BASELINE STUDY IN ENVIRONMENTAL RISK ASSESSMENT – Escalating need for computer models to be whole-system approach

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Abstract

Despite landfills having the potential to pollute the environment both during their operation and long after they have ceased to receive waste, they remain a dominant waste management option, particularly in the UK. In order to combat the environmental pollution caused by landfills, risk analysis is increasingly being employed through computer models. However, for a risk analysis process to be successful, its foundation has to be well established through a baseline study. This paper aims to identify knowledge gaps in software packages regarding environmental risk assessments in general, and especially those that have been developed specifically for landfills and landfill leachate. The research establishes that there is no holistic computer model for the baseline study of landfills, which risk assessors can use to conduct risk analyses specifically for landfill leachate. This paper also describes a number of factors and features that should be added to the baseline study system in order to render it more integrated – thereby enhancing quantitative risk analysis, and subsequently environmental risk management.

Keywords: baseline study; preliminary investigation; computer models; software packages; landfill leachate; risk analysis; risk assessment; waste disposal sites.

1.0 BACKGROUND

The advent of the industrial revolution led to the expansion of human populations and urban living, which in turn drove increasing economic growth at national and global levels. Unfortunately, this increasing prosperity resulted in ever-greater quantities of waste being generated. There is a link between economic growth and waste and this link is still evident today as industrial, commercial, and domestic waste streams. Waste is the inescapable outcome of the activities which characterise human society; indeed in one sense it is an indicator of the health of modern economy (Tromans and Stiles, 2004). A most recent evidence of strong and directly proportional relationship between economic growth and waste generation is the deceleration impact of the current economic downturn on the amount of waste. Statistics in the USA alone indicate that waste generation had always been escalating until 2007, when the downturn struck. In the years following 2007 the generation of waste has reduced (EPA, 2010). The same has been the case in the UK in various sectors (MBD Ltd., 2011).

There are two main issues regarding waste. One is the amount of waste that is generated, and the second is how it is dealt with or managed - where landfilling still is the most predominant waste management option (among others that include re-use, recycling, composting, and incineration). Regardless of the economic downturn impact, due to increasing environmental legislation and socio-environmental pressures, overall reduction has been noticed on both fronts of waste – that is, in the generation of waste as well as in the amount of waste that is landfilled in various regions, states and countries. However, this is not the case everywhere around the world. Furthermore, the amount of waste that is generated today, irrespective of how much has yet been reduced varyingly around the globe (for whatever reasons), still remains a great concern for the environment and for sustainability - particularly when the predominant part of the total waste is still landfilled (Environment Agency, 2011a; Eurostat, 2011; EPA, 2010; Scottish Government, 2011).

In the past (for instance), in the UK, 240 MT Controlled Wastes per annum and 190MT Uncontrolled Wastes per annum were produced (DoE and the Welsh Office, 1995a). This implied that every nine months there was enough waste in the UK alone to fill Lake Windermere (DoE and the Welsh Office, 1995b). Waste production continued to be on the increase in the UK till 2000 (Davies, 1999; DETR, 2000; Cabinet Office, 2002; DEFRA, 2003; 2005a; 2005b). However, new statistics show that, post-2000, waste began to be reduced overall; and so was the amount that is landfilled. For instance, in England and Wales the amount of waste has fallen by around 46% since 2000 (for which one of the principal reasons is the implementation of the Landfill Directive) (Environment Agency, 2011a). In Scotland, between 2000 and 2010 the total waste sent to landfill decreased by 59% (6.6 million tonnes) (Scottish Government, 2011). Similarly, at the European level, overall statistics show reduction in the generation as well as landfilling of waste (Eurostat, 2011).

Another implication of waste management is that even though waste generation is reducing in places (Scottish Executive, 2004), in a number of cases the transport of waste from the point of production to recycling facilities and outlets can outweigh the 'green' advantage; thereby rendering it unsustainable overall. By way of example, it was reported that the North-East's waste in the UK was being driven as far away as Wales for recycling (Ewen, 2005). So this question of overall sustainability remains unsubstantiated with hard evidence that would it be worth landfilling in such situations. Furthermore, no matter how much waste is minimised, re-used, re-cycled, composted, and even incinerated (which yields ashes for landfilling), there will always be some waste requiring disposal as landfill. Thus, it can be concluded that no matter how high we move up the Waste Hierarchy (Figure 1) there will always be some waste left for landfills one way or another. In the UK, landfill is still the predominant waste management option (Adu-Gyamfi et. al., 2010; DEFRA, 2006) and so is the case with many other developed countries (e.g. USA) (EPA, 2010), let alone the developing countries. A society with 'no-landfill' is practically and realistically impossible. Thus, the number of landfills can be reduced (and has been reduced) but cannot be made zero. Furthermore, there are plenty of improperly managed landfills which we have received as a legacy from the past which pose hazards and risks to the environment and to human health. Such inherited landfills also need to be managed safely, in addition to the safe managing of new ones, irrespective of how fewer they become in number.

Sustainable waste management simply means managing waste by prioritising, as specified in the 'waste hierarchy' presented in The National Waste Strategy (DoE and the Welsh Office, 1995a; 1995b; SEPA, 1999; DETR, 2000; Wilson, 2000; DEFRA, 2005a; 2005b). This implies that waste prevention is the top-most priority (if possible). The other priorities (in descending priority order) are reduction, reuse, and recovery (via recycling, composting, energy-from-waste), and disposal (which includes landfill). Another note-worthy fact in the hierarchy is that landfill is not only strictly at the bottom of the list but also partly constitutes the ‘Recovery’ category (which is prior to the ‘Disposal’ group of waste management options) (Figure 1). This means that even for the waste-from-energy option of waste management practice, landfill can be an approach to derive landfill gas for energy generation either as electricity or heating or even combined heat and power (CHP) technology. Therefore, this is yet another scenario in which a human society may end up having landfills, irrespective of how much waste generation is reduced.

PREVENTION *(as in zero or no waste at all)*

REDUCTION *(if zero waste not possible, then decrease at least)*

RE-USE *(the waste may undergo some degree of physical change but generally does not undergo any chemical/biochemical change)*

RECOVERY *(the waste may undergo some chemical/biochemical change)*

- Recycling *(may still give some waste at segregation stage)*
- Composting
- Energy *(recovered from landfill gas combustion, or waste incineration that reduces the waste volume by large but still some waste is left in the form of ashes which are generally landfilled)*

DISPOSAL

- Incineration *(without energy recovery)*
- Landfill (*without gas energy recovery)*

Figure 1: The Sustainable Waste Hierarchy (indicating that some waste for landfilling can still arise within the deployment of various waste management options)

2.0 INTRODUCTION

2.1 Research aims and methodology used

From the perspective of significance of baseline study in risk assessments, the main aim of the paper is to identify knowledge gaps in existing computer models or software packages regarding environmental risk assessments in general, and especially those that specifically regard landfills and landfill leachate. With reference to previous research works by the principal author, the paper also presents an account of some new insights in how to bridge the identified knowledge gaps, and the importance of why these gaps need to be closed. For instance, the paper presents a conceptual model of a holistic and categorically integrated baseline study structure, thereby, paving a path in the direction of a full-on methodology development in future for a whole-system baseline study for landfill leachate risk assessment along with a corresponding computer-aided model. This way the paper not only establishes the-state-of-the-science but also presents a way forward for future research work in this area.

In conjunction with a ‘sister’ paper (Butt et. al., 2014), this paper still briefly describes some elements from the sister paper so that this paper can sufficiently stand in its own right and readers of this paper do not have to cross reference between the two sister papers too much. This will help readers to avoid not only unnecessary inconvenience but also not to let this paper appear distorted and making no sense if read as a standalone. However, should readers of this paper want full details of the previous work which is an exhaustive review of literature and publications around environmental risk assessment in general and landfill risk assessment in particular, then they can refer to the previous sister paper. The study reported in this paper follows the same theme but specifically in the context of investigation of computer models and software packages, as opposed to review of the literature and publications (in the earlier sister paper). Thus, the study methodology applied in this paper constitutes of:

1. systematic selection of computer models and software packages to be investigated (i.e. firstly those which relate or can be related to risk assessment of landfills; and then those which regard risk analysis of environmental scenarios other than landfills);

2. With reference to the sister paper (Butt et. al., 2014), a list of knowledge gaps is described which is also used as a bench-mark to carry out the investigation of software packages against;

3. Some relevant environmental legislation is also referred to indicate how and why there is a need of whole-system approaches towards baseline study in computer models of landfill risk assessment.

2.2 Definition and scope

Landfilling, as a waste management option, has potential to pollute all the three main natural factors of the environment; which are land or soils (lithosphere), waters (hydrosphere) and air (atmosphere). Such pollution will be transmitted through these media and will impact, either directly or indirectly, upon humans, the natural environment (including aquatic and terrestrial flora and fauna), and the built environment. In addition, landfilling is such a multi-dimensional pollutant source that it has potential to create or deliver contaminating products in all three forms that a matter can exist in, i.e. more or less degraded waste which is solid; landfill leachate which is liquid; and landfill gas (which is combination of a number of different gases including methane, carbon dioxide, and hydrogen sulphide). However, the focus of this research study is landfill leachate, not landfill gas, nor landfill wastes themselves. Unlike landfill gas and (more or less) degraded landfill waste, by virtue of its nature, landfill leachate specifically can pollute all of the three aforesaid principal factors. For instance, leachate vapours or fumes can find their way into the ambient atmosphere in sufficient amounts to present danger to human health and the environment, whereas these vapours or fumes can be containing chemical and/or biological hazards, volatile organics, etc. Moreover, landfill gas also breaks through from landfill leachate. Leachate can be an extremely powerful pollutant of water both above and below ground level – hydrosphere and hydrogeosphere. In addition, leachate contaminants can pollute land/soils as they move through the ground either mixed with water or on its own (e.g. through the unsaturated zone under a landfill). Therefore, in general, landfill leachate can be seen as a lot more hazardous product of a given landfill than the other two – landfill gas and (more or less degraded) landfill waste. Therefore, *the term 'holistic', in line with the sister paper, in this paper also implies an overall framework or system, covering all aspects and factors of the baseline study from the start to end (only in the context of landfill leachate).*

Risk assessment is a relatively new and fast developing science. This is not just in relation to landfills and other environmental issues, but also in connection to other business fields, including the food industry, ecology, epidemiology, radiation, earthquakes, finance, construction management, contractual risk, insurance, economics, fire, landslides, ship navigation, and the oil industry (Rejda, 1995; Tweeds, 1996; WHO, 1997; Mitchell, 1998; HSE, 1998; CIWEM, 1999; CIWM, 2000; Butt and Oduyemi, 2003; Butt et. al., 2006). Regardless of the type of risk assessment and the environmental area of application, one of the important parts of any risk analysis is the baseline study (ICE, 1994; Asante-Duah, 1996; Blight and Fourie, 1998; CIRIA, 2001; Environment Agency, 2003a).

From the perspective of landfill risk analysis, a baseline study process is described by the authors as that fundamental and initial stage of a risk assessment exercise of landfill leachate in which all basic data and information are collected, organised, and analysed. In cases of landfill, the baseline study needs to take account of a wide range of multi- and inter-disciplinary issues, which the authors categorise into eight groups: geology, hydrology, hydrogeology, topography, meteorology, geography, human influence, and site management (Details in Table 1, Section 3.4) (Environment Agency, 1997a; 1999; 2003a; Butt et. al., 2014). Figure 2 exhibits this grouping in the form of a conceptual model of the holistic baseline study specifically for landfill leachate, as well as the position of the baseline study in the spectrum of subsequent stages of risk assessment. However, the stages of risk assessment which follow the baseline study do not form the remit of the paper.

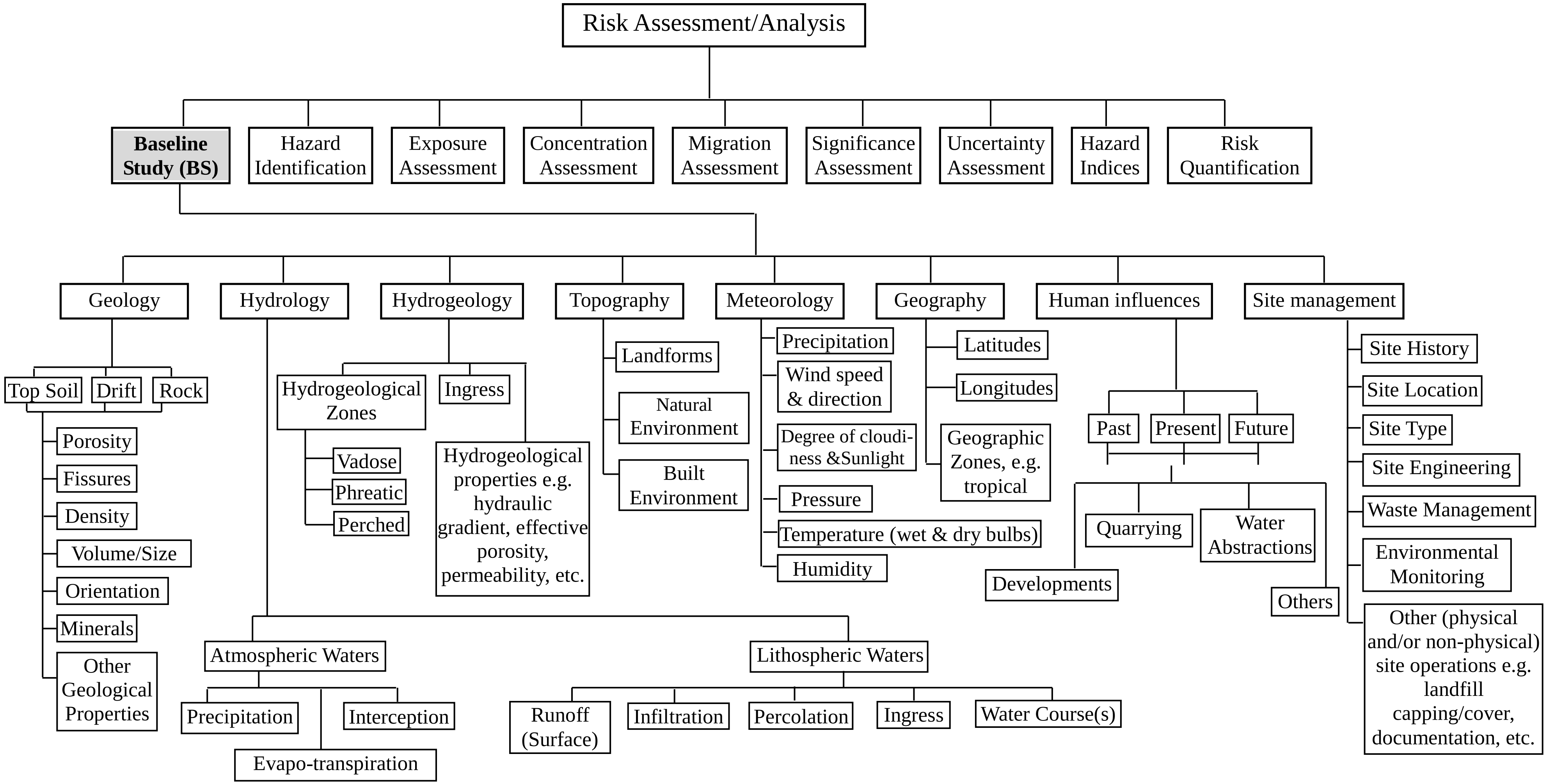

Figure 2: The Baseline Study modules and its position in relation to overall Risk Assessment Structure (Adapted, derived and concluded from the work of various authors including Peacock and Whyte, 1992; WDA, 1994; Tweeds, 1996; WHO, 1997; EPA, 2000a; TOSC, 2000; CIRIA, 2001; Viswanathan et. al., 2002; CMSA, 2004, Butt et. al., 2016)

3.0 SIGNIFICANCE OF BASELINE STUDY

The following four sub-sections explain why a strategic, integrated and whole-system baseline study is necessary with reference to landfill leachate from the perspective of risk analysis. For more details on these four sub-sections readers are referred to Butt et. al., 2014.

3.1 Inconsistency in risk assessment and baseline study

Inconsistency in risk assessments is an important issue, not only for the government sector (e.g. the Environment Agency and SEPA – who are environmental regulators) but also the commercial sector including environmental (risk) consultants and the landfill industry – who have to produce site-specific risk assessment reports for environmental regulators (Booth and Jacobson, 1992; Buss et. al., 2004; Environment Agency, 2007; SEPA, 2011). Irrespective of quality of site-specific data and variation in style and expertise of regulators and consultants, one of the most significant reasons of inconsistency is no two landfill scenarios are the same. Characteristics of landfill scenarios may vary widely from one to another, not only in terms of a landfill itself and its management practices but also the setting around it e.g. diversity of receptors, pathways, etc. Therefore, a holistic risk assessment system is required which encapsulates all possible characteristics, features, aspects and factors in one place – under one 'umbrella' – which risk assessors could use to appropriately choose from and even be able to explain what has not been included and why. This is not to be merely a check list of items but also a complete set of guiding principles of how, when, where and why various items of risk assessment interact with each other and what needs to be included (or even excluded) with justifications for a given risk assessment scenario. To help solve the issue of inconsistency and lack of holism in risk assessments, a holistic baseline study can be effectively useful. In other words, a consistent and coherent baseline study system is one of the crucial requirements to generate consistent and coherent risk assessments. This is explained further in Table 1 (Section 3.4). Since inconsistency among risk assessments also leads to compromise the degree of risk comparisons, therefore, consistency in risk assessments can help the issue of risk comparisons between two or more landfill scenarios in a number of ways e.g. where a new landfill can more safely be sited. Thus, a consistent baseline study system can also be useful in this regard.

3.2. Current and Future Legislation – becoming more and more holistic and integrated

Because of the significance and effectiveness of risk assessment in environmental management, environmental legislation has started to require risk analysis as a tool for meeting legal requirements associated with waste hazards (Environment Agency, 1997; 1999; 2003a). For instance, for the protection of groundwater from landfill leachate, a risk assessment requirement has been legislatively introduced in the UK from 1st May 1994, through Regulation 15 of the Waste Management Licensing Regulations (SI, 1994a; 2005) and the Groundwater Regulations (SI, 1998). The Landfill Directive is implemented in England and Wales through the Landfill Regulations (SI, 2002), made under the Pollution Prevention and Control (PPC) Act (England and Wales 1999). The equivalent legislation, which is called Landfill (Scotland) Regulations, has come out in Scotland (SSI, 2000; 2003; SEPA, 2005a; 2005b). It can be deduced from all these legislative instruments that the concept ‘out of sight, out of mind’ regarding wastes is no longer applicable. To achieve the maximum protection of the environment against the hazards associated with landfill sites, all potential hazards must be identified and risks associated with them assessed.

The current approaches regarding risk analysis and baseline study appear to be just sufficient to meet the current legislation requirements (for example, for drinking water standards). The approaches to this appear to have mainly considered humans as receptors. There is a lack of attention given to other environmental receptors, such as:

- Receptors other than humans, for instance, aquatic and terrestrial flora and fauna (like fish, sheep, crops);

- Natural and yet non-living receptors such as land/soil and air;

- Built environment (for example human-made ponds, buildings, structures and infrastructures (e.g. clean-water pipeline networks));

- Water courses, (other than used by humans for drinking), such as rivers of various water grades (SI, 1994b); and

- Insufficient consideration of various exposure routes such as dermal contact, fish contamination, bioaccumulation in plants, food-web chain, etc.

The areas listed above become more important as environmental legislation is becoming more and more stringent, versatile, inclusive, and integrated. For instance, the Water Framework Directive (EC, 2000), which has been employed in the UK, includes new requirements for protection and restoration not only of ground waters but also surface waters and dependent ecological systems (Environment Agency, 2003a). Another directive, generally referred to as the Habitats Directive (EC, 1992), brings legal obligation to combat hazards in order to guard and enhance natural habitats and wild fauna and flora. Thus, a more integrated approach towards risk analysis is required. This necessitates baseline study to be more integrated and strategic; as without a holistic baseline study being conducted, a holistic risk analysis is not possible.

3.3. Non-integrated risk assessment

The review of the environment-related literature (e.g. ICE, 1994; Asante-Duah, 1996; Blight and Fourie, 1998; Environment Agency, 2003a) clearly shows that a baseline study is a crucial and primary factor in an environmental risk analysis. Moreover, this investigation led to the conclusion that a comprehensive, robust, detailed, and sound computer model or software package of risk assessment, incorporating a number of essential features (including baseline study) does not exist in an integrated manner. Examples of such essential features are:

- Encompassing various types of landfill systems and their surroundings;

- Taking into account all possible characteristics of landfills in terms of risks and quantification of risks posed by landfills; and

- Embedding procedures of relevant modules (such as baseline study, hazard identification, hazard concentration assessment, exposure analysis, pollutants migration).

3.4. Non-integrated baseline study

A wide-ranging number of elements are contained in Table 1 (below) which need to be categorically integrated to form a holistic computer-aided system of baseline study to support risk assessments specifically in relation to landfill leachate. These elements can also be used as criteria or benchmarks to access existing computer models. A detailed account of currently available software packages is described in Section 4.0, which establishes that these elements are either entirely or partly absent in them. This way the paper draws upon the existing knowledge, identifies knowledge gaps, and thereby, presents the state-of-the-science in connection to computer-aided approaches to baseline study for risk assessment of landfill leachate.

Table 1: Elements absent in baseline study – Criteria used as benchmarks to access existing computer models.

Element Number	Absent elements	Description
1.	Eight Modules in a categorically, sequentially and integrated manner.	Keeping in view the multi- and inter-disciplinary nature of baseline study for landfill leachate, the authors divide it into eight modules that are listed below with examples of parameters which these modules can take into account. Current computer models are found not to have included all of these eight aspects in an integrated manner. *1-(i) Geology*: top soil, drift, rock, porosity, effective porosity, fissures, density, geological materials and minerals, depth and width or volume of the geological materials, and other geological properties. *1-(ii) Hydrology*: evaporation, transpiration, interception, surface runoff, infiltration, percolation, and groundwater ingress. *1-(iii) Hydrogeology*: vadose and phreatic (also called unsaturated and saturated) zones, perched groundwater, hydraulic gradient, permeability, groundwater speed and direction, and other hydrogeological properties. *1-(iv) Topography*: landforms and inclinations (to assist in measuring runoff to or from a given landfill), natural environment, habitats, built environment, water-courses, etc. *1-(v) Geography*: latitudes, longitudes, geographic zones e.g. tropical and other geographic properties that can also help in estimating other baseline study parameters (e.g. expected rainfall).

		1-(vi) Meteorology: precipitation (duration, frequency, intensity), wind speed and direction, wet and dry bulb temperatures, humidity, and degree of sunniness and cloudiness. *1-(vii) Human influences*: past, present or future potential anthropogenic activities like quarrying, water abstraction, construction, and development. *1-(viii) Site management*: site history, site type, site location, site design, and engineering (e.g. liners, drainage system), waste management activities, environmental monitoring, waste types.
2.	Comprehensive, algorithmic, ready-to-use, step-by-step baseline study system.	The authors do not find evidence of a computer model which contains a comprehensive, algorithmic, ready-to-use, sequentially-linked, categorical, user-friendly-formatted, continual, and step-by-step baseline study system, which a risk assessor could follow from start to end in a self-guiding fashion to identify and categorise all landfill site characteristics that are needed in different subsequent stages of a risk assessment process for landfill leachate.
3.	Uncertainty assessment of all modules and sub-modules of the	There is a lack of uncertainty assessment of all characteristics and parameters of modules and sub-modules of the baseline study, where these uncertainties could be due to models' limitations; estimation methods; lack of knowledge; data quality; etc.

	baseline study.	
4.	Significant assessment of all modules and sub-modules of the baseline study.	There is a lack of significance assessment of all characteristics and parameters of modules and sub-modules of the baseline study. For instance, is the amount of interception and/or liquid waste for a given landfill significant enough to consider in leachate quantity measurement? What conservative measures are taken and for which parameters and why?
5.	Systematic and categorical consideration of data collation.	No consideration is given to means of data collation at baseline study stage that could assist in working out worst-case and most-likely risk scenarios in subsequent stages of a risk assessment process. Such means are indicated in points 6, 7, and 8 below.
6.	Employment of statistical descriptions.	Lack of employment of statistical descriptions particularly in the context of maximum, minimum, and most-likely values of various parameters (e.g. evapo-transpiration, precipitation, interception, groundwater ingress, etc.). Such statistical descriptions can be helpful to figure out worst-case and most-likely risk scenarios; as well as to address uncertainties, and temporal and spatial variations.
7.	Consideration of	There seems to be lack of consideration of temporal and spatial variations of various parameters of baseline

	temporal and spatial variations.	study modules and sub-modules. For instance, temporal variation of leachate quality in terms of its becoming mature over time; spatial variation of the unsaturated zone underneath a given landfill in order to figure out effective vadose thickness; etc.
8.	Quantification of risk.	For risk assessment to be quantitative, all appropriate parameters of baseline study modules and sub-modules need to be quantified. Examples of such parameters are interception, precipitation, and groundwater ingress. The more the objective measurement of such parameters is, the more successful the quantification of the risk will be.
9.	Categorisation and consideration of landfill stages.	A given landfill can be at pre-operation stage (i.e. planning, design, and development phase), in-operation stage and/or post-operation stage (i.e. completed and post closure phase). In current computer-aided approaches, there is lack of consideration of the issues regarding the three landfill stages.

In order to integrate all these elements into a computer model or software package there is a need for a comprehensive, algorithmic, and systematic baseline study framework, which could provide guidelines on acquiring, sorting, and analysing all the data and/or information of preliminary investigation of a given landfill in such a useful format which could be systematically related to the subsequent stages of the risk analysis (Butt et. al., 2014).

4.0 COMPUTER MODELS OF RISK ANALYSIS AND BASELINE STUDY

The development of computational methods and the ability to model systems more precisely enables hazards to be quantified, their effects to be simulated and risk analyses to be pursued with greater accuracy, leading to more effective risk management. These developments are not only important for all areas of human endeavour, but have particular relevance to environmental issues where the risks involved are increasingly seen as substantial. However, the investigation of current computer models did not find a software package of risk assessment in a holistic format (McMahon et. al., 2001; Butt et. al., 2006). One of the elements which is found to be absent to a great extent in them all is an integrated and whole-system baseline study. A detailed account of features of a such a holistic baseline study is presented in Table 1 and a conceptual framework model is depicted in Figure 2.

4.1 Computer models/software – *associated* with landfills

In this section, the paper describes those computer programs that are recognised to be closely related to landfill risk assessments one way or another. Later, the article widens the circle of the investigation to include a number of those computer packages that are not closely related to landfills as such (in Section 4.3). Six software packages that are identified to be closely associated with landfills are: 1). LandSim (Environment Agency, 1996; 2001; 2003b; Golder Associates, 2012a); 2). HELP – Hydrogeological Evaluation of Landfill Performance (Schroeder et. al., 1994; FPLC, 1997; SSG, 1998; 2012; UCF, 2001; Wyoming Dept., 2009); 3). GasSim (Attenborough et. al., 2002; Golder Associates, 2003; 2012b; 2016); 4). GasSimLite (Environment Agency, 2002); 5). RIP – Repository Integration Program (Landcare Research, 2003; Golder Associates, 1998); and 6). 3MRA – Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (EPA, 2004). The first four computer programs are specifically designed for landfills, although the features of RIP were subsequently extended to take landfills into account on a comparatively large scale and 3MRA is not only for landfills but other waste management issues as well. Details on these six computer models and corresponding critique are contained in Table 2 as follows:

Table 2: Existing software packages closely associated with landfill risk assessment

Serial No.	Software/Model Name	Description
1.	LandSim software (which is purely for landfill risk assessment).	It can only contribute as a part of a total risk analysis process and does not offer a total risk assessment system (Butt et. al., 2011; 2009; 2006; Butt and Oduyemi, 2003). The software probabilistically estimates likely concentrations of leachate pollutants that can reach a given point in the ground (e.g. a groundwater abstraction point) in a certain time in terms of years. It also allows for temporal and spatial variations to an extent. However, specifically from the baseline study perspective, the software does not offer a comprehensive system encompassing all the elements indicated above in Table 1 (Section 3.4). Although the software can use various input data to prepare a site conceptual model for a given landfill, it does not completely describe what data to find, and how to organise, process, and collate data in order to derive which information and in what format so that it can be readily used in later stages of the risk assessment process as and when appropriate. Furthermore, all the elements described in Rows 2-9 of Table 1 are predominantly absent. Similarly, the geography and human influences modules are entirely absent, while the remaining six modules are addressed to a limited extent, for instance: precipitation (meteorology); leachate quantity and head (hydrology), consideration of landfill engineering features such as liners and capping (site management); likely receptors and landforms (topography); unsaturated zone (geology); and saturated zone (hydrogeology). However, these aspects are still not covered in an exhaustive, categorical and systematic fashion (as shown in Figure 2), that could assist a risk assessor to collate data and derive information in a full-on standardised

		format.
2.	HELP program	The HELP program contains only some aspects of landfill risk assessment. These are mainly the design features of landfill (such as liners, capping) and some other aspects (like precipitation, surface runoff and other water budget components). Its purpose is to guide the user through the design process of an open, partially closed or closed landfill. All these aspects can form part of the baseline study for a given landfill being assessed. However, the model does not and is not to offer a comprehensive baseline study system encapsulating many other facets indicated in Table 1 (Section 3.4) that could be applied as a complete preliminary investigation or foundation for a complete risk assessment of a landfill taking into account all potential hazards, pathways and receptors related to landfill leachate.
3.	GasSim	The software GasSim deals with some risk assessment modules (including gas generation, migration, impact and exposure); but as its name suggests, is designed for assessing landfill gas only, and not leachate. Even from the landfill gas perspective, this software does not address all the elements described in Table 1 (Section 3.4).
4.	GasSimLite	The GasSimLite is also developed from the perspective of landfill gas only and is used for calculating gas emissions. Also, this does not offer a 'total' baseline study approach in a categorical and algorithmic manner even for landfill gas.

5.	RIP Package	The RIP package is an integrated probabilistic simulator for environmental systems and designed generally for any potential pollutant source in the ground (such as a chemical storage tank). However, the features of RIP were subsequently extended to take landfills into account on a comparatively large scale. Still, however, the RIP package predominantly remains to be a generic software, and risk assessors have to adapt it to their specific environmental scenarios and that includes landfills too. This adaptation is time consuming and not easy. (Miller, 1998). Although RIP can be applied to landfills for issues like contaminant release and transport, it does not readily provide such a straightforward total procedure either for risk analysis or baseline study for landfill leachate as shown in Figure 2, which a risk assessor could readily follow in a sequential and systematic fashion.
6.	Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (3MRA)	The Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (3MRA) allows for evaluation of five waste management unit types and landfill is one of them. The other four are waste pile, aerated tank, surface impoundment, and land application unit (Leavesley and Nicholson, 2005). Thus, this renders the model more general than if it had been only specific to landfill leachate. The model encapsulates a host of living receptors but does not include mainly non-living items as a standalone category of receptors (though these may be indirectly covered as part of ecological systems to a degree) (CEAM, 2005; Weinberg et. al., 2003). This software concentrates on the exposure analysis section of risk assessment and not the baseline study part. Thus, the software, despite

		relating to landfills, does not present a comprehensive baseline study for landfill leachate as shown in the conceptual framework in Figure 2.

4.2 Computer models/software – *associable* with landfills

There are a number of other software packages that were also examined but they are not demonstrably related to landfill risk analysis, although they could be used to underpin some of the aspects of the baseline study for landfill risk assessment, thus, *associable* with landfills. For instance, Drill Guide (SSG, 1997/98) is useful in the sense that it can be included in the geology module of the baseline study of a given landfill, which consequently will help in the risk assessment process. Similarly, WinDes is a software package which is employed to estimate surface water runoff from a given site area, and such information can be used in the hydrology module of a baseline study of a landfill risk assessment to determine how much net water can runoff a landfill site to establish net leachate generation. InfoWorks (CS – Collection Systems or RS - River Systems), and WinDes also, can be used to estimate surface water runoff for a given catchment (Micro Drainage Ltd, 2007; Wallingford Software Ltd, 2007). Thus, they can be used in the hydrology module of baseline study to work out how much net water in a catchment could runoff towards the landfill to contribute to the leachate generation. The Flood Estimation Handbook (FEH) gives guidance on estimation of rainfall and river flood frequency in the UK. It is also available in the form of a computer software to support the implementation of the FEH procedures (CEH, 2008; 2002). Thus, the rainfall estimation aspect of FEH can be very useful in the hydrology module of baseline study to calculate how much rain will directly fall on a landfill site. Similarly, Flood Studies Report (FSR) is another tool, (also available in software format), that can be applied for rainfall runoff analysis, and consequently to measure surface runoff (Morris and Simm, 2000). Like WinDes, this facet of the tool can be employed to measure the amount of runoff to or away from a given landfill to assist in estimating net or effective quantity of landfill leachate. However, like WinDes and InfoWorks, both FEH and FSR can be employed only to some of hydrological and meteorological aspects of the baseline study in a landfill risk assessment; but these do not and can not address other modules and facets of the baseline study.

4.3 Other computer models/software – not closely associated or associable with landfills

In this section, the authors discuss a range of software packages that are not closely related to landfills as such. This discussion in contained in Table 3 below:

Table 3: Other computer models/software

Serial No.	Software/Model Name	Description
1.	(1-a) GoldSim (1-b) ConSim	GoldSim is a general-purpose simulation software to support a wider variety of applications, most of which fall into the following three categories: environmental systems modelling, business and economic modelling, and engineered system modelling (GoldSim Technology Group, 2003). Thus, it outgrows even the RIP software (discussed in Table 2) in terms of generics. Also, in parallel to RIP, users have to learn how to adapt GoldSim to their specific environmental problems. Similarly, the ConSim program is a tool for assessing the risks which are posed to groundwater quality by pollutants migrating from a contaminated land (Whittaker et. al., 2001; Golder Associates, 2004; 2012c). The authors find that this has not been specifically designed for use with landfills; particularly when landfills have a leachate head and/or liners, which is very likely with modern engineered landfills (Environment Agency, 2003c; Butt et. al., 2006). Neither GoldSim nor ConSim are specifically for landfills, let alone the fact that they do not contain a detailed baseline study framework with all the features highlighted in Table 1 (Section 3.4) and Figure 2 (Section 2.2) for any other environmental problems.
2.	CLEA (Contaminated Land Exposure Assessment)	The CLEA (Contaminated Land Exposure Assessment) software considers risks posed by hazards to human health only and not to other environmental receptors such as plants, animals, buildings, and controlled

	software	waters (Environment Agency, 2003d). Pathways are considered only from the perspective of soil as an exposure medium (Environment Agency et. al., 2002). The CLEA program has been designed for use with contaminated land and not specifically for landfills (DEFRA and Environment Agency, 2002). CLEA does not offer a complete risk assessment model for landfill leachate or even contaminated land. Also, a detailed baseline study framework with all the features highlighted in Table 1 (Section 3.4) and Figure 2 (Section 2.2) do not fall within the scope of the software.
3.	WRATE (Waste and Resources Assessment Tool for the Environment) software	The WRATE (Waste and Resources Assessment Tool for the Environment) software uses life cycle assessment and compares the environmental impacts of different municipal waste management systems (such as waste transportation, resources used and operation of a whole range of waste management processes with their environmental costs and benefits) (Environment Agency, 2011b; Golder Associates, 2012d). However, the software is still not specifically regarding comprehensive baseline study for landfill leachate as described in Table 1 and Figure 2, nor for any other waste management system.
4.	HWIR (Hazardous Waste Identification Rule)	The HWIR (Hazardous Waste Identification Rule) represents the manner in which a United States national-scale assessment of human and ecological risks is determined for establishing appropriate contaminant-specific exemption levels for relevant industrial waste streams. The HWIR modelling technology has also

		been developed to automate the HWIR system. The objective of the HWIR system is to reduce the possible over-regulation. Thus waste streams which qualify the HWIR rule (i.e. listed wastes that could meet the HWIR exit level criteria in a given scenario), would no longer be subject to the hazardous waste management system specified in RCRA (Resource Conservation and Recovery Act, United States). This way, HWIR can assist in sustainable waste management by supporting waste minimisation and the development of innovative waste treatment technologies. The HWIR approach covers a variety of natural and/or living receptors such as soil, fauna, mammals, and plants but does not address built environment constituents as receptors (e.g. underground pipeline infrastructures of gas, oil, clean-water, waste-water, etc.). The focus appears to be on wastes themselves rather than landfills (DOE, 1994; NERL, 2001; EPA, 1999a; 1999b; 2000; 2003; 2005). Furthermore, baseline study details for landfill leachate as described in Table 1 and shown in Figure 2 of the paper do not constitute the remit this system at all.
5.	SADA (Spatial Analysis and Decision Assistance)	SADA (Spatial Analysis and Decision Assistance) is a software package that incorporates tools from a number of environmental assessment fields into an effective problem-solving architecture (TIEM, 2006). These tools include integrated modules for visualisation, geo-spatial analysis, statistical analysis, human health risk assessment, ecological risk assessment, cost-benefit analysis, sampling design, and decision-analysis. Out of this wide range of tools or modules, only two that are most relevant are selected to describe

		here as examples. The Human Health Risk module provides a full human health risk assessment and associated databases from a range of land-use scenarios. These include residential, industrial, agricultural, recreational, and excavation; but not specifically landfills. Ecological Risk is another module or unit of the SADA which allows users to perform benchmark screenings and the ability to calculate risk to a number of terrestrial and aquatic receptors. This module may only be helpful to an extent to address only two aspects of landfill risk assessments. Firstly, assisting in identifying the whole range of environmental receptors (both aquatic and terrestrial); and yet for humans as receptors, the user still will have to consult the former module (i.e. Human Health Risk module). Secondly, in establishing critical concentration levels which can only be a factor of the hazards concentration assessment section of a total risk assessment process. The SADA appears to be a collection of a number of software packages addressing different scenarios. A landfill assessor will have to work on picking the right combinations of these different packages each time they are carrying out a landfill risk analysis, as the SADA is not to provide for each and every facet of the landfill risk assessment in a readily usable format. Moreover, as the software name suggests, the focus of the 'Spatial Analysis and Decision Assistance' appears to be more on spatial than temporal aspects. From the baseline study point of view, SADA does not appear to offer a readily usable computer model of baseline study for landfill leachate which could be comprehensive enough to take account of the diverse range of parameters stated in Table 1 (Section 3.4) and Figure 2 (Section 2.2).

6.	ARAMS (Adaptable Risk Assessment Modelling System)	ARAMS (Adaptable Risk Assessment Modelling System) is a computer-based, modelling, and database driven analysis system developed for the US Army for estimating the human and ecological health impacts and risks associated with military-relevant compounds (MRCs) and other constituents (ERDC, 2006). ARAMS takes various existing databases and models for exposure, intake, and health impacts, and incorporates them into conceptual site-models. The user may need to choose that which particular combination of model and database can be used appropriately for which scenario. The core of ARAMS is the object-oriented Conceptual Site Model (CSM) but that relies on yet another computer program called FRAMES (discussed below). Thus, it is not an easy task to ARAMS into a landfill leachate scenario every time if a landfill assessor decides to use ARAMS. Moreover, ARAMS appears to concentrate mostly on the exposure assessment facet of a risk analysis (which is just a part of a total risk assessment). It does not have other facilities such as a baseline study section (comprising, for instance: geology, hydrology, hydrogeology, and topography) that are necessarily required in a landfill risk analysis as explicitly described in Figure 2 (Section 2.2) and Table 1 (Section 3.4).
7.	MEPAS (Multi-Media Environmental Pollutant	MEPAS (Multi-Media Environmental Pollutant Assessment System) is another computer-based program which is a suite of environmental models developed to assess problems of environmental contamination for

	Assessment System)	government, industrial, and international clients (PNNL, 2006a). The software integrates transport and exposure pathways for chemical and radioactive releases to determine their potential impact on the surrounding environment, individuals, and populations. MEPAS modules have been integrated in the FRAMES software platform to allow MEPAS models to be used with other environmental models to accomplish the desired analysis. In the context of landfills, the situation with MEPAS is not much different than ARAMS. Both computer programs are not intended to present and do not present an overall risk assessment methodology specifically for landfill leachate with the intent of holism; and the same is the case with the baseline study.
8.	FRAMES (Framework for Risk Analysis Multi-Media Environmental Systems)	FRAMES (Framework for Risk Analysis Multi-Media Environmental Systems) is a software platform for selecting and implementing environmental software models for risk assessment and management problems which may even include electronic governance issues (Evangelidis, 2003). In other words, the purpose of FRAMES is to assist users in developing environmental scenarios and to provide options for selecting the most appropriate computer codes to conduct human and environmental risk management analyses (PNNL, 2006b). This program is a flexible and overall approach to understanding how industrial activities affect humans and the environment. It incorporates models that integrate across scientific disciplines, allowing for tailored solutions to specific activities, and it provides meaningful information to business and technical

		managers. FRAMES is the key to identifying, analysing, and managing potential environmental, safety, and health risks. As is obvious from this description that FRAMES is a hugely generic program; and yet it does not contain any software for landfill leachate analysis which could guide a landfill assessor to perform a landfill risk analysis along with a baseline study system comprising of the elements listed in Table 1 (Section 3.4).
9.	RESRAD (9-a) RESRAD (9-b) RESRADBUILD (9-c) RESRAD-CHEM. (9-d) RESRADBASELINE. (9-e) RESRAD-ECORISK. (9-f) RESRAD-RECYCLE. (9-g) RESRAD-OFFSITE.	The RESRAD is a combination of two words RESidual and RADiation (DMS, 2006), which is used as an acronym for 'residual radiation environmental analysis' (Farlex, 2006). The RESRAD is a suite of computer packages to provide a scientifically based answer to the question ‘how clean is clean?’ and to provide useful tools for evaluating human health risk from residual contamination (EAD, 2006a). These packages include (EAD, 2006a; 2006b): (9-a) RESRAD, for soil contaminated with radio-nucleides; (9-b) RESRADBUILD, for buildings contaminated with radio-nucleides; (9-c) RESRAD-CHEM, for soil contaminated with hazardous chemicals; (9-d) RESRADBASELINE, for risk assessments against measured (baseline) concentrate-ns of both radio-nucleides and chemicals in environmental media; (9-e) RESRAD-ECORISK, for ecological risk assessments;

		(9-f) RESRAD-RECYCLE, for recycle and reuse of radio-logically contaminated metals and equipment; and (9-g) RESRAD-OFFSITE, for off-site receptor dose/risk assessment. From this list, it is obvious that none of the packages is specifically for landfill leachate, although RESRAD addresses wide-ranging environmental issues and aspects. Even if they are used in combination, they are not able to address all factors and aspects of baseline study and risk analysis of landfill leachate. Furthermore, to combine these into a landfill leachate context alone would be a cumbersome task each time risk assessment and baseline study are performed for different landfill scenarios. However, there is nothing to prevent landfill assessors from processing landfill data sets using any of these seven packages (or any other software, if suitable), while they carry out a landfill risk analysis and baseline study. For instance, RESRAD-CHEM considers various exposure pathways (including inhalation of dust and volatiles), ingestion of plant foods, meat, milk, soil, aquatic food and water, and dermal absorption from soil and water contact. This package may help address aspects of exposure assessment, which is only one unit of a total risk assessment process. However, this package is no longer being updated (EAD, 2006c). In summary, the packages do not appear to holistically address all the factors and features of baseline assessment described in Table 1 (Section 3.4) and depicted Figure 2 (Section 2.2).

10.	RISC-HUMAN 3.1, RUM and Vlier-Humaan	RISC-HUMAN 3.1, RUM and Vlier-Humaan (Van Hall Institute of Business Center, 2000; 2001 and 2002, respectively) are three other software packages relating to risk analysis with a main emphasis on exposure assessment, not baseline study. Moreover, these are designed for use with contaminated land, and not specifically for landfills.
11.	HAZUS 99 software	HAZUS 99 software regards earthquake issues, whereas HAZUS-MH (Multi-Hazards) is available for modelling hazards (including wind and flood hazards) (FEMA, 2001; 2002; 2004). There are books on environmental modelling (such as Schnoor, 1996) which theoretically describe modelling in great detail for air, water, and soil. Other literature (such as Johnson et. al., 2001) describe and discuss practical application of wide ranging types of models including neural networks approach models, hydrological linear storage models, and mechanistic models (e.g. HYDRUSS, MACRO, etc.). However, these computer software/packages do not and are not to offer a complete and integrated system of either risk analysis or baseline study for landfills as described in Table 1 and shown in Figure 2.

In summary, from the above investigation of various computer models, (reported in Sections 4.1, 4.2 and 4.3), the paper establishes this. There is no holistic computer model for conducting a baseline study for landfills that contains all the required parameters and aspects (listed in Table 1 and shown in Figure 2) in an algorithmic and categorical manner in order to assist landfill risk assessors to execute a quantitative preliminary investigation comprehensively, and yet concisely. A model in which various factors and features of the baseline study are put in such a format of categories that they could be linked or related to other appropriate modules and sub-modules of a given risk assessment process in the later stages, simply does not exist. Further, there is a growing family of risk models that can help address different aspects and scenarios of risk (including baseline study), but nevertheless only in a piecemeal manner.

5.0 CONCLUDING REMARKS

A baseline study is not only one of the most important factors, but also the most fundamental initial stage of an effective risk analysis, as it leads to overall success of the risk assessment (and consequently of the risk management). In order to have a more inclusive, comprehensive, robust and integrated risk assessment, a correspondingly more holistic baseline study is required. On the other hand, current computer-aided approaches of risk analysis do not have a comprehensive, robust, and sound framework of risk assessment in a holistic manner, as a range of features are absent. One main absent feature is a holistic baseline study system which would encapsulate all necessary items that are needed to underpin a holistic risk analysis.

While the current and forthcoming legislation push forward to reduce both the quantity of disposed wastes and the environmental impacts of landfill sites, still there is a need to manage the current landfill sites and find solutions to control environmental pollution from these sites. In addition, although (according to the sustainable Waste Hierarchy), waste amounts are to be reduced that are disposed of at landfills, still it is not possible to have a 'no-landfill' society for a number of reasons. For example, waste production cannot be reduced to zero in every scenario. Commodities cannot be reused or recycled all the time (e.g. paper after recycling a number of times becomes non-recyclable as paper fibres deteriorate every time it is recycled). Not every waste can be composted or incinerated. Even the incineration of wastes leads to other wastes (e.g. ashes) being generated (though in much reduced amounts) which generally end up in landfills. Thus, landfills are inevitable. To be more exact, the number of landfills may be reduced but cannot be reduced to zero in order to establish a totally 'landfill-free' environment. Thus, despite having potentials to pollute the environment, landfills are not entirely avoidable, and are still required to whatever degree. Therefore risk assessment is necessary as an effective tool to guard the environment against landfill hazards.

Current software packages are just adequate in meeting the risk assessment requirements of the present environmental legislation, particularly in the UK. These computer-aided approaches are not holistic. Future environmental regulations, being derived from various European directives, are eminent to be more stringent and wider/inclusive in scope, and will encapsulate more environmental species including various food chain links, ecological systems, terrestrial and aquatic flora and fauna. Therefore a more comprehensive, yet concise, and robust risk analysis system, underpinned by well-integrated baseline study systems, will be needed. Based on the necessity and significance of a holistic baseline study in risk assessments of landfills, this research study has indicated knowledge gaps and limitations of computer models. A conceptual framework model of the holistic baseline study is also depicted. Therefore, this investigation paves a path for further research and study for developing a more complete and algorithmic computational procedure for holistic baseline study in an integrated fashion, specifically for landfill leachate. Furthermore, this paper comprehensively and yet categorically disseminates the state-of-the-science of computer software/packages regarding baseline study and risk assessment to a diverse range of stakeholders/audience (coming from the landfill industry in particular, and the fields of waste management and environmental management in general).

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