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Introducing a method of human health risk evaluation for planning and soil quality management of heavy metal-polluted soils—An example from Grugliasco (Italy)

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ABSTRACT

European governmental institutions, as well as local communities, have recently become aware of the threats arising from soil pollution for the welfare of the population. Humans contact with soils is more likely in urban than in rural areas, and is strongly dependent on land use. Spatial planning and land management may have important impacts on the potential transfer of pollutants from contaminated soils to humans. In the present study, we propose a land use-based method for the evaluation of human health risks arising from heavy metal-contaminated urban soils, addressing in particular the influence of planning measures and land use changes on such risks. The method accounts for the role of the bioavailability of soil metals as a key factor in health risk assessment. In order to increase method applicability, a step-by-step procedure and a calculation tool were elaborated. The method can be used to identify areas in which the current or planned land use is associated with unacceptable health risks and to optimise the allocation of a certain land use to areas that are well suited and where the risks are minimal. A risk index is calculated for the area, taking the land use into consideration, as the sum of the risks from different exposure pathways and different heavy metals. For those areas where risk is identified as unacceptable, alternative planning or management options should be defined to achieve a maximal risk reduction in a cost-effective way. The method is illustrated using the Italian municipality, Grugliasco.

1. Introduction

The development of urban areas is driven by socio-economic processes. Land use has always had a strong influence on soils. In most areas, it is the main factor in today's soil quality (Integrated Soil and Water Protection [SOWA], 2005). Threats to soils such as erosion, contamination, humus reduction, sealing, and excavation can be linked to land use (Bizer, 2005; European Commission, 2006b).

It is important to gain sufficient knowledge about the effects of different types of land use on soil properties and on the capacity of the soil to fulfil certain functions. Urban environments are the areas where soils most directly interact with humans (Stroganova et al., 1997). Many authors have highlighted the need for a better understanding of urban soils, focussing on the information needed for soil management (Stubenrauch et al., 1997; Ferguson et al., 1998; Swiss Agency for the Environment, Forests and Landscape [SAEFL], 2005; Wong et al., 2006).

The prolonged presence of the contaminants in urban soils and their proximity to people is amplifying the exposure of the urban population to metals. Information on the mobilization, dispersion, deposition, and distribution of potentially toxic metals in urban ecosystems plays an important role in the assessment of trace metal contamination and in the evaluation of potential environmental and health implications (Stroganova et al., 1997; Birke and Rauch, 2000; Bityukova et al., 2000; Romic and Romic, 2003; Wong et al., 2006; Hornburg et al., 1995; Herms and Brümmer, 1984). Health impacts of trace metal contamination of the urban environment are usually difficult to assess due to the complexity of the factors involved (Wong et al., 2006).

Risk assessment may be defined as the "characterisation of the potential adverse health effects of human exposures to environmental hazards" or the "process of estimating the potential impact of a chemical or physical agent on a specified ecological system under a specific set of conditions" (Markus and McBratney, 2001).

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A number of procedures have been proposed that provide sets of formal, scientific methods for estimating the probabilities and magnitudes of adverse impacts on human health, plants, animals and the ecology of a specified area posed by a particular stressor (National Environment Protection Council [NEPC], 1999a).

The health risk evaluation process involves the analysis of contaminant concentrations and releases, the identification of exposed populations, the identification of potential exposure pathways and the estimation of contaminant intakes for each pathway for a range of scenarios and land uses (Ferguson et al., 1998; U.S. Environmental Protection Agency [USEPA], 1998; Canadian Council of Ministers of the Environment, 1999; NEPC, 1999c,d; Norwegian Pollution Control Authority [SFT], 1999). Parameters needed for the quantitative estimation of the magnitude of contaminants intake along various intake routes have been compiled and are reviewed in numerous national and international frameworks (USEPA, 1991, 1998; Ferguson et al., 1998; Canadian Council of Ministers of the Environment, 1999; NEPC, 1999b; Norwegian Pollution Control Authority, 1999; The Netherlands National Institute for Public Health and the Environment [RIVM], 2001a; Department for Environment, Food and Rural Affairs [DEFRA] and Environment-Agency, 2002; TNNE, 2002; U.S. Department of Energy [USDoE], 2005). All of the parameters are related to statistical data on demographic and life habits. It is possible to follow a probabilistic approach by modelling the uncertainties of all the involved settings, e.g., by Monte Carlo simulations, or a deterministic approach by choosing a single value for the parameters with a less accurate estimation of the uncertainties (DEFRA and Environment-Agency, 2002; Nathanail et al., 2005).

The most important factors influencing health risks that arise from soil contamination are: land use, potential occupancy by children, bioavailability of contaminants, potential exposure pathways and state of the site surface (e.g., paved, with grass or exposed; NEPC, 1999c). The use of soil influences the selection of the parameters defining exposure scenarios, exposure frequency, and exposure pathways. Generic land use scenarios are based on how the soil is used and on how sensitive and dependent the activity is on the land. The definition of each land use accommodates generic conditions and puts boundaries on the receptors and exposure pathways (The Netherlands National Institute for Public Health and the Environment, 2001a; DEFRA and Environment-Agency, 2002; USDoE, 2005).

Quantitative guidelines for assessing risks are associated with several scientific problems. In the case of soil, it is particularly difficult to take into account the variety of soil types and particular site conditions, as well as the ranges of contaminants, contaminant species and contaminant mixtures.

Due to the complexity of the system, simplifying assumptions are made when establishing relationships between the concentration of a contaminant in soil and its effect on humans. There are difficulties in establishing limit values for concentrations of contaminants beyond which the risks from exposure to these contaminants are considered to be unacceptable, as well as in defining what is an unacceptable risk (Grasmuck and Scholz, 2005; Scholz and Schnabel, 2006). Soil is only one of the sources of exposure to contaminants. The risks due to soil contamination and the costs of dealing with soil contamination need to be kept in proportion with the total exposure to contaminants from all sources.

Generally applicable guidelines are needed. The new European Soil Thematic Strategy recommends the assessment of dangerous substances in soils that pose significant risk to human health or to the environment, taking into account current and approved land use (European Commission, 2006a,b). Numerous methods exist for assessing human health risks due to soil pollution. Table 1 gives a summary of the most important features of some EU models. Most countries have a common framework for contaminated land risk assessment procedures. Terminology and details vary substantially between countries (Ferguson et al., 1998). All these models adopt comparable approaches to assess health hazards arising from polluted soils. However, the input parameters and scenarios that are considered are different. Results obtained with different methods are therefore often not comparable (European Commission, 2006a). The Netherlands National Institute for Public Health and the Environment (2002) recommended a toolbox on the European level including:

- Standardisation of the common elements;
- definition of flexible elements to account for country/region-specific (geographical, ethnological and political) peculiarities;
- documentation on the sensitivity of calculated human exposure to the input parameters and guidelines on when and how to measure concentrations in the contact media;
- information on the uncertainty/reliability of calculated human exposure.

The implementation of human health risk information into urban planning would facilitate the development of healthy and sustainable urban environments (Wong et al., 2006). A decline in environmental quality within the city will eventually worsen the living conditions of the population (van Kamp et al., 2003; Brown, 2003). Most of the existing methods for the assessment of human health risks focus on single contaminants and heavily contaminated sites. The results of the evaluation are used to establish guidelines for site remediation. The majority of the existing methods are very complex, involving numerous parameters and assumptions. “Worst-case” assumptions are frequently used, but the resulting criteria are often impractical (Wragg and Cave, 2003). Data about human health risks need to be converted into a form that can be used in decision-making and for public awareness. Requests for tools that support decision-making have increased over the last few years. Tools that make such information available in an effective way for spatial planning and land management are essential for a sustainable development of urban areas (Adriassens et al., 2004; Termorshuizen et al., 2007).

In order to reduce risks to an acceptable level, management decisions should be based on risk-related information. The decisions are then based on the risk the decision-maker is willing to accept, along with the associated costs (Mays et al., 1997). The role of the soil scientist is to present the possible options for consideration and to assist the decision makers in choosing the best management options with acceptable costs and risks (Mays et al., 1997; Bizer, 2005). Many authors (Lyons, 1997; Ferguson et al., 1998; Dai et al., 2001; Korre et al., 2002; Wragg and Cave, 2003; Cui et al., 2005) addressed the need for a widely applicable method, providing information on how the risks for human health can be mitigated with optimisation of land use allocation in a certain area.

The aim of this work was to design a method to indicate the potential level of human health risks due to heavy metal concentrations in urban soils, accounting for the potential impact of land use on such risks and providing suggestions on the most suitable land use to reduce the risk. The method is designed to give preliminary indications on where the risk is more likely to exist in cases of diffuse pollution over wide areas, such as a whole municipality or administrative region. It is not designed for detailed health risk assessment in a contaminated site. The indication should help in planning and decision-making for a more sustainable management of urban soils. The method has to be easily applicable in planning and land management. The method proposed is adapted from already existing human health risk assessment frameworks, used for example in the US, UK, Australia, Norway, Canada, and

Table 1
Feature of 12 national EU human health risk assessment frameworks

	CETOX (DK)	CLEA (UK)	CSOIL (NL)	LUR (E)	France 2000	Sweden	ROME (I)	Flanders (B)	BAFU (CH)	SFT (N)	UMS (D)
Exposure pathways											
Soil ingestion	x	x	x	x	x	x	x	x	x	x	x
Crop consumption	x	x	x	x	x	x		x	x	x	x
Inhalation	x	x	x	x	x	x	x	x		x	x
Dermal contact	x	x	x	x	x	x	x	x		x	x
Input data											
Heavy metal soil content	x	x	x	x	x	x	x	x	x	x	x
Soil data	–	x	x	–	–	–	–	–	x	x	–
Social data	–	x	x	–	–	x	–	–	x	x	–
Kinetics		x			x	x					
Inclusion of mixtures exposure						x	x			–	–
Outputs											
Deriving soil quality standards	x	x	x	x	x	x		x		x	–
Risk assessment	x		x		x				x	x	–
Site-specific exposure assessment		x	x	x	x	x	x		x	x	–
Common use of the model		x	x	x		x		x			–
Standard scenarios included											
Agricultural						x			x	x	
Allotments	x	x	x			x			x		
Industrial	x	x	x	x	x	x	x	x		x	x
Parks						x					
Playground				x		x	x		x	x	x
Recreational	x	x	x	x		x	x	x			x
Residential		x	x		x	x	x			x	x
Residential with gardens	x	x	x	x	x	x	x	x	x		
Implementation											
Automation	–	x	x	–	–	x	x	–	x	–	x
GIS	–			–	–			–		–	

x: feature considered; –: no information available.

Switzerland. The method focuses in particular on the analysis of the impact of land use on such risks. The main adaptations are: (i) consideration of bioavailable forms of heavy metals for plants and humans; (ii) relationship with land uses; (iii) applicability in planning procedures.

The consideration of bioavailable forms of heavy metals is an important feature discussed by various authors (Gupta et al., 1996; Paustenbach, 2000; DEFRA and Environment-Agency, 2002; Ferguson et al., 2003; Wragg and Cave, 2003). Risk assessment based on total heavy metal concentrations is appropriate for long-term risks or for worst-case scenarios. The consideration of bioavailability, especially for humans, is important in order to set more realistic assessment of short- to medium-term risks (Gupta et al., 1996; Wragg and Cave, 2003).

2. Materials and methods

2.1. Human health risk evaluation

The method called HHRE (Human Health Risk Evaluation, Fig. 1) estimates risks derived from human exposure to heavy metals in soil, adopting the risk-based source-pathway-receptor pollutant linkage framework and a deterministic methodology. The process involves the analysis of concentrations of contaminants and releases, the identification of exposed populations or receptors, the identification of exposure pathways and the estimation of contaminant intakes for each pathway for a range of scenarios, such as land uses. The results of the release, exposure and consequence assessment steps are combined to provide a quantitative estimate of the likelihood of risks. The risk is defined as a combination of the consequence of a negative effect and the probability that the effect will occur (Paustenbach, 2000). The final output of the method is an index that gives an indication of the human health risks for the area. The Human Health Risk Index (RI) is calculated for the area under evaluation, considering the actual or the potential land use, as the sum of the risks from different pathways (hazard quotients) and heavy metals considered. Generic land use groups are envisioned based on how the land is used and on how sensitive and dependent the activity is on the land (USEPA, 1991; The Netherlands National Institute for Public Health and the Environment, 2001a; DEFRA and Environment-Agency, 2002; USDoE, 2005). Urban land use categories need to be selected carefully (Dai et al., 2001), as it is somehow complex to make an inventory and classify all types of land uses due to their diversity and intricacy. A summary of the most relevant characteristics is presented in Table 3.

The Risk Index (RI) was calculated as the sum of the hazard quotients of the pathways (Fig. 3). The symbols and abbreviations are listed in Table 2. The concentrations of heavy metals in soils were calculated using bioavailable contents instead of pseudototal concentrations. The human bioaccessible content approximates the concentrations of heavy metals that the human body is taking up. It is used in the direct ingestion pathway. The plant bioavailable content simulates the concentrations of heavy metals that are taken up by plants. It is used in the food chain pathway. The RI was defined as the ratio between the sum of the daily intake of heavy metals and the Tolerable Daily Intake (TDI). TDI is the amount of a metal that humans can ingest, directly or via food consumption, during a lifetime without adverse health effects (The Netherlands National Institute for Public Health and the Environment, 2001b). Multicriteria evaluation was used to combine the individual factors into a single number (Table 3). The hazard quotients were calculated as a linear combination of factors, where each of the factors has an influence on the final result (Eq. (1)):

$$HQ = IR \times DE \times LURC \tag{1}$$

The factors are weighted by a so-called Land Use Risk Coefficient (LURC). The coefficients represent the occurrence of different pathways in the land uses, as not all pathways have the same importance

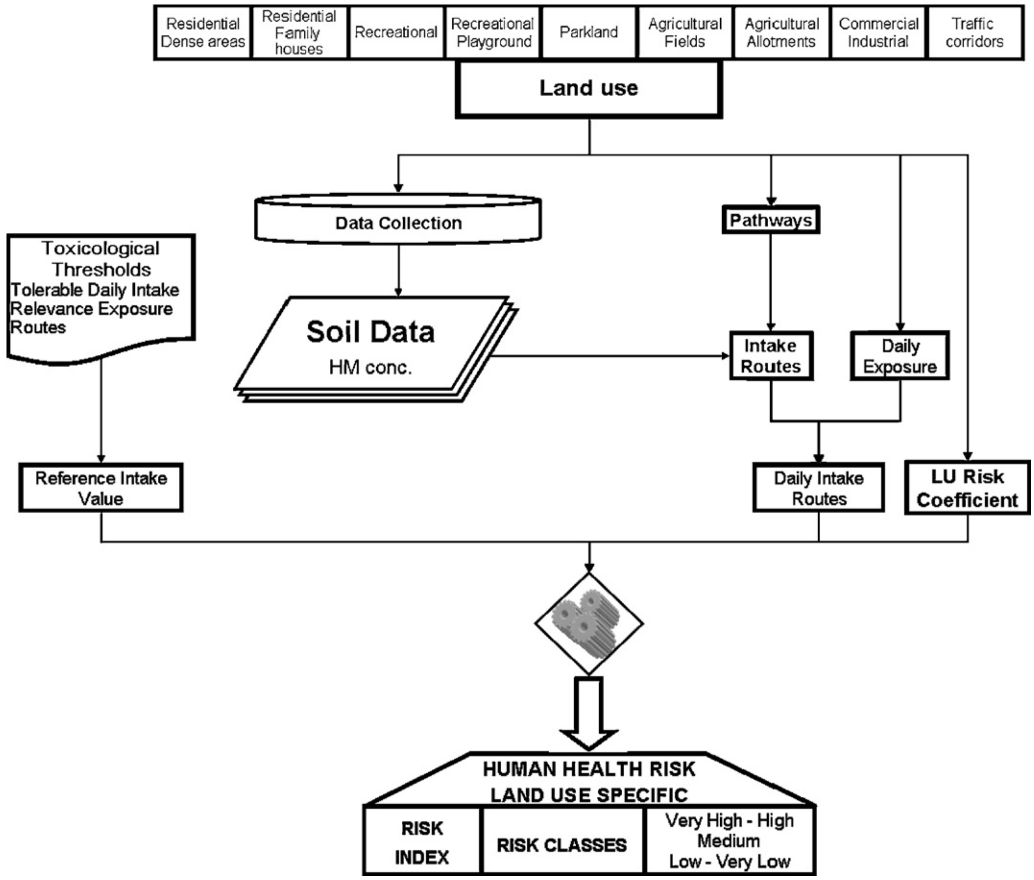

Fig. 1. Human health risk evaluation method.

for a certain purpose. The LURC were derived based on expert opinion, expressing the frequency of exposure in the land uses. A lower value indicates a lower contribution of that pathway to the total risk in the considered land use. The LURS were introduced in order to increase the flexibility of the method and its adaptability to local situations. The case of the Grugliasco region is given in Table 4, as example.

The method uses standard values of exposure frequency, exposure duration and human body characteristics for the pathways under examination. The equations and the parameters employed for the quantitative estimation were adapted and simplified from existing frameworks (USEPA, 1991; Stubenrauch et al., 1997; Ferguson et al., 1998; USEPA, 1998; The Netherlands National Institute for Public Health and the Environment, 2001a; DEFRA and Environment-Agency, 2002; The Netherlands National Institute for Public Health and the Environment, 2002USDoE, 2005).

The HHRE method was constructed in order to reduce the number of parameters that need to be determined in standard risk assessments. Exposure pathways calculated are the direct ingestion of soil and dust, and the consumption of home-grown vegetables. Dermal contact and inhalation of dust are not included. Dermal absorption is significant in the case of organic substances and organometallic compounds, but is negligible in the case of heavy metal ions (Korre et al., 2002; Nathanail et al., 2005). The contribution of inhalation to the human uptake of heavy metals is normally below 1% (The Netherlands National Institute for Public Health and the Environment, 2001b; Nathanail et al., 2005). The carcinogenic consequences of exposure to heavy metals were not considered due to the lack of quantified carcinogenic effects for most of the metals, including lead (Korre et al., 2002).

The risks due to heavy metals are summed up. The total risk from soil pollution may increase if a mixture of pollutants contributes to the risk (Cui et al., 2005) and when the impact occurs via several exposure pathways (SAEFL, 2005). The aggregated RI gives a preliminary estimate of the potential risk that can be used for planning

Table 2
Abbreviations used for exposure parameters (USEPA, 1991; The Netherlands National Institute for Public Health and the Environment, 2001a; DEFRA and Environment-Agency, 2002)

	Unit	Explanation
AT	day	Averaging time
BCF	$\mu g/gFW_{plant}/\mu g/gDW_{soil}$	Soil to plant bioconcentration factor for edible parts
BW	kg	Body weight
CR	g/day	Total daily consumption rate of each home-grown vegetable
C_{soil}	mg/kg	Concentration of a contaminant in soil
DIR	mg/day	Chemical exposure rate for intake route considered
ED	y	Exposure duration
EF	d/y	Exposure frequency
HF	%	Fraction of each vegetable consumed that is assumed to be home-grown
IR_{veg}	μg/day	Chemical exposure rate for vegetable uptake of HM
$IR_{veg,soil}$	μg/day	Chemical exposure rate for ingestion of soil adhering to vegetables intake route
LUR_c		Risk coefficient for land use for human health for each of the IR
RER	%	Relevance of human exposure routes
SIR	mg/day	Soil ingestion rate
TDI	μg/(kgBW d)	Tolerable daily intake

Table 3
Land use parameters: occurrence of pathways, critical receptor, frequency and intensity of exposure (USEPA, 1991; Norwegian Pollution Control Authority, 1999; DEFRA and Environment-Agency, 2002)

	Pathways		Critical receptors		Exposure	
	Ingestion	Food chain	Child	Adult	Frequency	Intensity
Residential dense areas	**	*	+	–	***	**
Residential family houses areas	***	**	+	–	***	**
Playground	***	–	+	–	*	***
Recreational	**	–	+	–	*	***
Parkland	*	–	+	–	*	**
Agricultural allotments	***	***	+	–	***	***
Agricultural fields	**	**	–	+	**	***
Commercial	–	–	–	+	*	*
Industrial	–	–	–	+	*	*
Services	–	–	–	+	–	*

***: severe; **: moderate; *: low; –: negligible.

Table 4
Results of the HHRE method and RI factors for the case study considered

	Pathways		LURc		Daily exposure	Risk index	Risk index classes
	Ingestion	Food chain	Ingestion	Food chain	Child		
Residential dense areas	0.46	5.52	0.7	0.3	0.96	0.66	Very low
Residential family houses areas			1.0	0.7		2.96	Average
Playground			1.0	0.1	0.57	0.50	Very low
Recreational			0.7	0.1		1.22	Low
Parkland			0.7	0.1		0.40	Very low
Agricultural allotments			1.0	1.0	0.96	3.93	Average
Agricultural fields			0.7	1.0		4.15	Average
Commercial			0.1	0.1	0.61	0.57	Very low
Industrial			0.1	0.1		0.57	Very low
Services			0.1	0.1	0.05	0.03	Very low

purposes as it shows where the greatest potential for risk is located (Hough et al., 2004).

The plant bioavailable content was used to estimate uptake into the food chain pathway, while the human bioaccessible content was used for the direct ingestion pathway. Plant bioavailability and the human bioaccessibility of heavy metals in soil are assumed to be represented by chemical extractions simulating the behaviour of plants and human digestion apparatus (Ure, 1996; Wragg and Cave, 2003). The human bioaccessibility of heavy metals is defined as the fraction of the ingested metal that is soluble in the gastrointestinal environment and it is available for absorption (Paustenbach, 2000).

The method was implemented in an Excel® tool to facilitate and to expedite the calculations for inclusion in planning and management procedures. Iterated calculations are made possible with a macro-routine in Visual Basic for Application®. The outputs are linked to a MS Access® database for easier interpretation with the support of a GIS environment. The estimated risks are classified in five categories, from "No Risk" to "Very High Risk". An end-user oriented procedure was designed in order to facilitate the integration of the method into planning and land management decisions, and a report form was prepared to organise the results for easy interpretation (Fig. 4.).

2.2. Case study description

Grugliasco is located in the western hinterland of Torino, a large industrial city in the northwest region of Italy. The territory of Grugliasco is characterised by a regular morphological flat surface with a weak southeast slope. It is located in an alluvial plain. The soils have no limitations for agriculture, being very fertile, deep, structured and well drained (Regione Piemonte, 1990, 2000, 2005). During the urban sprawl between 1950 and 1970, the population increased sixfold in size with the development of the car manufacturing industry. The agricultural areas diminished

Fig. 2. Site used as testing case of the HHRE method.

and were fragmented to satisfy the needs for housing and traffic spaces. Today the area shows a mosaic of agricultural and residential/industrial/services land uses.

The HHRE method is illustrated for the playground shown in Fig. 2. The site is in an urban green area in the centre of the municipality close to the part of the city that has been urbanised for a long time. The area is mainly used for recreational purposes, sports and walking.

The playground is primarily used by neighbouring schools and kindergartens. The soil was covered mainly by grass with some bushes; the surface coverage was around 30–70%. Known pollution sources were traffic and industrial emissions. The vegetation was generally healthy, with some slow growth. The site had no features of natural or cultural heritage. The soil layering was semi-natural. The soil showed little anthropogenic impact. There were only few stones. Many different human artefacts were found. The pH was neutral, with a medium content of organic matter. The texture of the fine earth was loam. The concentrations of Pb and Zn were above the respective Italian legislative thresholds (Gazzetta Ufficiale della Repubblica Italiana, 1999), those of Cu, Ni and Cr were below.

Soil data and information were taken from a soil survey carried out in Grugliasco. The selection of sampling points was based on the available metadata and the maps were organised in a GIS project (ArcMap 9.1 ESRI). Fifty-six sampling points were predefined using a regular sampling grid. Additional information was recorded at each sampling site: the degree of urbanisation, land use, vegetation, soil description and potential sources of pollution. Samples were dried at 20 °C, disaggregated and sieved. Each sample was characterised for general parameters such as pH, organic matter content and particle size distribution. Metals were analysed by flame atomic absorption spectrometer in various extracts: aqua regia (HCl/HNO_3, 3:1 solution), DTPA (Lindsay and Norwell, 1969) and modified PBET (Oomen et al., 2003; Ruby, 2004; Yang et al., 2003). The metal fractions obtained from these extractions are denoted as pseudototal content, plant bioavailable content and human bioaccessible content, respectively. The pseudototal content was used as a reference in the calculations. Human bioaccessible content was used for calculation of the direct ingestion pathway and the plant bioavailability for the food chain pathway (Fig. 3).

$$\mathrm{RI} = \sum_{\mathrm{HM}} \left(\mathrm{HQ}_{\mathrm{ing}} + \mathrm{HQ}_{\mathrm{food}}\right)$$

Hazard Quotient (HQ) for direct ingestion

$$\mathrm{HQ}_{\mathrm{ing}} = \mathrm{C}_{\mathrm{soil}} \cdot \frac{\mathrm{SIR}}{\mathrm{BW} \cdot 10^3} \cdot \frac{\mathrm{EF} \cdot \mathrm{ED}}{\mathrm{AT}} \cdot \frac{1}{\mathrm{TDI}_{\mathrm{ing}} \cdot \mathrm{RER}_{\mathrm{ing}}} \cdot \mathrm{LURc}_{\mathrm{ing}}$$

Hazard Quotient (HQ) for food chain – vegetable consumption

$$\mathrm{HQ}_{\mathrm{food}} = \mathrm{C}_{\mathrm{soil}} \cdot \frac{\mathrm{CR} \cdot \mathrm{HF} \cdot \mathrm{BCF}}{\mathrm{BW}} \cdot \frac{\mathrm{EF} \cdot \mathrm{ED}}{\mathrm{AT}} \cdot \frac{1}{\mathrm{TDI}_{\mathrm{food}} \cdot \mathrm{RER}_{\mathrm{food}}} \cdot \mathrm{LURc}_{\mathrm{food}}$$

Fig. 3. Equations for Risk Index (RI).

The model calculations for the chosen playground site in Grugliasco (Table 4) showed that higher risks would likely result from a use of the area for agricultural purposes. Comparable results were found for use as a residential area with private gardens. In all these land uses, the risks resulting from the food chain pathway were found to be high. A RI of 1.2 was found for the actual land use of the site, as a playground. In this land use, the food chain pathway is negligible but the risk of direct ingestion is severe. Very low risks were estimated for all other land uses. The results presented in Table 4 show that the risk is influenced by a change in land use and can be mitigated with an appropriate choice. In particular, recreational or parkland uses seem to be possible options. The risk is significantly lower than for the actual use, due to the interruption of the direct ingestion pathway. A land use change to parkland or a recreational area would be reversible and would not necessarily destroy the soil resources of the area. An increase in the grass cover would improve the situation at a low cost.

The report shown in Fig. 4 provides all of the important information needed by end users. The results are presented with a traffic light coding, where darker means a higher risk. The risk estimates for the various land uses support a decision about possible land use alternatives.

3. Results

3.1. Implementation: case study of Grugliasco

The model calculations for the playground site are presented in Table 4. The contribution of the same concentration of heavy metal in the soil depends on the pathway. Table 4 shows that the intake route (IR) due to heavy metal concentrations is 5.52 when considering the consumption of vegetables, but only 0.46 when looking at direct ingestion.

The LURC were introduced into the HHRE method because the contribution of a pathway to the risk of metal intake may be very different for different land uses. For example, vegetables are unlikely be grown on a site that is used as a kindergarten or parkland. The probability that the soil will be directly ingested is lower in a parkland area that in a playground or allotment garden. Table 4 reports the LURC determined for the Grugliasco area.

The daily exposure (DE) is a numerical expression of the amount of time a receptor spends in contact with the source of risk (Paustenbach, 2000). The DE depends strongly on land use. For example, a receptor is assumed (DEFRA and Environment-Agency, 2002) to spend more time in contact with soil in the backyard of a house than in a park or in a playground.

4. Discussion

The advantages of quantitative environmental risk assessments over the more commonly used qualitative approaches are widely accepted. The benefits of the land use approach in health risk assessment have been highlighted by numerous authors (Bien et al., 2004; Hough et al., 2004; Hooker and Nathanail, 2006). Land use is a factor with a strong influence on health risks (NEPC, 1999c). The type and the intensity of soil use determine the exposure pathways through which humans are exposed to health risks from soil pollutants. Differences in land use lead to differences in human exposure and hence in health risks. In the HHRE method, the LURC is used to quantify the importance of a pathway in a specific land use, and to express the frequency of the exposure to a specific pathway in the land uses. The coefficients relate exposure scenarios by land use groups, defining typical users and their activities. The evaluation method, with the introduction of LURCs, depends heavily on the perceptions and priorities of the evaluators. The modelling results are highly sensitive to the weights that are applied. The LURCs provide quantitative estimates of the incidence of pathways within different uses of soil. They facilitate the impact assessment of land use changes on health risks. The LURCs are adaptable to reflect local conditions and specificities of the evaluated area. A more objective procedure is needed to establish LURCs. The procedure should be designed in order to be scientifically sound. The coefficients that are derived should be a result of a consensus agreement between the various stakeholders involved.

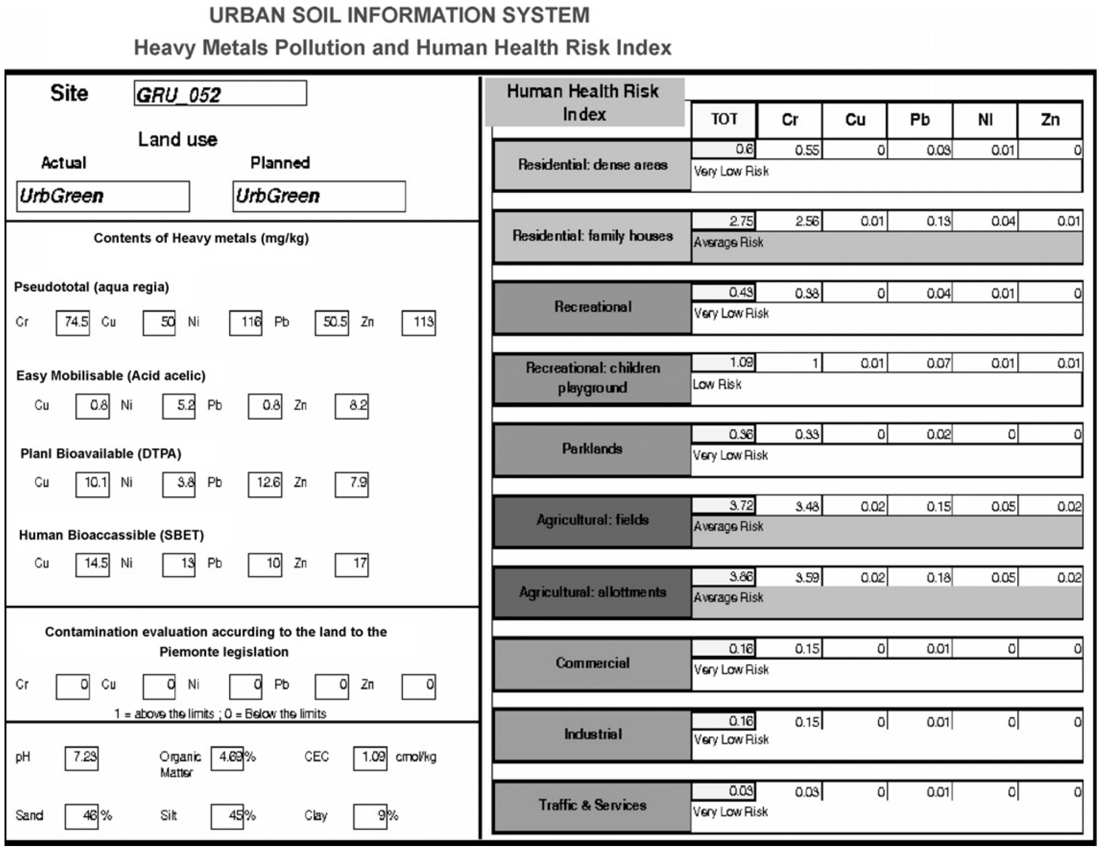

Fig. 4. Suggested report for applicability of the devised method.

The derived RI is of use when considering the risk to human health from chronic exposure to heavy metals in soil. It is based on a land use-related exposure analysis, considering the actual or planned land use. The RI depends on the extent of heavy metal contamination and on the type and intensity of use of the site in question. It also measures the impact of planning interventions. The index was used as an indicator and not as an absolute quantitative measure. Caution is required when interpreting the results of this form of risk assessment. An RI value of 1.0 means that the heavy metal concentrations in the soil are close to the amount that can be taken up by the human body through various pathways over a lifetime, without resultant adverse health effects. The RI is a conservative index. An RI > 1.0 suggests that a person may experience adverse health effects during a lifetime, and it is undesirable when looking at the overall health of an exposed population (Hough et al., 2004). A very high RI can have serious effects on human health. The RI is of use to identify population groups that are potentially at higher risk, and it indicates the relative severity of those risks.

An important goal in human health risk assessment is to provide assistance to policy makers in the development of an area. The evaluation results should assist planners in making decisions on land use alternatives for specific areas. For the areas where the risk has been identified as unacceptable, the management options have to be defined to minimise risk in a cost-effective way. The risk to human health due to heavy metal concentrations can be reduced by interrupting the source–receptor pathway. An option is to exchange contaminated soil with clean soil. Another option is the sealing of the soil surface. These kinds of remediation are expensive and not easily applicable. A more cost-effective solution may be a change of land-use. This kind of "remediation" implies the change to a less sensitive land use or a change in some characteristics of the actual land use in order to break the exposure pathways.

A major objective of land use planning is to evaluate the advantages and disadvantages of one use of land as compared to another in order to reach the most suitable land use and the conservation of soil resources (Dai et al., 2001). The request for tools to support decision-making has increased over the last few years. The HHRE method was designed to assist planners who are not experts in soil science and soil contamination issues. The calculated values provide information to decision-makers to help them answer questions like: (i) is the considered area suitable for the considered land use? or (ii) which is the less risky land use for the considered area?

5. Conclusions

Urban soils are often contaminated by heavy metals, elements which can cause serious health problems if present in high concentrations of metals. Humans contact with soils and exposure to heavy metals are strongly dependent on how the soil is used. Human health risk assessment, which is important in controlling risks that arise from soil contamination, should further take into account the role of land use for the exposure of humans to soil pollution. Spatial planning and land management decisions should be made in consideration of the effects on risks that arise from contaminated soils. Many frameworks for health risk assessment are applied in the evaluation of contaminated sites. The existing methods are very complex to be used for land management and spatial planning. Simplified methods are useful in providing an indication of possible problems. The HHRE method was developed to make health risk assessment information available for planning and soil management in an end-user oriented manner, providing an immediate spatial visualisation of risks that are likely to arise from current and planned land uses. By identifying the areas of concern for human health, it provides a basis for more informed decision-making on land use and for setting soil protection guidelines.

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