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Review

# Risk assessment of urban soils contamination: The particular case of polycyclic aromatic hydrocarbons

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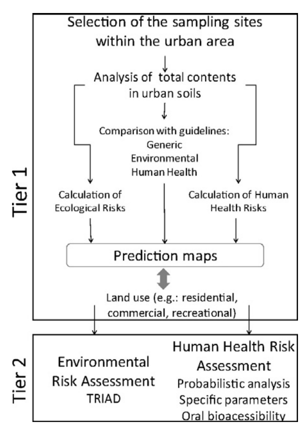
## HIGHLIGHTS

- The tiered approach was adapted to perform a risk assessment of urban soils.
- Existing models to calculate ecological and human health risks are presented.
- Chemical screening combined with geostatistics in a first tier is cost-effective.
- There is much to improve to obtain a reliable risk assessment of PAHs in soils.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The assessment of soil quality and characterization of potential risks to the environment and human health can be a very difficult task due to the heterogeneity and complexity of the matrix, the poor understanding about the fate of contaminants in the soil matrix, scarcity of toxicological/ecotoxicological data and variability of guidelines. In urban soils these difficulties are enhanced by the patchy nature of urban areas and the presence of complex mixtures of organic and inorganic contaminants resulting from diffuse pollution caused by urban activities (e.g. traffic, industrial activity, and burning of carbon sources for heating). Yet, several tools are available which may help to assess the risks of soil contamination in a simpler, cost effective and reliable way. Within these tools, a tiered risk assessment (RA) approach, first based on a chemical screening in combination with

*Abbreviations:* ACE, acenaphthene; ACY, acenaphthylene; ADD, average daily dose; ANT, anthracene; AT, averaging time; BAA, benzo(a)anthracene; BAP, benzo(a)pyrene; BAPeq, BAP equivalent concentration; BBF, benzo(b)fluoranthene; BGHI, benzo(ghi)perylene; BKF, benzo(k)fluoranthene; Bw, body weight; C, concentration; CAM, concentration addition model; CEV, critical exposure value; CRY, chrysene; $CSF_O$, chronic oral slope factor; Csoil, concentration in soil; DBAH, dibenzo(ah)anthracene; EC, effect concentration; ED, exposure duration; EqPT, equilibrium partitioning theory; ERA, ecological risk assessment; Exp, exposure; FLA, fluoranthene; FLU, fluorene; HC, hazard concentrations; HHR, human health risk assessment; HI, hazard index; HQ, hazard quotients; HU, hazard unit; IND, indeno(1,2,3-cd)pyrene; IR, intake rate; IUR, inhalation unit risk; IV, intervention value; $LC_{50}$, median lethal concentration; LoE, line of evidence; LOEC, lowest observed effect concentration; LR, lifetime risks; MPC, maximum permissible concentration; NOEC, no observed effect concentration; NP, naphthalene; OC, organic carbon; OM, organic matter; PAF, potentially affected fraction; PAHs, polycyclic aromatic hydrocarbons; PHE, phenanthrene; PNEC, predicted no effect concentration; PYR, pyrene; RA, risk assessment; RAM, response addition model; RfC, inhalation reference concentration; $RfD_O$, oral reference dose; SQG, soil quality guidelines; SRC, serious risk concentration; SSD, species sensitivity distribution; SSL, soil screening level; TDI, tolerable daily intake; TEFs, toxic equivalent factors; TLCR, total lifetime cancer risk; TMoA, toxic mode of action; TP, toxic pressure; TU, toxic unit; TUm, toxic units of the mixture; TV, target value; VF, volatilization factor.

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geostatistical tools, may be very useful in urban areas. However, there is still much to improve and a long way to go in order to obtain a reliable RA, especially in the case of hydrophobic organic compounds such as polycyclic aromatic hydrocarbons (PAHs). This paper aims at proposing a RA framework to assess the environmental and human health risks of PAHs present in urban soils, based on existing models. In addition, a review on ecotoxicological, toxicological, and exposure assessment data was made, as well as of the existing soil quality guidelines for PAHs that can be used in the RA process.



**Contents**



## 1. Introduction

The ecological functions of soils may be strongly affected by different anthropogenic pressures and, according to the EU Soil Thematic Strategy, some of the major threats for soil in Europe are compaction, point and diffuse contamination, and sealing (EC, 2006). These threats are more evident in urban areas, and due to the great urban growth, challenges regarding soil pollution have become very important. Particularly, diffuse pollution, which is normally characterised by continuous and long-term emission of contaminants below risk levels, can be a major problem. The main reason is that the terrestrial environment acts as a sink for contaminants, due to its capacity for holding and retaining pollutants. Therefore, due to long-term accumulation of contaminants, the quality of soils may be negatively affected (Cachada et al., 2009, 2012, 2013; Liu et al., 2010; Peng et al., 2013; Wang et al., 2015a, 2015b). Soil can also act as source of contamination, depending on the controlling soil properties and contaminants themselves, and therefore it may have deleterious effects on ecosystems and human health.

Among the most relevant and widely studied compounds in urban soils are the polycyclic aromatic hydrocarbons (PAHs). PAHs are a global environmental issue due to their carcinogenic and/or mutagenic potential, their continued emission, persistence and mobility throughout the environment (Jones and de Voogt, 1999; Biasioli and Ajmone-Marsan, 2007; Cachada et al., 2012; Ma et al., 2009; WHO, 2003). Their lipophilic nature, hydrophobicity and low chemical and biological degradation rates leads to their bioconcentration, bioaccumulation and bioamplification, thereby potentially achieving relevant toxicological concentrations in organisms (Jones and de Voogt, 1999). Several studies have been conducted to assess the levels and sources of PAHs in urban soils, and in the last years some were focused on the assessment of risks to human health (Cachada et al., 2012; Liu et al., 2010; Peng et al., 2011, 2013; Qu et al., 2015; Wang et al., 2015a, 2015b). However, the assessment of risks to the environment is not normally addressed, when PAHs are the contaminants of concern, regardless of the importance of soil's ecological functions even in urban areas.

The assessment of potential risks to the environment and human health of contaminants present in urban soils can be a very difficult task due to the heterogeneity and complexity of the matrix, the existence of multiple point and diffuse sources, and the presence of mixtures of contaminants. Considering this, following a risk assessment (RA) plan based on a tiered approach can be the simplest, most cost effective and reliable way of assessing potential risks related to urban soils contamination. One of the major advantages that turns this approach into a cost-effective way of identifying the potential risks is its flexibility that allows a tiered fitness-for-use approach, i.e., sequential steps with increasing complexity as needed, being the principle "*simple if possible, complex when necessary*" (Swartjes et al., 2012). However, for hydrophobic organic contaminants such as the PAHs, there are several issues that need to be improved in order to obtain a reliable approach: the poor understanding about the fate of contaminants in the soil matrix; the scarcity of toxicological/ecotoxicological data; and the variability and reliability of guidelines. Therefore, this paper aims at presenting some of the existing tools to assess the environmental and human health risks resulting from PAHs present in urban soils and identifying the need for improvements. It is intended to suggest a framework to assess the impacts of PAHs in urban soils in a systematic way.

## 2. General overview of the diagnostic risk assessment approach

A RA plan allows identifying the contaminants of potential concern and receptors at risk, becoming possible to obtain a risk characterization (i.e., the probability of occurring an adverse effect as a result of an exposure to a substance or a mixture of substances) for a given area (EC, 2003; Posthuma et al., 2008). Specifically, the diagnostic (or retrospective) RA approach consists of the assessment of damages or effects caused by contamination at a given site and selects priorities for