Italian Region [9]. According to the specific score-sheet of Table 4, the so-called ARPA Study has a calculation approach similar to LR and CSSM criteria, with three migration pathways (Soil – Direct Contac, Ground and Surface Waters) and three factor categories (Contamination Source, Vehicle of Contamination, human and/or environmental Targets).

2.6 ARGIA Criterion

The so-called “A.R.G.I.A.” method has been recently developed by the Regional Environmental Agency of Emilia-Romagna Region in order to elaborate a priority list of the contaminated sites included in the regional register [10]. The method takes both into account the RBCA Tier 1 and HRS criteria, developing a specific conceptual model and logical framework. The A.R.G.I.A. method finally defines a unique risk index IR, by the following equation:

$$IR = \sum_m IRI_m \quad (3)$$

where m range from 1 to n = number of contaminants.

$IRI_m = \sum_i IVT_{im}$ is the risk index for each contaminant calculated for the $i = 5$ migration pathways (Groundwater/Ingestion, Surface Water/Direct Contact, Soil/Direct Contact + Ingestion, Air/Indoor Inhalation, Air/Outdoor Inhalation) as the sum of the product of the scores related to sources (S), transport/pathways (T) and Receptors (R) categories:

$$IVT_{im} = PtS_{im} * PtT_i * PtR_{ij} \quad (4)$$

where the j index goes from 1 to 8, taking into account all the assumed receptors. It is important to notice that the A.R.G.I.A. method is based on the product of the three categories related to sources, pathways and receptors, while other criteria, basing on the average values of the scores, underestimate the minor component. The use of the product of the scores allows eliminating the contribute related to inconsistent scenarios (unused pathways, unreached receptors, etc.).

3 Possible criteria comparative analysis

3.1 Comparative indexes

A possible, critical comparative analysis among Italian regional hazard ranking criteria, using either an additive (as PR and CR approaches) or a multiplicative (as LR, CSSM and ARPAM approaches) scoring method, can be easily carried out with the following comparative indexes (as previously defined in [2]):



Table 4: ARPAM Study score-sheet.

Factor categories and factors	Max value	CRW [%] ¹	Factor categories and factors	Max value	CRW [%] ¹
<i>SOIL (S) MIGRATION PATHWAY</i>			<i>SURF. WATER (AS) PATHWAY</i>		
<i>Source (Ss):</i>			<i>Source (ASs):</i>		
1. Soil Surface / waste deposit volume	10	58,9	1. Soil surface	10	33,3
2. Toxicity	7	41,1	2. Hydro-solubility	10	33,3
3. Ss [$\frac{1}{2}$ *(lines 1 + 2)]	8,5	-	3. Toxicity	10	33,3
<i>Transport Vector (Sv):</i>			4. ASs [$\frac{1}{3}$ *(lines 1 + 2 + 3)]		
4. Accessibility	10	50	<i>Trans. Vector (ASv):</i>		
5. Worker presence	10	50	5. Permeability	10	50
6. Sv [$\frac{1}{2}$ *(lines 4 + 5)]	10	-	6. Distance to surface water	10	50
<i>Targets (So):</i>			7. ASv [$\frac{1}{2}$ *(lines 5+ 6)]		
7. Land use	10	25	<i>Targets (ASo):</i>		
8. Sensitive targets	10	25	8. Surface water use	10	50
9. Distance to town	10	25	9. Sensitive targets	10	50
10. Inhabitants < 1 km	10	25	10. ASo [$\frac{1}{2}$ *(lines 8 + 9)]	10	-
11. So [$\frac{1}{4}$ *(lines 7 + 8 + 9 + 10)]	10	-	<i>Surface water score:</i>		
<i>Soil score:</i>			FRAS = lines 4 * 7 *		
FRS = lines 3 * 6 * 11	850	-	10	1,000	-
<i>GW (F) MIGRATION PATHWAY</i>			<i>SITE SCORES</i>		
<i>Source (Fs):</i>			IR = $\sqrt{[(FRS^2 + FRF^2 + FRAS^2) / 3]}$; % Plausibility		
1. Soil volume	10	33,3			
2. Hydro-solubility	10	33,3			
3. Toxicity	10	33,3			
4. Fs [$\frac{1}{3}$ *(lines 1 + 2 + 3)]	10	-			
<i>Transport Vector (Fv):</i>					
5. Permeability	10	33,3			
6. Aquifer	10	33,3			
7. Depth to aquifer	10	33,3			
8. Fv [$\frac{1}{3}$ *(lines 5 + 6 + 7)]	10	-			
<i>Targets (Fo):</i>					
9. Distance to wells	10	50			
10. Groundwater use	10	50			
11. Fo [$\frac{1}{2}$ *(lines 9+ 10)]	10	-			
<i>Groundwater score:</i>					
FRF = lines 9 * 10 * 11	1,000	-			

¹ CRW as referred to sum of max factor values

- the Category Relative Weight (CRW), calculated - for each factor - as (factor score of max hazard effect / category score of max hazard effect) * 100.
- the Pathway Relative Weight (PRW), calculated – for each category – as (max category score / max not normalized pathway score) * 100.



Table 5: PRW values for HRC Legend: GW = Groundwater; SW = Surface Water; DC = Direct Contact; A = Air; NP = no pathway distinction; (1) Normal PRW; (2) PRW compared with Target/Receptor PRW.

Factor Categories		PRW									
		GW		SW		DC		A		NP	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
<i>Italian Regional Criteria</i>											
L R	Source	0.83	1.46	2.86	3.11	2.78	1	-	-	-	-
	Vehicles	0.38	0.67	1.29	1.40	2.78	1	-	-	-	-
	Receptors	0.57	1	0.92	1	2.78	1	-	-	-	-
C S S M	Source	0.0025	2	0.0025	2	0.0025	2	0.0025	2	-	-
	Transport	0.0012	1	0.0012	1	0.0012	1	0.0012	1	-	-
	Targets	0.0012	1	0.0012	1	0.0012	1	0.0012	1	-	-
P R	Source (WC)	-	-	-	-	-	-	-	-	27.0	1.53
	Vehicle (SC + SHSC)	-	-	-	-	-	-	-	-	55.4	3.15
	Tar. (SESH)	-	-	-	-	-	-	-	-	17.6	1
C R	Source	-	-	-	-	-	-	-	-	31.7	1.53
	Transport	-	-	-	-	-	-	-	-	47.6	2.30
	Receptors	-	-	-	-	-	-	-	-	20.7	1
A R P A M	Source	1	-	1	-	1	0.8	-	-	-	-
	Transport	1	-	1	-	1.18	1	-	-	-	-
	Targets	1	-	1	-	1.18	1	-	-	-	-
<i>International standards</i>											
A G A P E	Compounds	0.04	1	0.04	1	0.04	1	0.04	1	-	-
	Migration	0.04	1	0.04	1	0.04	1	0.04	1	-	-
	Targets	0.04	1	0.04	1	0.04	1	0.04	1	-	-
N C S	Contamin. character.	-	-	-	-	-	-	-	-	33	1
	Exposure Routes	-	-	-	-	-	-	-	-	34	1.03
	Receptors	-	-	-	-	-	-	-	-	33	1
H R S 8 2	Waste char. * Contain. (GW, SW, DC); Observ. Release (A)	0.14	1.56	0.12	1.33	1.04	6.93	0.13	1.18	-	-
	Route char.	0.03	0.33	0.02	0.22	0.01	0.07	0.06	0.54	-	-
	Targets	0.09	1	0.09	1	0.15	1	0.11	1	-	-
H R S 9 0	Waste char. Likelihood of release	0.0012	0.67	0.0012	0.67	0.0012	0.67	0.0012	0.67	-	-
	Targets	0.0067	3.72	0.0067	3.72	0.0067	3.72	0.0067	3.72	-	-
	Targets	0.0018	1	0.0018	1	0.0018	1	0.0018	1	-	-

These indexes reflect the relative importance of a given factor within its proper category, or a particular category within its corresponding migration pathway (or overall hazard route). The score-sheets of Tables 1-4 are comprehensive of CRW values respectively for CSSM, PR, CR and ARPAM criteria. Table 5 instead reports PRW values for these Italian regional criteria, and also for relevant international hazard ranking standards. Particularly, for



international comparison the German AGAPE criterion [11], the Canadian National Classification System (NCS) [12], and both versions of US.HRS [3], [13] have been considered.

The particular scoring approach of A.R.G.I.A. model, does not allow yet – at least in this comparative evaluation - the easy definition of related indexes.

3.2 Comparative analysis

The previously defined PRW and CRW indexes are useful for a comparative analysis respectively of category and factor weights within a given criterion. For instance (Table 1) in CSSM criterion “Toxicity” is always the most predominant factor within “Source” category for each considered migration pathway. Furthermore, PRW and CRW values allow for an interesting comparative analysis among different hazard ranking criteria. The data of Table 5 suggest for instance the following considerations:

- in LR criterion, “Source” category is predominant (apart for “Direct Contact” pathway), according to the same behavior of HRS ’82 version.
- in CSSM criterion, PRW value order is the same within each considered migration pathway, like AGAPE criterion and ARPAM study. However, unlike AGAPE and ARPAM criteria, CSSM “Source” category has a double relative weight as compared to other categories (Transport and Targets);
- even if without a clear migration pathway distinction, PR and CR criteria attribute a predominant weight to the (theoretical aggregated) “Transport” category, whereas the reference NCS international standard doesn’t introduce such unbalance among category weights;
- finally, “Likelihood of Release” (as equivalent of “Transport” category) predominance in actual HRS version is indeed only theoretical (that is, based on the reasonable worst case category values), being in fact “Targets” category in this version not really constrained to a consistent max value [13].

4 Conclusions and perspectives

The hazard ranking criteria play in Italy a key role in the planning of remediation activities at a regional scale. The comparative risk analysis allows comparing different hazard scenarios by simplifying and reducing to scores some complex phenomena. The strict dependence of the risk analysis models from the adopted procedure and different weight of input parameters together with the regulation directives, shows the need of official standards and guidelines. These are now being developed by the Italian Environmental Agency (APAT) in co-operation with other scientific institutes, in order to give a common tool to the regional environmental authorities for the application of comparative risk analysis for contaminated sites at their regional levels.

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