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A possible approach for Tier 2 risk assessments of polluted sites: Framework, computer spreadsheet and application

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ABSTRACT

Owing to the increasing attention placed on problems concerning site pollution that environmental geotechnics deals with, an implementation of Tier2 risk assessment (forward and backward mode) is proposed and developed in a computer spreadsheet. Consistently with a Tier 2 approach, contaminant migration is described by analytical solutions of transport models using site-specific parameters. The calculations are implemented with Microsoft Excel® while the user interfaces, which manage the various worksheets, were built with Visual Basic®. The spreadsheet was validated by comparing it with other available software that implement the same model for a given migration pathway. In the present version, the computer tool is consistent with Italian guidelines for Tiers 2 risk assessment. However, the tool can be easily adapted to comply with different regulations and recommendations. Some illustrative examples of applications are given in the paper: a case study of risk assessment for contaminated site is illustrated and a sensitivity analyses of transport factors to site-specific parameters is presented.

1. Introduction

In accordance with recent international environmental regulations, an appropriate risk assessment is required in order to determine the risks and Clean-up levels (CLs) associated with contaminated sites. Therefore, risk assessment procedure plays an essential role in the management of polluted sites. Risk assessment has become common in the last few decades; it was first developed in the USA [1,2] and afterwards in Europe [3], boosted by the necessity to remediate a high number of polluted sites. In Italy, risk assessment was first introduced as a possible tool to apply by specific regulation on polluted sites (D.Lgs. 471/99). UNICHIM association published one of the first handbooks on risk assessment in 2002 [4]. Afterwards, risk assessment has become a mandatory step in the management procedure of polluted sites (Environmental Code – D.Lgs. 152/06). To date, the Italian Regulatory agency (ISPRA) has issued three successive revisions of guidelines for the application of risk assessment, and the most recent one was in March 2008 [5].

A site-specific risk assessment is defined as an evaluation of the risks posed to the health of human beings and to the surrounding environment by the exposure to the contamination present at a given site in various media: unsaturated zone of the subsoil, saturated zone (groundwater), indoor and outdoor air [1]. Most codes-of-practice and guidance instructions, issued by several agencies and organisations dealing with contaminated sites (e.g. [1,3,4,6,7]), have adopted a tiered approach to risk assessment procedures. In particular, a 3-tiered approach is widely adopted, in accordance with RBCA guidelines (ASTM E2081-00 – Reapproved 2010: Standard guide for Risk Based Corrective Action). Within the RBCA framework, mathematical models are used to determine corrective action goals, for example, risk-based Screening Levels (SLs), site-specific Clean-up Levels (CLs), and to help in developing a strategy for achieving these goals. These models are most typically associated with assessing the fate and transport of chemicals in the environment. In particular, in Tier 1, analytical transport models and (usually conservative) site-generic data (e.g., soil parameters which appear in transport models) are used. In Tier 2, analytical transport models are also adopted but data are site-specific (i.e., they are derived by a targeted site characterization). In Tier 3, numerical transport models are adopted and site-specific data are used.

A Tier 1 is normally used to derive preliminary screening levels while Tier 2 is commonly used to develop a site-specific risk assessment. The use of simplified closed- form solutions, typical of Tier 1 and Tier 2 assessment, is obviously a limitation of the application but the essence of the procedure is that, as the user proceeds to higher tiers, the knowledge gained about the site is used to tailor the degree of investigation needed [7]. A Tier 3, which may involve more complex numerical modeling and site-specific data, is recommended when remedial action based on corrective action goals are not practicable (e.g., when the CL derived

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Nomenclature

ADF	Air Dispersion Factor
CL	Clean-up level
$CL_{S\text{-}GW}$	clean-up level for groundwater
C_{POC}	concentration at compliance point
C_{POE}	concentration at point of exposure
C_{POEOFF}	concentration at point of exposure off-site
C_{POEON}	concentration at point of exposure on-site
$C_w(C_{GW})$	concentration at water table
C_{w0}	concentration in pore water within soil source limits
C_{wf}	concentration in GW located under soil source
DAF	dilution attenuation factor
D^{eff}_{crack}	effective diffusion coefficient in cracks
D^{ef}_{fs}	effective diffusion coefficient inn unsaturated soil
D^{eff}_{ws}	effective diffusion coefficient in the pathway from water table
E	Intake rate (average daily dose)
EM	specific exposure value
FT	transport factor
HI	hazard index
HI_{GW}	groundwater hazard index
K_{ws}	soil–water partition factor
LDF	leachate dilution factor
LF	leaching factor
L_w	thickness of source located in unsaturated soil
MCL	maximum contaminant level in groundwater
POC	compliance point
POE	point of exposure
R	cancer risk
R_i	retardation factor
RSC	representative source concentration in soil
RSC_{GW}	representative source concentration in groundwater
SAM	soil attenuation model
SS	surface soil
SubS	subsoil
v_e	Seepage velocity
VF_{GW}	volatilization factor from groundwater
VF_s	volatilization factor from soil
VF_{SS}	volatilization factor from surface soil
VF_{SubS}	volatilization factor from subsoil

from lower tier analyses, usually based on conservative or simplified assumptions, are not economically sustainable).

Italian Regulations have adopted the multi-tiered approach and expressly require the implementation of a Tier 2 risk assessment. The peculiarity of a Tier 2 is the use of site-specific parameters and analytical models of pollutant migration to determine the risk to the human health and to the environment. Simple analytical solutions to fate and transport models represent a reasonable compromise between the need for a detailed site assessment and the advantage of handling a rather simple and easy-to-use management tool [8]. However, efforts are being made to improve the simulation capability of multimedia transport models especially in computing the inter-media flux (e.g. leachate release) [9]. On the other hand, limitations in modeling are not avoidable because of the complexity of the processes and of the contaminant behavior [10].

Several commercial software and freeware packages that assist in risk assessment procedure have been developed and updated over the years. Each package adopts a slightly different modeling approach, but all of them need site-specific parameters to be entered as input values. In fact, accurate site-specific data are crucial to enable reliable simulations of the exposure scenario [11]. The methodology recommended in Italian guidelines for risk assessment is not strictly implemented by any available commercial software or freeware. This has stimulated the writers to develop and computerize a calculation procedure that is strictly compliant with the instructions of the Regulatory Agency. Initially, only some *fate and transport* models were automated with the sole aim to compare the results with those of other software commonly used to carry out risk assessment. Afterwards, the idea to implement the entire risk assessment procedure by means of a simple interactive spreadsheet arose. Microsoft Excel® and Visual Basic® were used to perform the calculations and to link the various worksheets, respectively. As a result of the work, the "SMART-Risc" tool was developed. The accuracy of calculations was verified by the with other software outputs for a given transport model. In addition to risk assessment, the developed spreadsheet allows very easy carrying out of sensitivity analyses of a given transport model [12]. These analyses are important in order to identify which parameters are "driving" the risk values and to consequently focus the resources in site characterization, [13,14]. At the present state of progress, the simplified approach to contaminant migration modeling, that is inherent to Tier 2 risk assessment, and the compliance to Italian guidelines only, represent the major limitations of the proposed tool.

The paper describes the adopted framework and the details of the calculation procedure.

As an illustration of the potential applications of the proposed tool, the paper presents some examples of sensitivity analyses. These analyses were conducted with reference to a particular site and source geometry and concerned some of the pollutant transport factor (FT), as a function of site-specific parameters. A case study is finally illustrated in which a Tier 2 risk assessment was carried out with the help of the proposed spreadsheet.

2. Overview of different approaches to risk assessment

The definition and the first guidance to develop risk assessment was the standard ASTM E1739-95, published in 1995 and edited by a working group led by ASTM (American Society for Testing and Materials) and composed by petrol industry delegates, USEPA (United States Environmental Protection Agency), regulatory agencies and environmental consulting offices. The document introduced the term RBCA (Risk-based Corrective Action) that refers to the new philosophy for the management of polluted sites. The standard was updated in ASTM E2081-00 and reapproved in 2010. The greatest amount of guidance and supporting resources has been issued by USEPA (e.g. [1,2]).

At the same time, in Europe, the CARACAS (Concerted Action on Risk Assessment for Contaminated Sites in the European Union) programme was funded by the European Commission. Most European countries participated to the project, which aimed at tackling the problem of contaminated land. A book was edited to review the scientific basis and explain the perceived research needs in the context of current approaches for contaminated land risk assessment in European countries [6]. The RBCA approach was adopted in 1997 in the Report n. 2 "European Oil Industry guideline for risk-based assessment of contaminated sites" prepared by the CONCAWE (CONservation of Clean Air and Water in Europe) Water Quality Management Group and updated in 2003 [3].

In Italy, the first complete handbook was developed in 2002 for UNICHIM (handbook n.196/) and followed the RBCA philosophy