

Application of the “ARA-CoS_{SSLs}” risk analysis approach at a sub-area of a relevant Italian contaminated site

F. Tatàno, M. Giavazzi & R. Trabucchi

Science and Technology Faculty, University of Urbino “Carlo Bo”, Italy

Abstract

This paper describes a significant case-study application of the “ARA-CoS_{SSLs}” risk analysis approach, which has been developed as a University research study and presented at the past “Brownfields 2006” Conference. Specific, procedural steps have been considered for the selection of contaminants of concern, the definition of representative concentrations, and estimation of relevant modelling factors.

Keywords: absolute risk analysis, application, case-study, contaminated sites.

1 Introduction

Management of contaminated sites represents a relevant, environmental challenge in many industrialised countries. Within an integrated plan (at a given territorial scale: provincial, regional, national) for the identification, characterisation and final remediation of contaminated sites, the application of reliable and scientifically based absolute risk analysis criteria (as a possible category within the overall soil and groundwater quality approaches [1]) is a necessary, initial step. Referring to the Italian situation, a few years ago the national technical-scientific regulation on contaminated sites was changed, with consequential effects on the regulative application conditions for the absolute risk analysis. In fact, the old Italian Ministerial Decree “No. 471/1999” on contaminated soil management (issued in 1999 [2]) enforced a particularly restricted regulative use of the health-sanitary absolute risk analysis [1]. On the contrary, the current (issued in 2006) Italian regulation on contaminated sites (as a part of the Legislative Decree “No. 152/2006” [3]) reflects (in Section IV, Title V) a “multi-tiered” approach on the quality criteria for contaminated sites,



expressly requiring the application of a “Tier 2” absolute sanitary risk assessment to calculate contaminant site-specific target levels while the contaminant “limit values” (for soil-subsoil and groundwater) already defined by the mentioned Decree “No. 471/1999” (indeed with some minor changes) properly act as “Tier 1” screening values [1]. Consequently, as a complementary contribution within this increased (legislative and applicative) attention to the absolute risk analysis at the Italian level, the “ARA-CoS_{SSLs}” modelling approach for human health (“Absolute Risk Analys_is for Contaminated Sites”) has been recently derived (due to a University research study) in its initial, simplified version with predominant reference to the US-EPA “SSLs, Soil Screening Levels” procedure [4-6], and directly implemented on a computer worksheet basis. An original paper published in the “Brownfields III” Proceedings expressly reports on the fundamentals, calculation structure and computer implementation of the “ARA-CoS_{SSLs}” approach [7]. As a useful step in the approach validation and verification, this paper deals with the procedural elaborations for the “ARA-CoS_{SSLs}” approach exercise application at a significant potentially contaminated sub-area of a relevant Italian industrial site.

2 The case-study industrial sub-area: synthetic description

The case-study industrial sub-area refers to a power plant settlement with a complex mixture of numerous, detected contaminants exceeding (in soil-subsoil samples, small surface aquifer and primary aquifer water samples) the corresponding “contamination screening values” for soil-subsoil (commercial/industrial use) and groundwater of the mentioned Decrees “No. 471/1999” and “No. 152/2006” (see Section 1). Precisely, these detected contaminants belong to the following chemical groups: inorganic compounds (comprehensive of metals), aromatic compounds, polycyclic aromatic hydrocarbons, chlorinated aliphatic compounds, halogenated aliphatic compounds, chlorinated benzenes, PCDDs/DFs and total petroleum hydrocarbons. Referring to the available overall site investigation informative documents, the average sub-area geo-lithological and hydro-geological stratigraphy is approximately identifiable in the following order (from the top): an uppermost, heterogeneous layer of backfill soils and materials (average thickness 3.5-4.0 m), inclusive of a small and discontinuous surface aquifer with infiltration waters connected to the existing precipitation cycle; an underlying, discontinuous low permeability layer, consisting of clay, clayey silt and peat materials (average thickness 4.0-4.5 m); a primary, sandy aquifer (average thickness 5.0 m); an underlying aquitard, consisting of alternating silty clay, clayey silt and peat materials (average thickness 4.0 m); and finally, a secondary, sandy aquifer. The mentioned spatial discontinuity of the low permeability layer (underlying the upper backfill materials), precisely resulting in several areal conditions with its partial or total absence, is geologically attributable to the combined phenomena of previous natural erosions and subsequent natural and/or artificial backfilling with permeable, fine soils. Consequently, these localised situations of partial/total absence of the intermediate low permeability layer could realistically imply significant areal conditions of hydraulic connection



between the small surface aquifer and the primary aquifer (see Section 3.1). According to the investigation of informative documents available for the case-study industrial sub-area, Figure 1 shows the mutual location map (derived from geo-referenced topographical co-ordinates) of the drilled subsurface soil borings, with altogether more than 890 chemical analytical determinations (in core samples) exceeding the corresponding Italian screening values (for commercial/industrial land use: see Section 1). Referring instead to the surface and the primary aquifers underlying the case-study industrial sub-area, respectively for no. 3 and no. 2 monitoring wells, it is documented that the condition of groundwater chemical analytical determinations exceeds the corresponding Italian groundwater screening levels (see Section 1).

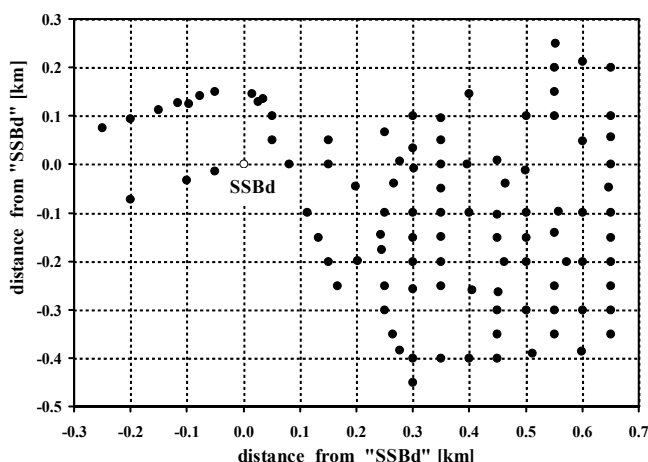


Figure 1: Case-study industrial sub-area: mutual location map of drilled “SSBs, subsurface soil borings”, as referred to the “deepest” boring (symbolically “SSBd”) topographic co-ordinates.

3 Procedural steps for the case-study application of the “ARA-CoS_{SSLs}” approach

3.1 Developed conceptual site model, contaminants of concern and representative concentrations

Referring to the conceptual site model for the case-study industrial sub-area (see Section 2), a non-residential (commercial-industrial) scenario has been expressly assumed, with an outdoor worker as the related human receptor. Consequently, according to the current “ARA-CoS_{SSLs}” calculation options [7], the following, potential exposure pathways have been evaluated: for surface soil, direct ingestion, dermal contact and outdoor fugitive dust inhalation; for subsurface soil, migration to groundwater with consequential water ingestion (indeed mainly theoretical, due to the current situation of the absence of groundwater drinking use in the sub-area location territory) and outdoor volatile inhalation.



With regard to the selection of contaminants of concern (from a whole number of nearly fifty chemicals in subsoil and groundwater exceeding the mentioned “screening values” at the case-study sub-area), the application of the alternative criteria of “TS, Toxicity Score” and “normalised Comparative Hazard Index” (as described in [8]) has been carried out according to the specific assumptions (considered human exposure routes for “TS” criterion; considered generic soil screening levels for “normalised Comparative Hazard Index” criterion) and consequential results of Table 1. The final, inclusive selection of contaminants of concern for the “ARA-CoS_{SSLs}” case-study application is reported in the last row of Table 1: indeed, 2,3,7,8-TCDD, 1,2,3-Trichloropropane and Copper have been compulsorily excluded, as they are not in the original “US.EPA SSLs” chemical property database [6] and consequently (see Section 1) not yet implemented in the current computerised version of the “ARA-CoS_{SSLs}” approach [7].

Table 1: Case-study industrial sub-area: application of selection criteria for contaminants of concern. Legend: (*) resulting contaminants listed in “TS” score ranking order, comprising 99% of the total “TS” score; (**) in round brackets, max Hazard Index (100%) and normalised Hazard Indexes within at least 70% of the max value.

Applied criterion	Resulting contaminants
<i>“TS, Toxicity Score” criterion [8]</i>	
TS – human ingestion exposure, carcinogenic effects (max contaminant concentration in soil)	Beryllium, 1,1-Dichloroethylene, Tetrachloroethylene, 1,2-Dichloroethane, Arsenic, 1,1,2-Trichloroethane, vinyl chloride, 2,3,7,8-TCDD, Trichloroethylene, 1,2,3-Trichloropropane (*)
TS – human ingestion exposure, non-carcinogenic effects (max contaminant concentration in soil)	Trichloroethylene, 1,1,2-Trichloroethane, Arsenic, Mercury, Beryllium, Vanadium, Chromium, Antimony, Copper, Tetrachloroethylene, Vinyl chloride, Cadmium, 1,1-Dichloroethylene, cis-1,2-dichloroethylene, Hexachlorobenzene (*)
TS – human inhalation exposure, carcinogenic effects (see above)	Chromium, Beryllium, Arsenic, 1,2-Dichloroethane, 1,1,2-Trichloroethane (*)
TS – human inhalation exposure, non-carcinogenic effects (see above)	Beryllium, Chromium, Mercury (*)
TS – human ingestion exposure, carcinogenic effects (max contaminant concentration in primary aquifer water)	Vinyl chloride, Arsenic, 1,1-Dichloroethylene (*)
TS – human ingestion exposure, non-carcinogenic effects (max contaminant concentration in primary aquifer water)	cis-1,2-Dichloroethylene, Arsenic, Vinyl chloride, Trichloroethylene (*)
<i>“normalised Comparative Hazard Index” criterion [8]</i>	
Considering US.EPA generic SSLs for commercial/industrial scenario, outdoor worker, ingestion-dermal [6]	Tetrachloroethylene (100%), 1,2-Dichloroethane (89%), Arsenic (72%) (**)
Considering US.EPA generic SSLs for commercial/industrial scenario, outdoor worker, volatile inhalation [6]	1,2-Dichloroethane (100%) (**)
Considering US.EPA generic SSLs for commercial/industrial scenario, outdoor worker, migration to groundwater (Dilution Factor = 20) [6]	1,1,2-Trichloroethane (100%), 1,2-Dichloroethane (96%) (**)
<i>Totally selected contaminants of concern for the “ARA-CoS_{SSLs}” application</i>	
Antimony, Arsenic, Beryllium, Cadmium, Chromium, Mercury, Vanadium, Zinc, 1,2-Dichloroethane, 1,1-Dichloroethylene, cis-1,2-Dichloroethylene, Trichloroethylene, Tetrachloroethylene, 1,1,2-Trichloroethane, Vinyl chloride, Hexachlorobenzene	



The applied procedures for defining the representative concentrations for the selected contaminants of concern, in the different environmental media at the given case-study industrial sub-area, are schematised in Figure 2. Referring to subsurface soil, initially a specific, double concentration weighing criterion has been adopted, precisely consisting of a first core-length weighing step on individual soil borings according to the following eqn (1) (and related Figure 3, left-hand side), and a second weighing step for a “normalised” concentration on the whole contamination source volume based on the following eqn (2) (and related Figure 3, right-hand side):

$$c_{sb} = \frac{\sum c_i \cdot l_i}{d_{sb}} \quad (1)$$

$$c_{sb,n} = c_{sb} \cdot (d_{sb} / d_{sb,max}) \quad (2)$$

where c_{sb} is the length-weighted contaminant soil boring concentration, $c_{sb,n}$ is the “normalised” contaminant soil boring concentration, c_i is the documented concentration available for core segment of length l_i , d_{sb} is the soil boring depth, and $d_{sb,max}$ is the max available depth of soil borings for the given contaminant. Subsequently, for the chemical groups of the selected contaminants of concern, the conclusive, statistical determination of representative subsurface soil concentrations have been carried out with the following approaches, differentiated according to the available no. (N) of $c_{sb,n}$ values for given contaminant (Figure 2): 1) for contaminants of concern belonging to the chlorinated aliphatic group (all resulting with $N > 10$), the maximum value, arithmetic mean and “UCL_{95%}, 95% Upper Confidence Limit” on the mean have been comparatively assumed; 2) on the contrary for inorganic contaminants of concern (some instead resulting with $N < 10$ and others with $N > 10$), the maximum value and UCL_{95%} have been considered respectively for the conditions $N < 10$ and $N > 10$ (indicatively referring to a procedural rule of the methodological document on absolute risk analysis – 2005 version [9] – produced by “APAT, Italian Environmental Protection Agency and Technical Services”); 3) finally for hexachlorobenzene (precisely characterised with $N < 10$), the maximum value has been assumed. All UCL_{95%} determinations have been properly carried out according to the US.EPA “ProUCL” software [10]. Moreover, it should be pointed out that expressly for organic (chlorinated aliphatic) contaminants of concern, the following, alternative “hypothetical” calculation conditions (as properly implemented in the “ARA-CoS_{SSLs}” approach [7, 8]) have been simulated: 1) “real” three-phase chemical content on soil material (S), in soil water (W) and soil air (A) (“[S-W-A]r” symbol); 2) potential soil gas loss during sampling (“[S-W]r” symbol condition), and consequential, automatic derivation of “estimated” total three-phase concentration (“[S-W-A]e” symbol). Referring instead to surface soil, no direct top soil sample concentrations have been documented in the available case-study sub-area investigation documents; in this condition, surface soil concentrations have been roughly assumed as the corresponding available sample concentrations (related to drilled soil borings) of the core segment at minor depth, and consequently the similar statistical calculation procedures as for subsurface soil have been applied

(Figure 2). Finally, concerning groundwater, for the small surface aquifer the available max concentration values have been approximately considered as “measured” representative concentrations, due to the extremely limited number of monitoring wells (see Section 2). Referring instead to the more significant primary aquifer (see Section 2), apart from the same assumption for “measured” representative concentrations, additional “estimated” values have been directly generated in the “ARA-CoS_{SSLs}” approach (based on the implemented US.EPA theory of soil/water/air contaminant partition in unsaturated zone and subsequent aquifer dilution) [4-8], under the theoretical hypothesis (approximately supportable with some geological evidence: see Section 2) of a partial (at least) hydro-geological connection between the contamination source and the primary aquifer.

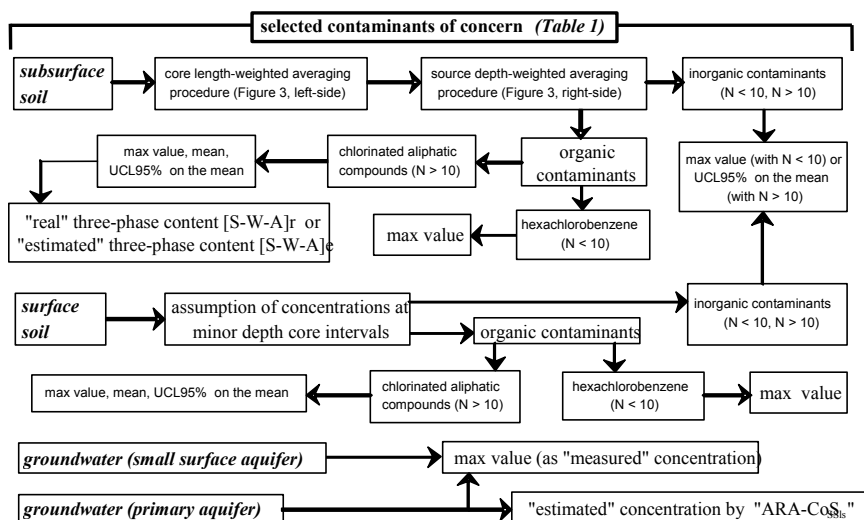


Figure 2: Case-study industrial sub-area: applied procedures for the definition of contaminant representative concentrations. Legend: N = number of boring concentrations (normalised, for subsurface soil; at minor depth, for surface soil).

3.2 Specific calculation of air dispersion and groundwater dilution factors

Referring to the “ARA-CoS_{SSLs}” modelling approach for the outdoor inhalation of particulate and volatiles [7, 8], the specific estimation (for the case-study sub-area) of the related US.EPA “SSLs” air dispersion factors “ Q/C_{wind} ” (for fugitive dusts emitted from surface soil [6]) and “ Q/C_{vol} ” (for volatiles emitted from subsurface soil [6]) has been carried out according to the sequential procedure of Figure 4. As a starting step, only contaminants showing subsurface soil boring normalised concentration sets (calculated according to eqns (1), (2)) with some values exceeding the corresponding Italian screening levels (industrial-commercial use: see Section 1) have been considered. Consequently, according to a geostatistical “Kriging” interpolation method with Surfer® 8.0 software

(Golden Software, Inc.), the corresponding concentration isopleth maps have been separately contoured for the considered contaminants. On the basis of these maps, source areal extents have been estimated (individually for each contaminant) by geostatistical integration over the perimeters defined with the proper isopleths corresponding to the mentioned Italian screening levels (see Section 1). Finally, the arithmetic mean (precisely 27.4 acres) of these resulting surface areas has been approximately assumed as the representative site areal extent A_{site} [acres], which is a specific input parameter in the US.EPA “SSLs” calculation equations (reported in Appendix D of [6]) for Q/C_{wind} and Q/C_{vol} . The resulting specific values for the case-study industrial sub-area are $49.09 \text{ (g m}^{-2} \text{ s}^{-1} \text{ per kg m}^{-3}\text{)}$ (Q/C_{wind}) and $35.46 \text{ (g m}^{-2} \text{ s}^{-1} \text{ per kg m}^{-3}\text{)}$ (Q/C_{vol}) respectively.

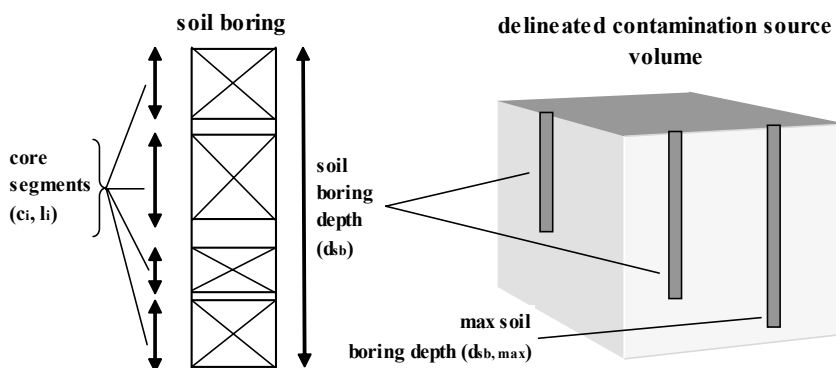


Figure 3: Contaminant representative concentrations in soil borings: assumed schematisations (for the case-study industrial sub-area) of the core length-weighted averaging procedure (left-side) and the subsequent source normalisation procedure (right-side).

Referring to the specific case-study derivation of the “DF, Dilution Factor” [4-6] in the “ARA-CoS_{SSLs}” modelling approach of migration to the primary aquifer pathway (as expressly related to the “estimation” procedure for representative groundwater concentrations: see Figure 2) [7, 8], Figure 4 additionally shows the adopted procedure. Precisely, primary aquifer hydraulic conductivity (assumed as $1,734.5 \text{ m yr}^{-1}$), thickness (assumed as 5 m: see Section 2), and infiltration rate (assumed as recharge of 0.20 m yr^{-1}) have been roughly estimated from available technical-scientific informative documents on the location territory of the case-study sub-area. Instead, under the assumption of a representative square contaminant source (which is consistent with the US.EPA “SSLs” procedure [4, 5]), the contamination source length has been calculated as the square root of the average site areal extent as previously defined (yielding a value of 333 m).

On the contrary, the specific determination of groundwater flow direction and consequential hydraulic gradient (properly yielding a value of 0.0013 m m^{-1}) has been carried out (as shown in Figure 5) by firstly mapping (with the above mentioned geostatistical approach) the contoured total hydraulic head equipotentials for the overall location territory of the case-study sub-area, and

secondly overlapping the subsurface soil boring mutual position map of Figure 1. The relevant mixing zone depth should be theoretically estimated (using all previous hydro-geologic input parameters) with the proper adopted US.EPA “SSLs” modelling equation [5, 6]; resulting in this theoretical value above the primary aquifer thickness for the case-study sub-area, consequently this aquifer thickness has been usefully used as the upper limit for mixing zone depth [5, 6]. Conclusively, the implemented (in “ARA-CoS_{SSLs}” approach [7, 8]) US.EPA “SSLs” modelling equation for the Dilution Factor [4-6] has given a DF value of 1.17 for the case-study industrial sub-area. This specific condition (practically identifiable with the conservative situation of $DF = 1$) is indicative of little or no contaminant dilution, potentially attributable to a non-thick primary aquifer (in fact limiting the mixing zone depth) in relation to a quite large source (representative extent of 27.4 acres) causing a predominant effect of the overall infiltration flux [5,6].

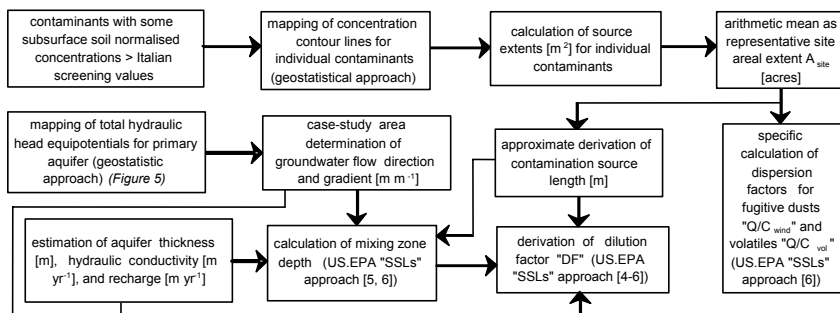


Figure 4: Case-study industrial sub-area: adopted procedures for the specific determination of air dispersion and groundwater dilution factors.

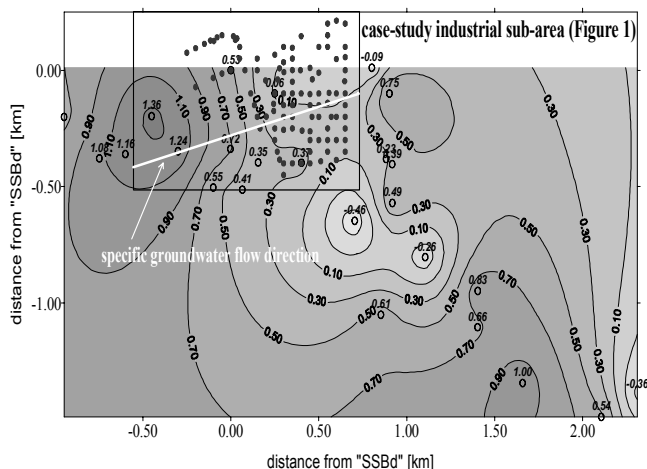


Figure 5: Case-study industrial sub-area: total hydraulic head equipotential map for primary aquifer in the location territory, and specific flow direction line for groundwater hydraulic gradient determination.

4 Summary of case-study risk analysis results and conclusions

The resulting individual risks, according to a “direct” risk assessment mode [7, 8], are summarised in: Table 2, with reference to the inorganic contaminants of concern; Table 3, related to the chlorinated benzene contaminant of concern; and finally Table 4, related to the chlorinated aliphatic contaminants of concern, indeed indicatively reporting (for synthesis reasons) only risk results based on the statistical calculation condition of “UCL_{95%}” for surface and subsurface soil representative concentrations (see Section 3.1). Acceptable individual risk levels are usually adoptable as $1 \cdot 10^{-6}$ excess “CR, Cancer Risk” for carcinogenic effects and a “HQ, Hazard Quotient” of 1 for non-carcinogenic effects [4, 5].

Expressly focusing on the adopted procedural steps of Sections 3.1, 3.2 and the modelling structure of the “ARA-CoSSSLs” approach, the critical analysis of Tables 2-4 conclusively allows (at least) the following, synthetic considerations: 1) apart from Cadmium and Zinc, all remaining selected contaminants in the last row of Table 1 cause at least one non-negligible individual risk level; 2) for migration to groundwater pathways, apart from the magnitude order equivalence condition on Arsenic, for considerable organic contaminants (excluding cis-1,2-

Table 2: Case-study (industrial sub-area) application of the “ARA-CoSSSLs” approach: calculated, individual risks for inorganic contaminants of concern (see Table 1). Legend: CR, HQ = see Section 4; N/D = not derivable; Cr = representative concentration; DF = Dilution Factor; * with $Q/C_{\text{wind}} = 49.09 \text{ g m}^{-2} \text{ s}^{-1}$ per kg m^{-3} .

	Direct Ingestion		Dermal Absorption		Inhalation of Dusts *	
	CR	HQ	CR	HQ	CR	HQ
Antimony	N/D	1.79E-01	N/D	N/D	N/D	5.04E-05
Arsenic	5.62E-05	3.49E-01	1.11E-05	6.92E-02	1.58E-07	9.82E-05
Beryllium	2.54E-04	3.31E-01	N/D	N/D	1.40E-06	9.31E-05
Cadmium	N/D	2.45E-02	N/D	6.47E-03	1.55E-08	6.89E-06
Chromium	N/D	2.13E-01	N/D	N/D	4.49E-06	5.99E-05
Mercury	N/D	3.65E-01	N/D	N/D	N/D	3.59E-04
Vanadium	N/D	5.02E-01	N/D	N/D	N/D	1.41E-04
Zinc	N/D	1.16E-02	N/D	N/D	N/D	3.27E-06
Mercury	Inhalation of Volatiles (Q/C _{vol} = 35.46 g m ⁻² s ⁻¹ per kg m ⁻³)					
	CR			HQ		
	N/D			1.29E+00		
	Migration to Groundwater					
	Measured Cr			Estimated Cr (DF = 1.17)		
	CR	HQ	CR	HQ		
Antimony	N/D	N/D	N/D		7.75E+00	
Arsenic	1.94E-03	1.21E+01	2.34E-03		1.46E+01	
Beryllium	N/D	N/D	7.30E-03		0.95E+00	
Cadmium	N/D	N/D	N/D		0.70E+00	
Chromium	N/D	N/D	N/D		0.57E+00	
Mercury	N/D	N/D	N/D		9.28E+00	
Vanadium	N/D	N/D	N/D		1.13E+00	
Zinc	N/D	N/D	N/D		0.83E+00	



Table 3: Case-study (industrial sub-area) application of the “ARA-CoS_{SSLs}” approach: calculated, individual risks for chlorinated benzene contaminant of concern (see Table 1). Legend: see Table 2.

	Hexachlorobenzene	
	CR	HQ
Direct Ingestion	9.00E-06	1.97E-02
Inhalation of Dusts ($Q/C_{wind} = 49.09 \text{ g m}^{-2} \text{ s}^{-1} \text{ per kg m}^{-3}$)	2.55E-09	5.54E-06
Inhalation of Volatiles ($Q/C_{vol} = 35.46 \text{ g m}^{-2} \text{ s}^{-1} \text{ per kg m}^{-3}$)	2.60E-05	5.65E-02
Migration to Groundwater (DF = 1.17)	1.71E-03	3.74E+00

Table 4: Case-study (industrial sub-area) application of the “ARA-CoS_{SSLs}” approach: calculated, individual risks for chlorinated aliphatic contaminants of concern (see Table 1), “UCL_{95%}” approach. Legend: see Table 2 ([S-W-A]_r, [S-W]_r, [S-W-A]_e: see Section 3.1, [7, 8]).

	Direct Ingestion		Dermal Absorption		Inhalation of Dusts *	
	CR	HQ	CR	HQ	CR	HQ
1,2-Dichloroethane	1.13E-04	N/D	N/D	N/D	3.17E-08	N/D
1,1-Dichloroethylene	2.07E-04	1.08E-01	N/D	N/D	1.70E-08	3.02E-05
cis-1,2-Dichloroethylene	N/D	8.78E-03	N/D	N/D	N/D	2.47E-06
Tetrachloroethylene	5.78E-06	3.11E-02	N/D	N/D	6.34E-11	8.75E-06
1,1,2-Trichloroethane	6.79E-05	8.34E-01	N/D	N/D	1.88E-08	2.34E-04
Trichloroethylene	3.97E-07	N/D	N/D	N/D	6.03E-11	N/D
Vinyl chloride	1.45E-05	1.88E-02	N/D	N/D	8.71E-11	5.54E-07
Inhalation of Volatiles (“IV”) ($Q/C_{vol} = 35.46 \text{ g m}^{-2} \text{ s}^{-1} \text{ per kg m}^{-3}$)						
	[S-W-A] _r (or [S-W] _r)		[S-W-A] _e			
			$\theta_w - f_{oc} \text{ (IV modelling)}$		$\theta_w - f_{oc} \text{ (MGW model.)}$	
	CR	HQ	CR	HQ	CR	HQ
1,2-Dichloroethane	1.78E-03	N/D	1.85E-03	N/D	1.81E-03	N/D
1,1-Dichloroethylene	7.71E-04	1.37E+00	1.12E-03	1.98E+00	1.00E-03	1.78E+00
cis-1,2-Dichloroethylene	N/D	2.11E-01	N/D	2.32E-01	N/D	2.22E-01
Tetrachloroethylene	4.51E-06	6.23E-01	5.14E-06	7.09E-01	5.11E-06	7.05E-01
1,1,2-Trichloroethane	5.54E-04	6.92E+00	5.64E-04	7.05E+00	5.60E-04	7.00E+00
Trichloroethylene	5.09E-06	N/D	5.46E-06	N/D	5.45E-06	N/D
Vinyl chloride	1.46E-05	9.30E-02	2.91E-05	1.85E-01	2.07E-05	1.32E-01
Migration to Groundwater (“MGW”)						
	Measured Cr		Estimated Cr (DF = 1.17)			
			[S-W-A] _r (or [S-W] _r)		[S-W-A] _e	
	CR	HQ	CR	HQ	CR	HQ
1,2-Dichloroethane	8.07E-06	N/D	1.16E+00	N/D	1.18E+00	N/D
1,1-Dichloroethylene	8.53E-04	0.44E+00	3.64E-01	1.89E+02	4.73E-01	2.45E+02
cis-1,2-Dichloroethylene	N/D	1.20E+02	N/D	8.49E+01	N/D	8.96E+01
Tetrachloroethylene	N/D	N/D	2.03E-02	1.09E+02	2.30E-02	1.24E+02
1,1,2-Trichloroethane	1.08E-07	1.32E-03	4.78E-01	5.87E+03	4.83E-01	5.94E+03
Trichloroethylene	7.96E-06	N/D	2.14E-03	N/D	2.29E-03	N/D
Vinyl chloride	1.17E-02	1.52E+01	8.38E-02	1.09E+02	1.19E-01	1.54E+02

Dichloroethylene) individual risks related to the “measured” approach (certainly influenced by the extremely limited number of available groundwater determinations: see Section 2) are decreased compared with the “estimation” approach (see Section 3.1); 3) expressly according to Table 4, individual



subsurface soil risks related to the “estimated” three-phase approach are increased compared with the hypothetical “real” two phase condition (see Section 3.1), but generally non-significantly (apart from the magnitude order increase registered for: 1.1-Dichloroethylene, volatile inhalation carcinogenic effect; Vinyl chloride, volatile inhalation non-carcinogenic effect and groundwater carcinogenic effect).

Acknowledgements

The authors would like to mention Dr.-Ing. Laura D’Aprile at APAT (Italian Environmental Protection Agency and Technical Services, Rome) for her availability and support concerning the site investigation and technical-scientific informative data on the case-study industrial sub-area.

References

- [1] D’Aprile, L., Tatàno, F. & Musmeci, L., Development of quality objectives for contaminated sites: state of the art and new perspectives, *Int. J. Environment and Health*, Vol. 1, No. 1, pp. 120-141, 2007.
- [2] Italian Ministry of Environment, *Technical Regulation D.M. No. 471/1999 on containment, remediation and environmental restoration of contaminated soils*, Annex of the Italian Official Gazette No. 293, 15.12.1999 (in Italian).
- [3] Legislative Decree No. 152, *Environmental Framework Regulation*, Annex of the Italian Official Gazette No. 88, April 14, 2006 (in Italian).
- [4] United States Environmental Protection Agency (US.EPA), *Soil Screening Guidance: User’s Guide*, Publication 9355.4-23, 1996.
- [5] US.EPA, *Soil Screening Guidance: Technical Background Document*, Office of Emergency and Remedial Response, EPA/540/R95/128, 1996.
- [6] US.EPA, *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*, OSWER 9355.4-24, 2002.
- [7] Giavazzi, M. & Tatàno, F., “ARA-CoS_{SSLs}” risk analysis approach (on a computer worksheet basis) for contaminated sites: implementation and case study application, *Brownfields III* (C.A Brebbia & Ü. Mander Editors), WIT (Wessex Institute of Technology) Press, pp.63-73, 2006.
- [8] Giavazzi, M. & Tatàno, F., A possible sanitary risk analysis approach for contaminated sites, *Int. J. Environment and Health*, Vol. 1, No. 2, pp. 199-220, 2007.
- [9] Italian Environmental Protection Agency and Technical Services (APAT), *Methodological criteria for absolute risk analysis application at contaminated sites*, Version June 2005 (L. D’Aprile, R. Baciocchi & G. Marella Editors), available at www.apat.it (in Italian).
- [10] US.EPA, *ProUCL Version 3.0*, User Guide, EPA/600/R04/079, April 2004.

