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Development of a conceptual framework of holistic risk assessment — Landfill as a particular type of contaminated land

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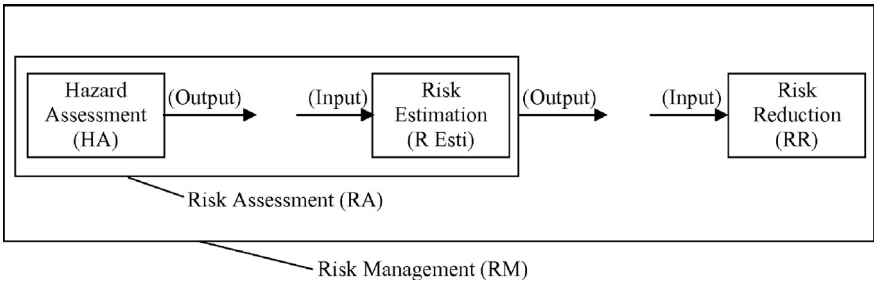
HIGHLIGHTS

- For a whole-system risk management of landfill leachate, a holistic and integrated risk assessment is required, which could yield one overall (total) risk value via aggregating individual risks posed from all the respective combinations of all the leachate hazards via all the pathways to all the receptors.
- Such a holistic and integrated methodology is presented for the first time for landfill leachate by assembling existing knowledge from varying disciplines and yet generating new building blocks (with innovative insights) to bridge a number of knowledge gaps.
- For instance, an innovative notion of 'Least Bad' scenario of risk is developed as opposed to commonly used 'Most Likely' and 'Worst Case' scenarios of risk. Furthermore, the paper also introduces a new concept of how these three scenarios as a 'triple stream' approach can be employed as bench marks in risk assessment.
- Hazard Index is generally attributed to non-carcinogenic hazards. This paper shows how hazard indices approach can also be applied to carcinogenic hazards. Similarly, unlike to the convention of considering risk quantification approach only for carcinogenic hazards, the paper additionally demonstrates how risk quantification approach can be considered even for non-carcinogenic hazards of landfill leachate. Furthermore, the paper explains why and how a risk assessment can be carried out beyond the stage of hazard indices, by explaining an innovative concept of dividing the receptor into two categories, namely: biota/living and non-biota/non-living.
- The environmental legislation (examples described in the paper) is not only growing stringent but also integrated; therefore such a holistic risk analysis of landfill leachate is becoming an escalating need of the time. On the other hand, landfill leachate is a multi-dimensional pollutant source. Therefore, the paper's scope is multi-faceted bringing together appropriate aspects of the antroposphere/technosphere, biosphere, lithosphere, atmosphere and hydrosphere.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfills can be regarded as a particular type of contaminated land that has a potential to directly and indirectly pollute all of the four main spheres of the environment which are the lithosphere, atmosphere, hydrosphere and eventually adversely impact the biosphere. Therefore, environmental risk assessment of a landfill has to be more integrated and holistic by virtue of its nature of being a multidimensional pollutant source. Despite this, although various risk assessment approaches have been adopted for landfill waste disposal sites, there are still wide-ranging knowledge gaps and limitations which need to be addressed. One important knowledge gap and limitation of current risk assessment approaches is the inability to fully identify, categorise and aggregate all individual risks from all combinations of hazards, pathways and targets/receptors (e.g. water, air, soil and biota) in connection to a certain landfill leachate and yet at any stage of the landfill cycle. So such an approach is required that could not only integrate all possible characteristics of varying scenarios but also contain the ability to establish an overall risk picture, irrespective of the lifecycle stage of the landfill (e.g. planning stage/pre-operation, in-operation or post-operation/closed). One such approach to address the wide-breadth of landfill impact risks is by developing a more holistic risk assessment methodology, whose conceptual framework is presented in this paper for landfill leachate in a whole-system format. This conceptual framework does not only draw together various constituting factors and sub-factors of risk assessment in a logical sequence and categorical order, but also indicates the "what, why, when and how" outputs of and inputs to these factors and sub-factors can be useful. The framework is designed to identify and quantify a range of risks associated with all stages of the landfill lifecycle, and yet in a more streamlined, logical, categorical and integrated format, offering a more standardised and unified whole-system approach.

1. Introduction

1.1. Background

As with other types of contaminated land, risk assessment (RA) is increasingly being applied to landfill sites, at the planning, operational and/or completion stages (Environment Agency, 2003a, 2003b, 2004; DETR (Department of the Environment, Trade and the Regions), 2000). Risk analysis is also being supported by environmental legislation in various countries (Butt et al., 2008) thus making it a mandatory part of the landfill design process. For example, a risk assessment requirement for the protection of groundwater from landfill leachate has been a legislative requirement in the UK since 1st May 1994, through Regulation 15 of the Waste Management Licensing Regulations, 1994 (SI (Statutory Instruments) UK, 1994; SI (Statutory Instruments) UK, 2005). RA is a vital tool for determining the level of environmental risk control, which subsequently dictates the level of risk reduction – the ultimate aim of a risk assessment procedure. Thus, the degree of effectiveness of the risk control and risk reduction is highly dependent on the level of accuracy and detail of information derived from the RA.

An exhaustive review of risk analysis approaches carried out by Butt et al. (2008) highlighted that a comprehensive, robust and sound framework of RA in a holistic manner, with a range of features does not exist. Examples of such features are listed below. Butt et al. (2008, 2009, 2014) also explained why a holistic RA approach can be more useful than traditional tools. For instance, the Water Framework Directive (EC (European Community), 2000) is being transposed and implemented in the UK and the other European Union member states. This Directive includes new requirements for the protection and restoration not only of ground waters but also surface waters and dependent ecological systems (Environment Agency, 2003a). Similarly, the Landfill Directive and Regulations take it beyond surface and ground waters only, and include air, soil, global environment, greenhouse gases, and human health (EC (European Community), 1999; SI (Statutory Instrument), 2002, 2004, 2005a, 2005b; Scottish Executive; Welsh Assembly Government; Department of the Environment (DoE) Northern Ireland; and Office of the Deputy Prime Minister (ODPM), 2005). Another directive, generally referred to as Habitat Directive (EC (European Community), 1992), introduces a legal obligation to combat hazards in order to guard and enhance natural habitats and wild fauna and flora. On the basis of these key pieces of environmental legislation, which are increasingly becoming more holistic, it can be concluded that a sound holistic approach towards RA is not only appropriate, but may well be mandated in the near future. Despite this, current guidance notes and approaches (such as chemical prioritisation) regarding risk assessments do not offer a holistic framework specifically for landfills and do not appear to have the following (Butt et al., 2008, 2009, 2014; Butt and Oduyemi, 2000, 2003; DEFRA (Department for Environment, Food and Rural Affairs) and the Environment Agency, 2004; Clarke et al., 2009; Daginnus et al., 2010; Adidas Group, 2013; Mendes et al., 2003):

- Systematic features to help establish an overall risk posed by a given landfill by aggregating all the individual risks for each combination of all the hazards, pathways and targets/receptors;
- Structured characteristics that could clearly distinguish between toxic, non-toxic, carcinogenic and non-carcinogenic hazards; and accordingly workout either hazard indices or risks or both;
- Various types of landfill systems and their surroundings encompassed in the framework;
- Taken into account all possible characteristics of landfills in terms of risks and quantification of risks posed by landfills;
- Included procedures for individual constituents of RA (e.g. baseline study, hazard identification and categorisation, hazard concentration assessment, exposure assessment with exposure quantification; pollutant migration analysis and likelihood or probability of a target/receptor to be effectively hit by the hazard.)
- Included other features and scenarios that render RA more comprehensive such as significance assessment, uncertainty assessment, risk measurement for most likely and worst case scenarios.

1.2. Aim and scope

One of the most important knowledge limitations identified in the literature is the absence of a sequential/stage-by-stage, categorical and quantitative methodology to perform risk analysis in a holistic fashion for a contaminated land in general and for landfill leachates in particular. Where various disciplines (such as hydrology, geology, hydrogeology, topography, toxicology, statistics) are explicitly integrated in a multi-,